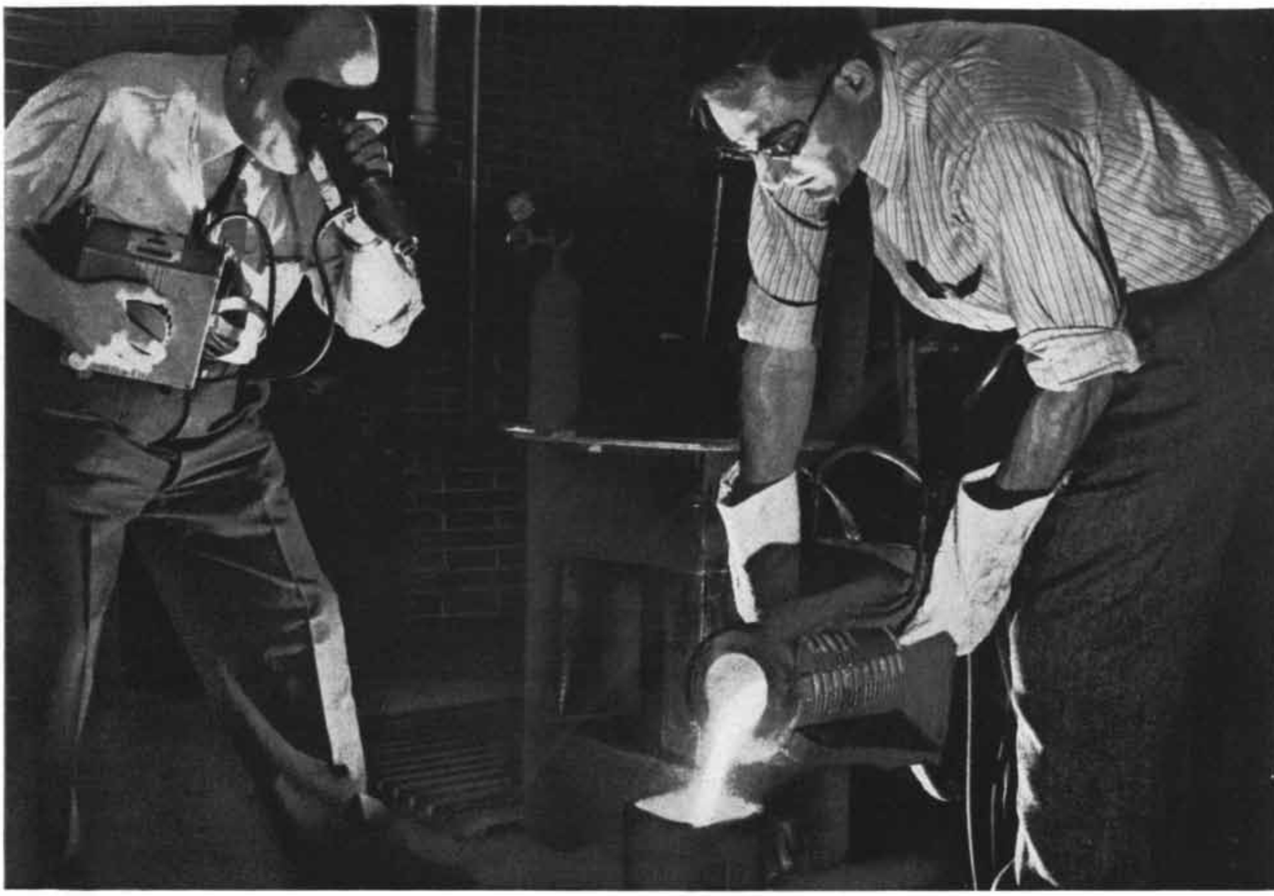
SCIENTIFIC AMERICAN

HEAT

FIFTY CENTS

September 1954



One Phase of the search for answers to high-temperature questions is the continuing development and testing of new alloys. Here Inco metallurgists pour a carefully controlled composition of metals from their laboratory radio-frequency induction furnace. The resulting alloy may help to solve some of the unanswered high-temperature problems facing engineers today.

What causes high-temperature failure?

Strange reactions can take place when metals and alloys are exposed to high heat.

Even common soot and the air itself become destructive corrosives that can disintegrate a metal and waste away its strength. The more these reactions are studied the more evident it becomes that the damage caused by high temperature corrosion is one of the most serious reasons for metal failures.

Unless a metal or alloy can resist destruction by its corrosive environment under operating conditions, it makes little difference how high or low its mechanical properties may be.

No single metal or alloy can resist all these corrosive conditions. For 20 years Inco metallurgists have been experimenting with carefully controlled compositions of metals . . . searching for the answers to the problems posed by expanding temperature frontiers. From this work have come such strong, heat-resisting alloys as Inconel and Inconel "X", Incoloy and the Nimonic Alloys.

Yet with the gas turbine seemingly held in check by the temperature limits of metals, with the chemical and petroleum industries moving from "red-hot" to "white-hot" process temperatures, and with the development of the rocket engine and nuclear power pushing ahead, you may be asking yourself,

"Have metals reached their limit of practical service at today's operating temperatures?"

Inco metallurgists think not. Who knows what future research programs may reveal?

If you have a problem involving high temperatures, the solution may already be in the files of Inco's High Temperature Engineering Service. If not, our engineers will be glad to work with you to find it. The first step is to write for a High Temperature Work Sheet, our form that helps you outline your problem for study. After that it is up to us. There is no obligation on your part.

The International Nickel Company, Inc.
67 Wall Street New York 5, N. Y.

Inco Nickel Alloys

MONEL® • "R"® MONEL • "K"® MONEL • "KR"® MONEL • "S"® MONEL • INCONEL® • INCONEL "X"® • INCONEL "W"® • INCOLOY® • NIMONIC® ALLOYS • NICKEL • LOW CARBON NICKEL • DURANICKEL®

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Vol. 191
No. 3

The E.R.A. 1103 Computing System

Tomorrow's Design Today...

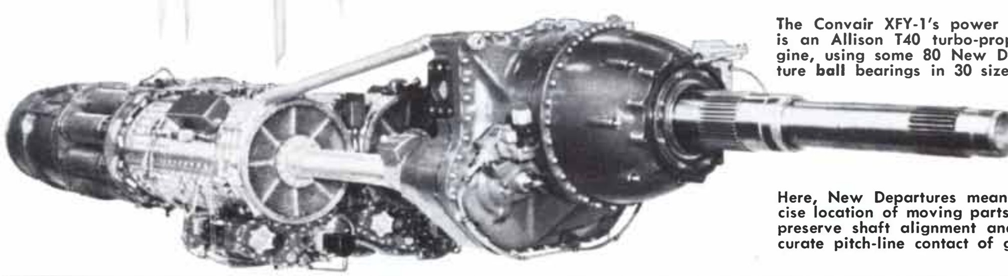
Airplane design involves a staggering amount of data processing—a seemingly endless number of computations and tests between the drawing board and the production line. Every hour...every day... every week gained here brings the time when the finished plane takes off on its first flight just that much closer.

In the aircraft industry, as in many other engineering applications, the Remington Rand ERA 1103 Electronic Computing System has proven how easily it can handle the most difficult research problems. Here are some reasons why leading aircraft builders and other prominent users are counting on the ERA 1103 these days:

Because of its ability to reduce large volumes of data at extremely high speeds, the ERA 1103 is the ideal computing system for scientific applications. Its speed is matched by many other outstanding characteristics: superb operating efficiency, obtained through large storage capacity... great programming versatility... the ability to operate simultaneously with a wide variety of input-output devices... and far greater reliability than any computer in its class.

For more information about the ERA 1103, or for information about how you might apply the system to your particular problems, write to...

ELECTRONIC COMPUTER DEPARTMENT, Remington Rand INC. ROOM 1915, 315 FOURTH AVE., NEW YORK 10



The Convair XFY-1's power plant is an Allison T40 turbo-prop engine, using some 80 New Departure **ball** bearings in 30 sizes.

Here, New Departures mean precise location of moving parts . . . preserve shaft alignment and accurate pitch-line contact of gears.

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for a "Pogo" Pilot

Vertical take-off! Tailfirst landing! Fighter action! It's the Navy's newest—the Convair XFY-1 "pogo stick."

In its Allison T40 turbo-prop engine, some 80 New Departure **ball** bearings assure positive positioning of moving parts. And in the hub mechanisms of the Curtiss-Wright Turbolectric propellers, New Departures carry heavy loads.

Throughout defense and industry, you'll find New Departure **ball** bearings ideal for countless applications. So whatever your bearing problem, *talk with your New Departure engineer . . . now!*

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In Canada: McKinnon Industries, Ltd., St. Catharines, Ontario

Lockheed Missile Systems Division

Lockheed Aircraft Corporation : Van Nuys, California

An Invitation to
Physicists and Engineers:

High temperature plays an important part in the missile systems field. Temperature information derived from the studies of the upper atmosphere and of meteors is being related to our missile work

Missile systems research and development is not confined to any one field of science or engineering. Broad interests and exceptional abilities are required by the participants. Typical areas include systems analysis, electronics, aerodynamics, thermodynamics, computers, servomechanisms, propulsion, materials research, design and fabrication.

Because of the increasing emphasis on the missile systems field, there is opportunity to share in technical advances which have broad application to science and industry.

Those who can make a significant contribution to a group effort of utmost importance -- as well as those who desire to associate themselves with a new creative undertaking -- are invited to contact our Research and Engineering Staff.

E R Quesada

E. R. Quesada
Vice President and
General Manager

HOW MANY DECIBELS IN A DIN?

The development by Altec Lansing engineers of the M14 High Intensity Microphone System marks a great step forward in the accurate measurement of industrial sound. It provides reliable indication of the approach to dangerous noise levels and permits precise control. It is particularly applicable for measurement and analysis of pulsed or continuous sound levels of high intensity.

The M14 High Intensity Microphone System is another milestone in the story of accomplishment by Altec Lansing engineers—men and women who have contributed outstandingly to progress in the field of sound. No aspect of sound development, no matter how specialized, no phase in the manufacture of audio equipment is outside the scope of the Altec Companies.

Priceless experience and the highest standards of craftsmanship coupled with a select staff of outstanding engineers drawn from throughout the world have earned for the Altec Companies an unquestioned position of leadership in the field of sound.

If you have any problems relating to sound, call on the Altec Companies for help... in research, development, manufacture and maintenance. Altec quality is top quality in the field of sound.

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ALTEC SERVICE CORPORATION

PEERLESS ELECTRICAL PRODUCTS

THE ALTEC COMPANIES

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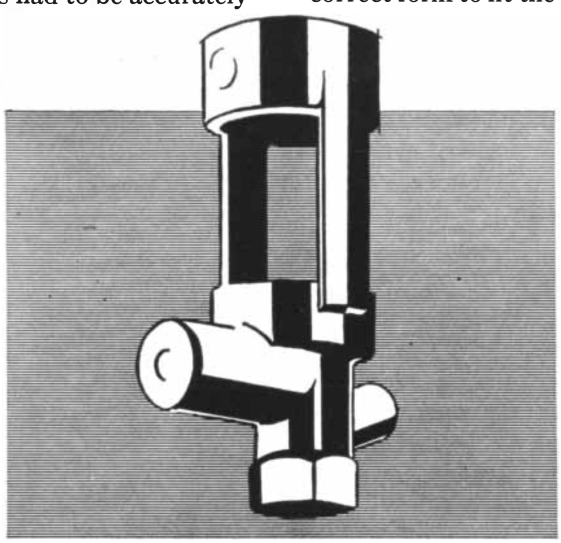
9356 Santa Monica Blvd., Beverly Hills, Calif.
161 Sixth Avenue, New York 13, N.Y.

BUSINESS IN MOTION

To our Colleagues in American Business . . .

There is an interesting story behind the brass forging shown here. It is part of a high-pressure lubricator. Originally a casting was used, but this proved to be more expensive than expected, due to blow holes, sand inclusions and the like; there were too many leakers, too many rejects. It then was decided to assemble the part out of four different brass items. The bottom was a forging, the top was machined out of round brass rod, and the two side supports were rectangular brass rod. To assemble, the four parts had to be accurately aligned, and silver soldered together. The result was an improvement, but costs were still too high, due to the time-consuming assembly process, and the expensive silver solder.



It was then suggested that the entire part perhaps could be made as a one-piece forging. Could Revere do it? We thought we could, and our forging people sat down with the lubricator manufacturer, studying blueprints and specifications. When both parties thoroughly understood both the possibilities and the limitations a bid was made, and accepted. Introduction of the forging on a production basis showed sizable economies. Machining is done more quickly, output is increased, rejects have decreased to practically zero. In addition, the part is better in every way.

The forging process is an excellent one, and has wider applications than many people realize. As in the case reported here, rather intricate shapes can be forged, shapes that many people would consider would have to be built up of several parts. The Revere files contain many similar examples of parts formerly expensively put together but now delivered to the customer in a one-piece forging, with resultant economies.

Revere produces forgings in copper, brass and other copper-base alloys, and in aluminum alloys. Many forgings begin as extruded shapes which have the correct form to fit the forging dies with a minimum of "flash." When the dies close on the hot metal, design details, including names and numbers, are accurately reproduced. The metal is dense, being twice wrought, and has a typical smooth forged finish. Customers find that a Revere forging usually is ready for assembly after a minimum of simple machining operations, such as drilling and tapping a hole or two.

The point about this story is that Revere, as a supplier, was able to collaborate with a customer, and show how to use a special process to make an intricate part better and at less cost. Perhaps your business, no matter what it is, could benefit by the knowledge and skill of your suppliers. They know what can be done with their materials. Why not take them into your confidence, and ask them how you can save money? It might very well pay you handsomely.

REVERE COPPER AND BRASS INCORPORATED

Founded by Paul Revere in 1801

***Executive Offices:* 230 Park Avenue, New York 17, N.Y.**

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Ideas in the Making!

The ARALDITE® Epoxy Resins developed by Ciba are simplifying manufacturing methods, improving product efficiency and opening new fields of product development. The formulator and the end product producer will want to know more about them. We at Ciba want to help you further your development.

★ **LARGEST TRANSFORMER CASTING**

2200 lbs. of Ciba Araldite Epoxy Resin were cast to enclose the electrical components by the Pacific-Oerlikon Company. The Araldite resin, with the electrical properties recommended for this field of use, is described below.

★ The complete body unit illustrated here was constructed by using CIBA contact pressure laminating Epoxy Resin. The physical properties of the Araldite resin recommended for this type of application are described below.

ELECTRICAL PROPERTIES OF CASTINGS MANUFACTURED WITH ARALDITE 6060

Property	Test Method	Values
Dielectric Strength, Short Time, 1/8" Section (volts/mil)	ASTM D 149-44	400-410
Surface Resistivity (ohms)	ASTM D 257-49T	$> 5.7 \times 10^{12}$
Volume Resistivity (ohm-cm)	ASTM D 257-49T	$> 8.0 \times 10^{13}$
Dielectric Constant	ASTM D 150-47T 26.7°C.	
60 cycles		3.89
10^6 cycles		3.50
Power Factor	ASTM D 150-47T 26.7°C.	
60 cycles		0.0012
10^6 cycles		0.026

PHYSICAL PROPERTIES OF CONTACT PRESSURE LAMINATES MANUFACTURED WITH ARALDITE 502 (using 181 cloth with various finishes)

Property	112 Finish	Volan A Finish	Garan Finish
Flexural Strength, PSI	41,000	65,000	47,000
Modulus of Elasticity in Flexure, PSI	2.01×10^6	2.23×10^6	1.88×10^6
Resin Content Wt. %	40	42	40
Laminate Thickness	0.085"	0.085"	0.085"

CIBA

ARALDITE **Epoxies**

CIBA COMPANY INC. PLASTICS DIVISION S.A.-I

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Please send me full information on The CIBA ARALDITE Epoxies.

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Company __________ *Title* __________

Address __________

Type of Business __________

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There are a lot of things about vacuum furnaces that are hard to predict. You can't always work them out ahead of time on *a slide rule.* But time and again you can pull sound answers out of a backlog of *experience.*

The best training in designing and building vacuum furnaces is to run them — lots of them — all types — year after year.

That's just the kind of experience we have here at National. We've not only *built* more vacuum furnaces — but we have *operated* more than anyone else and over a longer period of time.

We think that's an important reason National's vacuum furnaces are engineered so closely to our customers' production requirements and why they have such a "trouble-free" reputation. NRC Vacuum Furnace bulletin now in preparation. Send your name for a copy.

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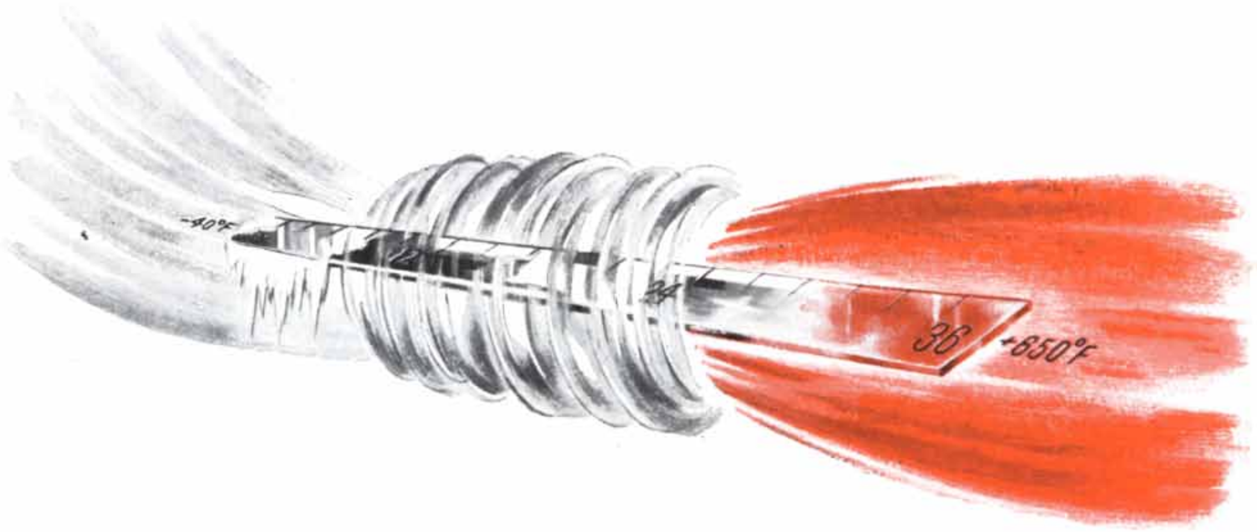


FROM ARCTIC CHILL TO VOLCANIC HEAT IN 3 FEET AND 10,000 RPM.

You can almost *hear* the metal parts of the rotor trying to protest . . . superfrozen at the intake by Arctic cold . . . superheated by highly compressed air at the outlet only 3 feet away. And the whole mechanism is built to rotate smoothly at over 10,000 rpm.

From making the parts and complete assemblies for jet aircraft engines, the Jet Division has gathered a vast amount of information on how metals behave at high temperatures. And how different metals work together under extremes of heat and cold, and of stress and rotation.

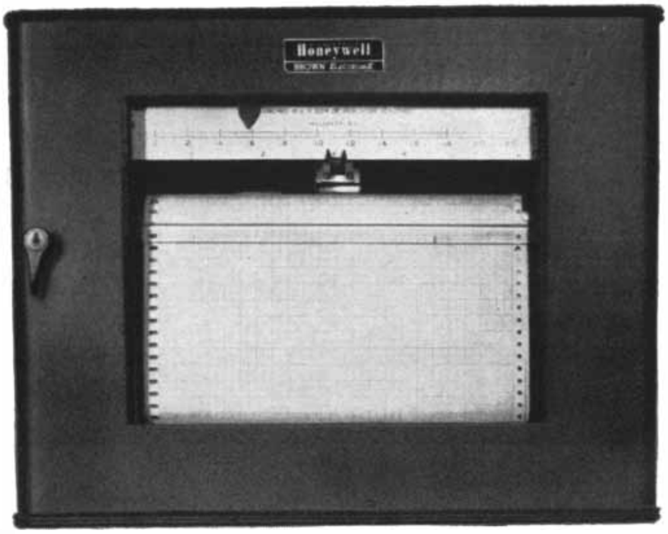
Our research and development facilities are equipped to take on your high-temperature problems and projects. We give you answers and designs based on a half-century of experience in making metal parts tougher and stronger to combat ever-greater operating temperatures in engines and machines.

Tell us when to call, to work on *your* high-temperature problem.

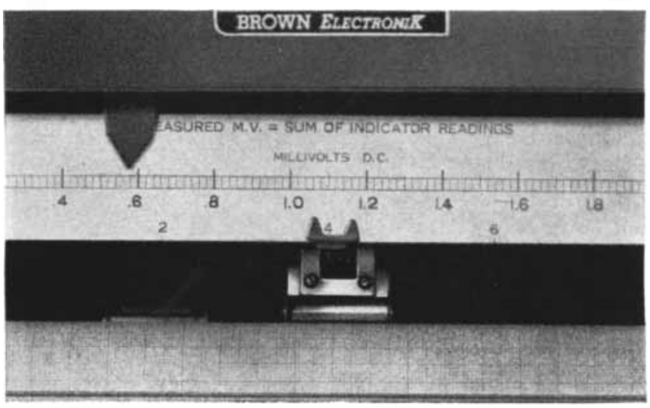
JET DIVISION

Thompson Products, Inc.

DEPT. JS-9 • CLEVELAND 17, OHIO



Now...the answer to high-resolution recording of test data ...*the* Extended Range *ElectroniK* Recorder



Closeup of indicating scale. Upper pointer shows millivolts within the span; lower pointer indicates millivolts to be added. Total reading: 4.58 mv.

DESIGNED especially for recording variables which change over a wide range, this new *ElectroniK* instrument records on a chart effectively *55 inches in width.* It has five equal measuring spans. Whenever the variable being measured reaches either the upper or lower limit of one of these ranges, the instrument automatically steps to the adjoining range and continues recording.

Two indicating pointers show the range in use and the value within the range. Connected to each pointer is a pen; one draws a purple record showing the range, the other draws a red record of the variable itself. To get the complete reading, you simply add both pen or pointer indications.

The complete range is 10.2 millivolts, in five 2-millivolt steps with an extra 0.2 millivolts on the high end of each span to provide an overlap that facilitates measurements near the change-over point. Pen speed of 4½ seconds full scale affords rapid response to quickly changing variables.

You'll find this new instrument particularly valuable in strain gage measurements and in dozens of other uses where high resolution aids interpretation of data. Your nearby Honeywell sales engineer will be glad to discuss your specific application . . . and he's as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, Wayne and Windrim Avenues, Philadelphia 44, Pa.

● **REFERENCE DATA: Write for Data Sheet No. 10.0-18, "Extended Range Recorder."**

H HONEYWELL

MINNEAPOLIS **Honeywell** BROWN INSTRUMENTS

First in Controls

WHICH "150" fits *your* oscillographic recording need?

4-CHANNEL

As a graphic example of the design idea that has brought new versatility to industrial recording, a Carrier Preamplifier (A) is shown above in position to plug into a Driver Amplifier in framework with Power Supply (B) which are normally already in place in the Basic Cabinet Assembly.

The identical design principles of the four-channel system are provided in the two-channel, the only difference being the number of channels.

Sanborn "150" Recording Systems that put to use the original design concept of amplifier interchangeability (illustrated at the left) start with either a four-channel or two-channel standard Basic Assembly, to which the user adds whatever selection or combination of preamplifiers (A) are needed for his recording problem. The standard Basic Assemblies comprise a metal Cabinet, Recorder, and a built-in Driver Amplifier and Power Supply (B) for EACH channel. Presently available Preamplifiers are: AC-DC, Carrier, DC Coupling, Servo Monitor, Log-Audio, and Low Level Chopper.

Advantages common to ALL Sanborn Recorders are: inkless recording (by heated stylus) on plastic coated strip chart paper, and in true rectangular coordinates . . . high torque galvanometer movement . . . time and code markers . . . numerous paper travel speeds.

2-CHANNEL

"150"

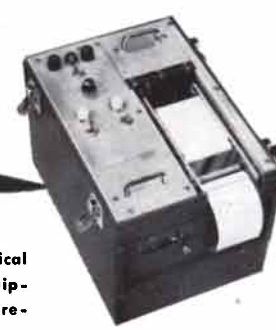
COMPLETE FOUR-CHANNEL SYSTEM FOR USE WITH ANALOG COMPUTERS

This "150" system consists of a Cabinet Assembly, a four-channel Recorder, and *two* dual channel DC Amplifiers. Each amplifier is complete with a common power supply. Each measures and records two separate single-ended signals, at sensitivities between one and one hundred volts per centimeter. The *two*-channel version of this system will comprise Cabinet, *two*-channel Recorder, and *one* dual channel amplifier.

"150"

SINGLE-CHANNEL RECORDER

A compact, lightweight unit for use when only one channel is required — provides permanent, inkless recording in *true* rectangular co-ordinates; *five* paper speeds (5, 10, 25, 50, 100 mm/sec.); *extra* stylus for either manual or remote timing and coding marks. Designed for simple, patch cord connection to *any* of the several "150" preamplifiers (plus driver amplifier and power supply), available soon in portable metal cases.



Ask, also, for a copy of the *Right Angle* — a Sanborn publication devoted to oscillographic recording in industry.

Catalog and technical data on all "150" equipment available on request.

SANBORN COMPANY
Industrial Division
CAMBRIDGE 39, MASS.

LETTERS

Sirs:

In his review of the new translation of Pierre Duhem's *The Aim and Structure of Physical Theory* [SCIENTIFIC AMERICAN, August], Max Black has both ignored the chief point at issue between Duhem and his critics and implicitly endorsed Duhem's erroneous view on this issue. For at least 2,500 years philosophers have been arguing that there is a metaphysical reality behind appearances (a noumena behind phenomena) which scientists cannot observe but which metaphysicians can *reason* about. Priests and theologians also believe in an unobservable reality which scientists cannot observe and study. The key facts about Duhem are that he agrees with both philosophers and theologians on this point, that he wrote his book to make this point, and that he is therefore obviously not a positivist.

The essential and distinguishing feature of positivism is complete rejection of the ancient dogma that there is some kind of reality behind appearances. Positivists affirm that men can study and know only what they can observe, and that the only correct method of study is the scientific method.

Early positivists treated the question of whether there is an unobservable reality behind appearance as meaningful. Modern or logical positivists consider it meaningless because it is impossible to conceive of any method of

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SILICA AEROGELS

500 billion particles per cubic inch produce remarkable physical structure which enables aerogels to kill weevils, flat varnishes, or thicken liquids with equal ease

THE STORY of aerogels begins in the early thirties with a brilliant experiment by Dr. S. S. Kistler. Working in the laboratory, he produced gels unlike any ever made. Gels in which air replaced water. With them, he clearly proved that water is *not* an integral part of gel structure. And he named the new materials aerogels.

There the story should end. Aerogels were only part of the experiment. They were difficult to make. They were expensive. They would soon be forgotten.

But it didn't turn out that way, for one important reason — physical structure. As the first commercial producers of a silica aerogel—we call it Santocel—we found its structure worth a lot of trouble to obtain.

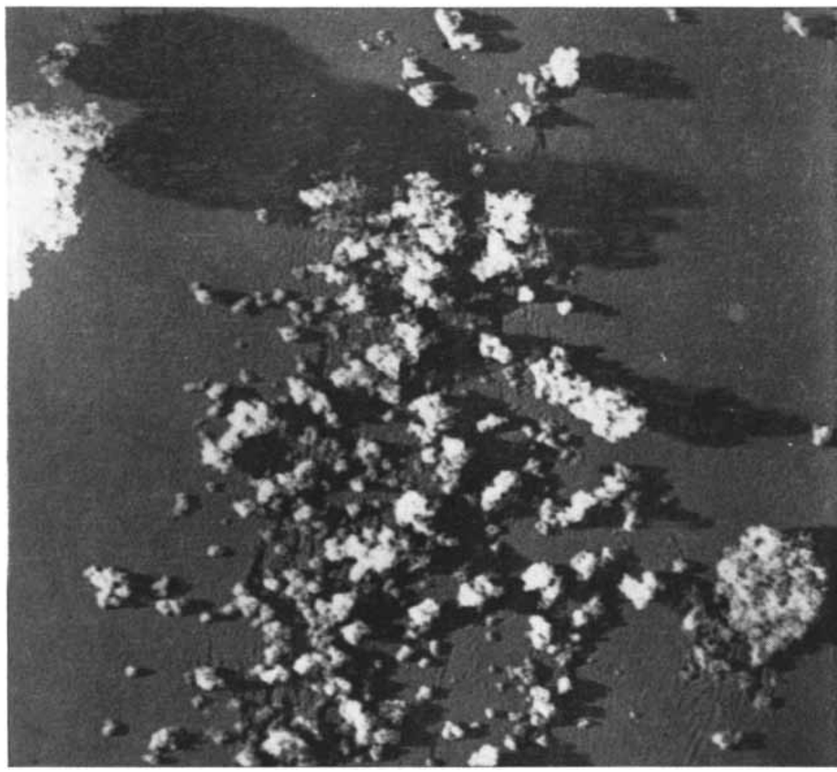
And we *did* have trouble. We had to find a production method which would (a) wring the water out of the silica hydrogel, (b) replace the water with air, and (c) *still allow no shrinkage in volume.* (We finally did it, but how is another story for another time.)

The structure itself, when first studied, reminded one of our workers of Churchill's phrase about "a riddle wrapped in a mystery inside an enigma." We finally picture Santocel (see photograph) as a tenuous webbing of microscopic filaments which envelop thousands of minute air cells. This means Santocel has a remarkably large surface area, is chemically inert, highly porous and incredibly light.

We've found this structure ideal for some unusual jobs. In thickening, for example, Santocel is extremely effective for altering the viscosity of nonpolar liquids. This has made it worthwhile as a thickener in printing inks, resins and various pastes.

Santocel is also versatile in other ways. Laboratory tests show that it has the lowest thermal conductivity of any known substance. This makes it ideal for extremely low temperature insulation in liquid oxygen plants and similar applications, where it saves up to 50% on insulation space.

Santocel does other things, too. It is a flatting agent for varnishes and lacquers; a grinding aid for powdery materials; an anticaking agent for insecticide dusts; and a mold lubricant. It can even act as an insecticide in nonfood grains and kill weevils and other insects by abrading the coating of their cuticle.



STRUCTURE OF SILICA AEROGEL shown in electron photomicrograph consists of primary particles of B-Crystobalite, about 8 Angstroms in diameter. These chain together to form "a tangled brush pile" of interlocked fibers and give the gel its unusual properties.

Moral of our story: in all of these applications the *unusual* properties of Santocel perform *unusual* jobs. Perhaps these same properties can now help solve the processing or product problem facing you. For more information why not send in the coupon? Santocel may be what you've been looking for.

Santocel: Reg. U.S. Pat. Off.

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verifying any answer to it. On this vital point Black sides with Duhem. He repeatedly uses the word *reality* as if it were a meaningful term and therefore implies that Duhem is talking sense when he is in fact making statements which modern positivists consider to be senseless. Black is of course entitled to side with Duhem against the logical positivists, but he ought to have explained the nature and importance of this issue and why he thinks Duhem is correct.

It is especially unfortunate that Black referred to the metaphysical reality and discussed the "objective reference" of scientific theories. This seriously obscures the fact that, like Duhem, he is talking about an unobservable metaphysical reality or noumena and whether scientific terms can denote parts of this reality.

Black also overlooked the logical positivist answer to Duhem's claim that physical theories must be expressed in mathematical terms. If a theory is so expressed, it does not contain any nouns which denote observed things or events, and therefore it cannot be verified by observation and is meaningless. Mathematics is invaluable in stating scientific theories, but mathematical terms must be used only as adjectives modifying words which refer to observable referents. Hence, no purely mathematical theory is useful or factually meaningful.

BURNHAM P. BECKWITH

Laguna Beach, Calif.

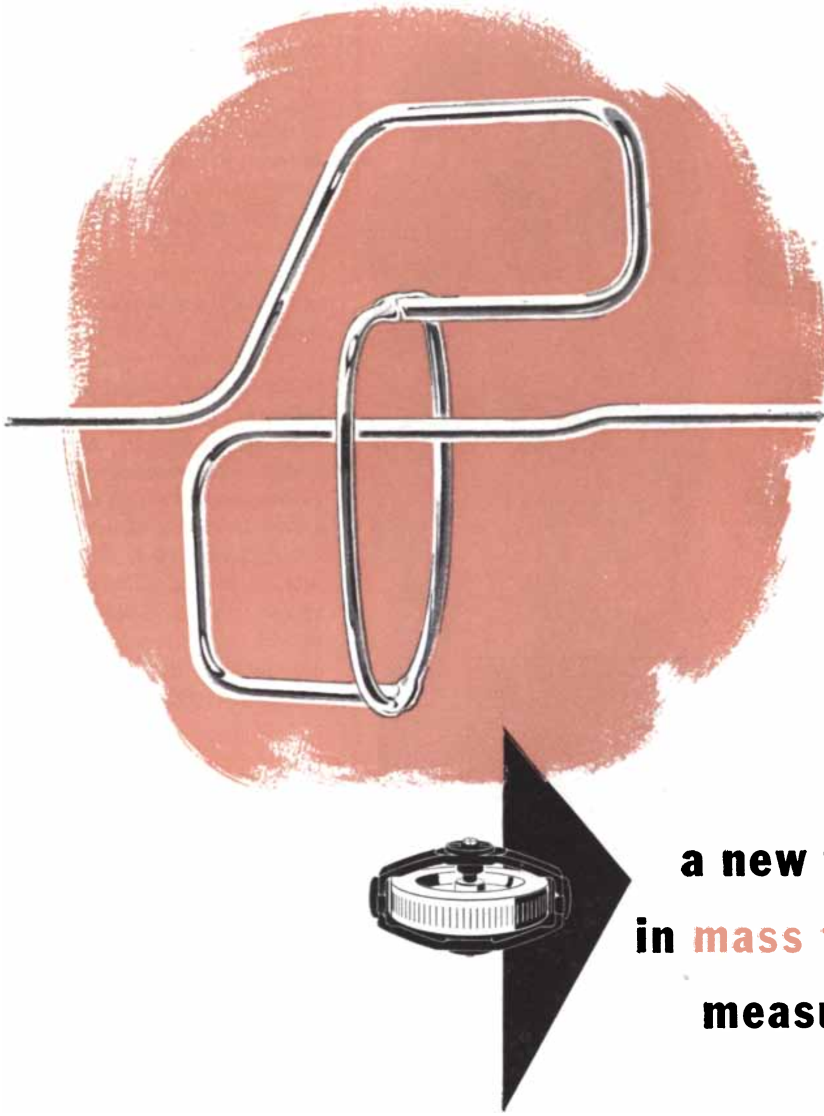
Sirs:

We should like to correct an error in the article by Lawrence P. Lessing entitled "Pure Metals" [SCIENTIFIC AMERICAN, July].

The Oak Ridge National Laboratory has produced pound quantities of several of the rare earth elements but not by the mass spectrograph (calutron) method as stated in the foregoing article.

The naturally occurring *isotopes* of lanthanum, cerium, neodymium, samarium and gadolinium have been enriched in the Oak Ridge mass spectrographs. The isotopes of dysprosium will be separated in the near future.

The separation of the isotopes of the rare earth elements is made possible by the combined efforts of Dr. C. E. Normand and L. O. Love, who direct the mass spectograph *isotope* separations, and Boyd Weaver, who directs the preparation of the rare earth *elements* to be



a new twist in **mass flow** measurement

In the NORWOOD CONTROLS Gyro Meter fluids flowing through a pretzel of pipe correspond to the action of a rotating gyro wheel. The first instrument to measure *true mass flow* directly, it sets a new standard of accuracy for the precision metering of bulk fluids.

When the gyro is precessed by rotating the pretzel about the axis of flow, it produces a torque. The torque produced by this precession is directly proportional to the mass flow of the material flowing through the pipe.

The ability to achieve greater simplicity, accuracy and dependability through the application of new engineering techniques has established NORWOOD CONTROLS as a leader in the fields of flow, pressure, temperature and weight measurement.

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Controls Division

CONTROL ENGINEERING CORPORATION

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Complete technical information will be supplied upon request.

used as charge material in the mass spectrographs. Mr. Weaver and associates have developed a tributyl phosphate–nitric acid extraction process for the successful separation of most of the rare earth elements. It is only a matter of time before all the rare earth elements become available in our laboratory for isotope separation and other uses. Monazite and gadolinite ores are the raw materials employed.

We believe you will agree that a liquid-liquid continuous extraction technique is not "laborious."

We also believe the word "laborious" is not entirely appropriate even when referring to isotope separation by the mass spectrographs. After all, the Oak Ridge mass spectrographs separate isotopic atoms to a high degree of purity at a rate in excess of one billion atoms in one billionth of a second! Hence in a few hours our mass spectrographs can supply the researcher with highly enriched, separated isotopes in adequate amounts for his objectives of advancing basic and applied science.

C. P. KEIM

Director
Stable Isotope Research and
Production Division
Oak Ridge National Laboratory
Oak Ridge, Tenn.

Sirs:

May I offer a word of appreciation to Lawrence P. Lessing [SCIENTIFIC AMERICAN, April] for his fine tribute to Edwin H. Armstrong—one of the very few really creative pioneers in the field of radio. May I also thank Mr. Lessing for coming to Armstrong's defense again [SCIENTIFIC AMERICAN, July] against an adversary who could not refrain from attacking him once more when he is no longer here to defend himself.

Armstrong was my friend. I valued him as a clean, honest man. I admired him as a brilliant, creative genius. I respected him as a doughty fighter for his rights against strongly entrenched and powerful adversaries, with that fine spirit of independence that made our country great. He has fought a good fight.

I have carefully refrained from getting into that controversy, and I prefer to stay out of it now. Since Armstrong has gone across the Great Divide and the dust of battle has settled so that men can see more clearly, may I venture to suggest that Armstrong's adversary was

CUPS — Through these clear Tenite Butyrate pipes, paper cups are blown hundreds of feet from forming machines to the packing area. Traveling overhead and out of the way of plant operations, the cups come through unmarked and unscratched. *Could a pneumatic conveying operation via Tenite pipe save time and space in your plant?*

TENITE

pipe carries many things

Pipe made of Tenite Butyrate is finding new jobs every day.

And no wonder . . . it offers so many advantages.

Extruded Tenite pipe has extra-smooth walls that mean less drag, greater flow, less chance for deposits. It can withstand the corrosive attack of many chemicals. Buried in the ground, it is unaffected by the electrolytic and corrosive action of soils. It's much lighter than metal pipe.

Tenite pipe can be readily lifted, carried, sawed and joined. Tenite pipe is usually joined with slip-sleeve couplings of the same material. A solvent cement applied to the pipe ends and the coupling forms a joint stronger than the original pipe.

Pipe is but one use of Tenite Butyrate. For more information on properties and adaptability to your product demands, write for the illustrated booklet, "TENITE." EASTMAN CHEMICAL PRODUCTS, INC., Kingsport, Tenn., subsidiary of Eastman Kodak Company.

OIL — Millions of feet of Tenite Butyrate pipe are in use in the oil industry. Tenite resists sour crude oil, salt water and electrolytic soils . . . gives oil men the durable, corrosion-resistant pipe they need. *Does Tenite pipe suggest a better way to carry something in your plant?*

ELECTRIC CABLE — Used here as underground cable conduit, Tenite Butyrate pipe saved 80% in installation time and successfully resisted the attack of the strong alkali soil. *Would a similar use of Tenite pipe effect economies for you?*

TENITE
BUTYRATE
an Eastman plastic

Information regarding Tenite also can be obtained from local representatives listed under "Plastics—Tenite" in the classified telephone directories of the following cities: Chicago, Cleveland, Dayton, Detroit, Houston, Leominster (Mass.), Los Angeles, New York City, Portland (Ore.), Rochester (N. Y.), St. Louis, San Francisco, Seattle and Toronto — elsewhere throughout the world, from Eastman Kodak Company affiliates and distributors.

not the first inventor of a regenerative feedback circuit, nor of a regenerative electrical oscillator.

May I cite two patents issued to me on August 28, 1906, on applications filed February 28, 1905, and November 14, 1905? They are numbered 829,447 and 829,934. One is for a method and the other for an apparatus. The titles are respectively: *Method of and Apparatus for Producing and Utilizing Undamped or Sustained Electrical Oscillations.* The first method claim is as follows:

"1. The method of producing electrical oscillations, consisting in exciting or controlling a field by the oscillations of an electrical oscillating circuit, electrically commutating energy by means of such field, and adding by such commutation increments of energy to such oscillating circuit."

If that is not regenerative electrical oscillation operating by a regenerative feedback circuit, what is it?

The specification explains clearly the principle and practice of regeneration. It states further: "This may be done . . . by the effect of an electrostatic field upon the discharge of cathode particles in a vacuum tube." That is aptly descriptive of the mode of operation employed in the thermionic vacuum tube.

Those patent claims are fundamental and they have never been attacked. They were acknowledged by substantially the entire radio and telephone industries and by the United States government by taking licenses thereunder.

Armstrong and I were both students at Columbia University under the eminent authority on electromagnetic theory—Professor Michael Idvorsky Pupin.

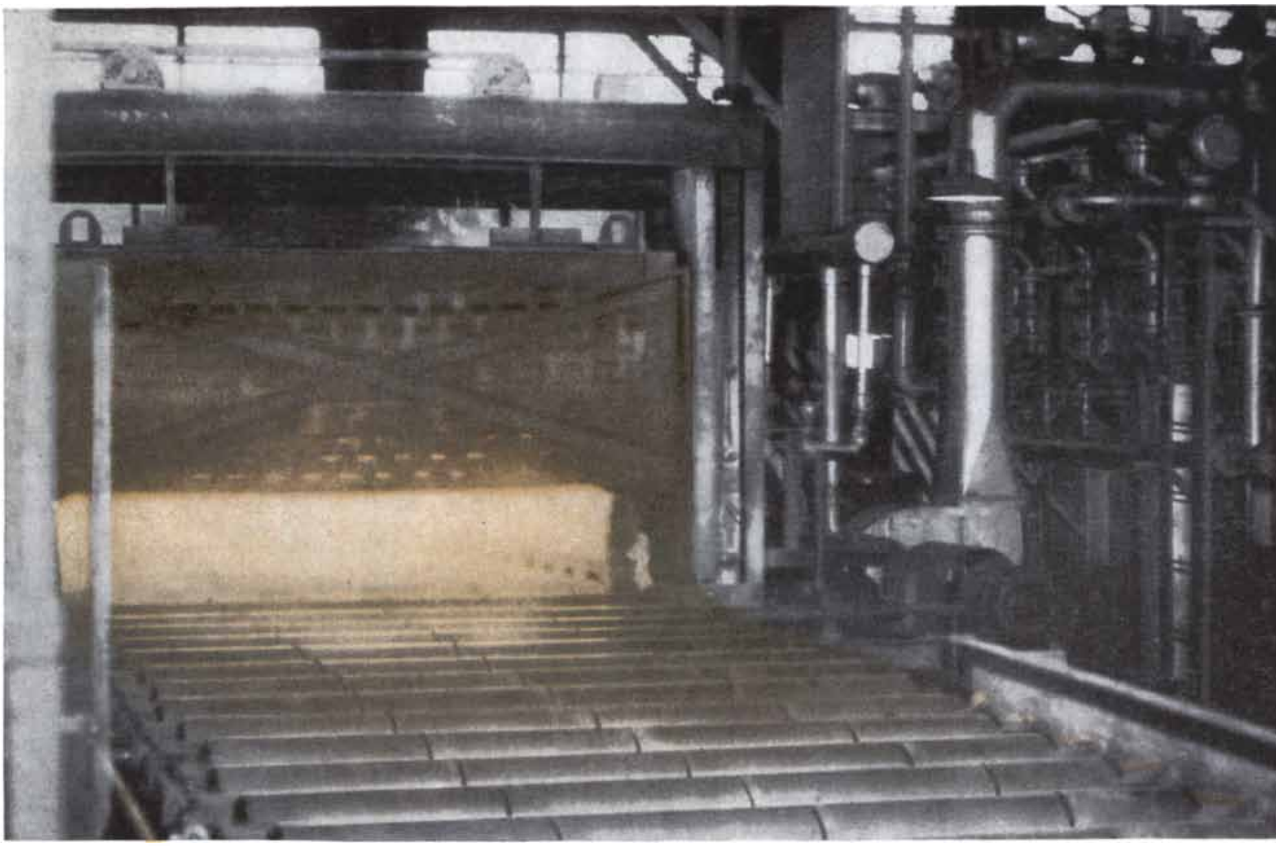
I can never forget the day when a large and distinguished company of engineers gathered together in New York to do homage to the man who laid the foundation of long-distance telephony by creating the loaded telephone line. When the great thinker rose to respond he brushed aside his own outstanding achievements in the fewest possible words and then told about two young men who had been his students. He leaned heavily on his cane and said affectionately: "They were two of my chickens."

Such is the simplicity of greathearted genius.

Such was the inspiration of Ed Armstrong and his friend.

FREDERICK K. VREELAND

Vreeland Laboratory
Vreeland Corporation
Mill Valley, Calif.



3800 hours at 2150 deg. F.

The HASTELLOY alloy X rollers in this gas-fired heating furnace have been in use for 3800 hours. They operate in a neutral atmosphere at 2150 deg. F. They are also subjected to mechanical and thermal shock as they come in contact with the cold sheet metal being heated. A recent inspection showed that the HASTELLOY alloy X parts are still in excellent operating condition.

The rollers were fabricated from HASTELLOY alloy X sheet, 3/16 in. thick. The sheets were formed into shells 7½ in. in diameter and six feet long. The shells were then slipped over 2-in. water-cooled pipe, and refractory material was packed into the space between the shells and shafts. Spiders on the shafts were used to keep the shells concentric.

HASTELLOY alloy X has excellent forming characteristics, and good creep and stress-rupture properties. At 1200 deg. F. this nickel-base alloy has an ultimate strength of 82,000 lb. per sq. in., and even at 1500 deg. F. the ultimate tensile strength is 48,000 lb. per sq. inch. Its outstanding resistance to oxidizing, reducing, or neutral atmospheres makes it especially useful in furnace applications.

For information on prices, sizes, and properties of HASTELLOY alloy X write to any of the district sales offices listed below.

"Hastelloy" and "Haynes" are registered trade-marks of Union Carbide and Carbon Corporation.

HAYNES
TRADE-MARK
ALLOYS

HAYNES STELLITE COMPANY

A Division of Union Carbide and Carbon Corporation

UCC

General Offices and Works, Kokomo, Indiana

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Look what's new in metals

Modern Living Demands

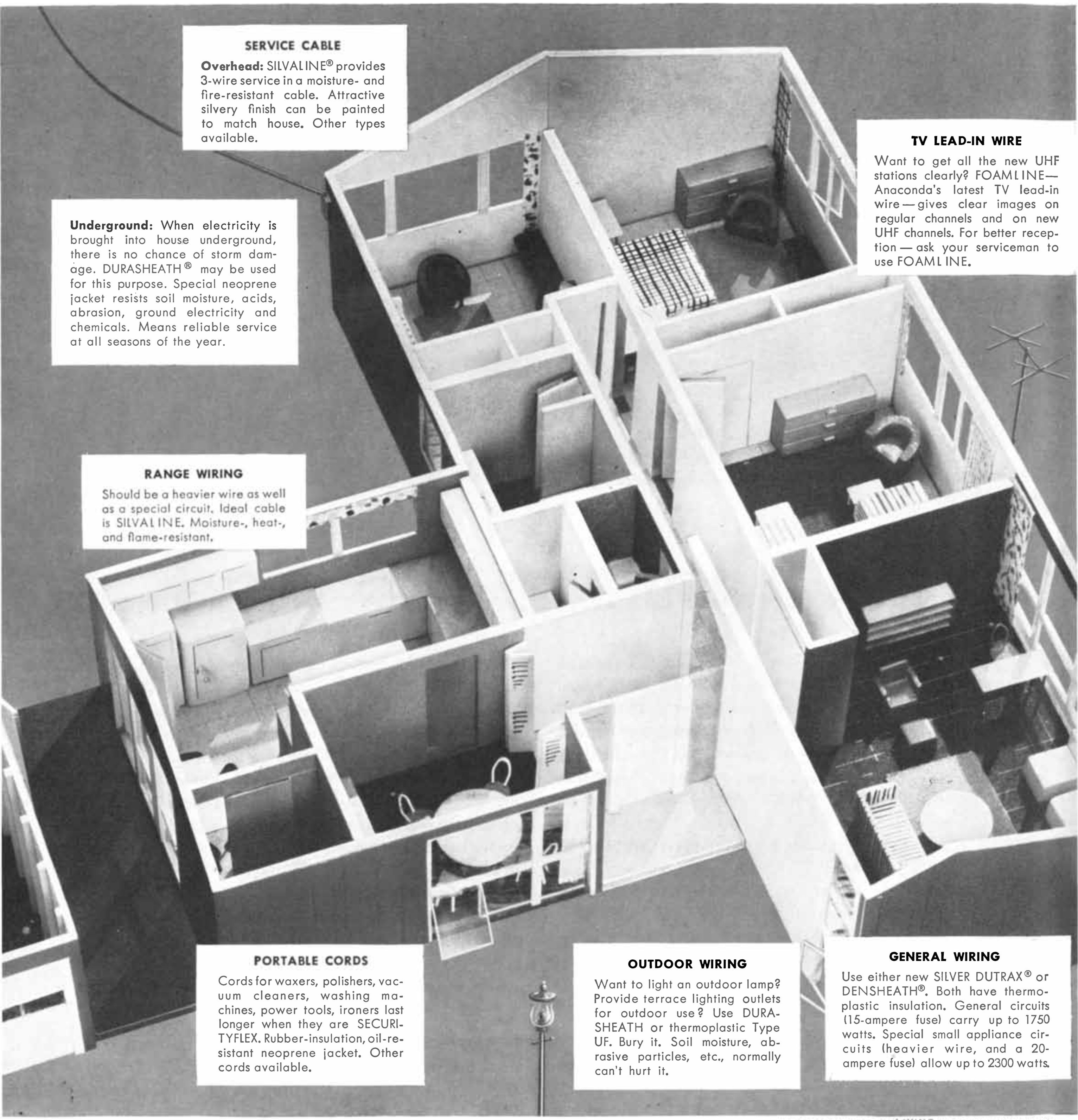


ILLUSTRATION COURTESY LIVING FOR YOUNG HOMEMAKERS

HOW SHALL I WIRE MY HOME? Though Americans live in an electrical wonderland of exciting new appliances, few realize how many types of wire are needed to make a house a home. Here are shown some of the wires that Anaconda has developed to help your electric company and your electrical contractor do a better job of home wiring—from pole to meter to appliance. For 15¢ in coin we'll be glad to send you a helpful 24-page booklet, "Getting the Most out of Your Electrical System." It has been prepared by The National Adequate Wiring Bureau. Write for your copy to Anaconda Wire & Cable Company, 25 Broadway, New York 4, N.Y.

Modern Wiring

THE PROBLEM OF OUTMODED, INADEQUATE WIRING HAS PLAGUED THE ELECTRICAL INDUSTRY FOR YEARS. NOW THE BOOM IN ELECTRICAL APPLIANCES MAKES THE SITUATION CRITICAL.

Millions of Americans had no electrical problems to speak of—until they began to plug in millions of the new electrical appliances. Then this became a nation of popped fuses. And now everyone is learning that the wiring in most American homes simply cannot carry the current required by today's electrical living.

Anaconda Wire and Cable Co. has consistently campaigned for greater adequacy in *industrial* wiring since 1937. Electric companies, wholesalers, contractors and industry all worked together. They so improved the power arteries through which flowed the lifeblood of millions of electrically operated tools and machines—large and small—that American industry was far better prepared for its now famous "miracle of production" in World War II.

What's the answer?

Now the problem has shifted to the home front. American homes, new and old alike, need millions more circuits and greatly increased conductor capacity.

Through research in conductors and insulations, Anaconda is helping to meet the wiring needs of the nation—in common with other leading manufacturers. Adequate wiring campaigns are now spreading over the land. Builders and electrical contractors are responding with better wiring in new homes—and by encouraging adequate rewiring of existing buildings.

To help implement these efforts, Anaconda offers not only a complete line of efficient, modern and economical building wires and cables (described on the opposite page)—but also a complete package of promotional material available to electric companies, contractors and electrical wholesalers.

Everyone lives better—electrically

An adequately wired America not only enjoys itself more—but spends more money for *more* electrical appliances.

Good wiring benefits everyone—local businessman, manufacturer, parts-supplier, builder, and contractor.

Good wiring means good living—more fun, less work, more comfort.

54277

ANACONDA

"ANACONDA" IS A REGISTERED TRADEMARK

PRODUCERS OF: Copper, zinc, lead, silver, gold, platinum, cadmium, vanadium, selenium, uranium oxide, manganese ore, ferromanganese, and superphosphate.

MANUFACTURERS OF: Electrical wires and cables, copper, brass, bronze and other copper alloys in such forms as sheet, plate, tube, pipe, rod, wire, forgings, stampings, extrusions, flexible metal hose and tubing.

SEVEN-TON BITE OF COPPER ORE! Since November, 1953, these big shovels have been working at Anaconda's new open-pit mine near Yerington, Nevada. The ore is trucked to the adjoining treatment plant. After this the ensuing copper-rich precipitate is shipped to Anaconda's Montana plants for smelting and refining. Since World War II, "Yerington" was the first of the nation's new copper mines.

HOW MUCH DOES RUST COST? Rust costs Americans 5 times as much as fire each year. Hot and cold water lines, drainage systems, conventional or radiant heat piping, gutters, downspouts and flashings *in Anaconda Copper* can't rust . . . save homeowners money and trouble.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

SEPTEMBER, 1904: "The world's petroleum production for 1903 stands at 20,000,000 tons, and of this more than one half is furnished by Russia, the rest coming from the United States and Canada, Roumania and Borneo. The demand for petroleum greatly exceeds the present production. The substitution of oil for coal, in order to be advantageous, needs a better regulation of the methods of producing it and also of the price."

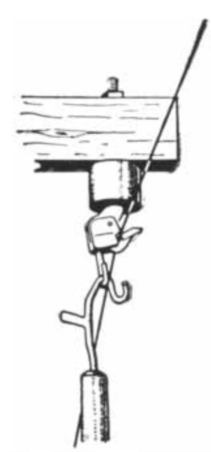
"Again the United States has surpassed all competitors in its yearly output of iron ores. This is the most important fact contained in the report made by Mr. John Birkinbine to the United States Geological Survey on the production of iron ores in 1903. The quantity mined in 1903 is the second largest recorded and is greater than the combined totals for the year 1902 of Germany, Luxembourg and the British Empire, which are the nearest competitors of the United States."

"The principal item of astronomical news for the past month comes from the Harvard Observatory. It may be remembered that in 1899 the announcement was made that a faint satellite of Saturn had been discovered in photographs taken at the Harvard station at Arequipa, Peru. So long a time has passed since then that astronomers were beginning to fear that the satellite had been 'lost,' because it had not been possible to obtain enough observations to determine its orbit. But a short note from Harvard, which appeared a few weeks ago, sets these doubts at rest. The satellite has been photographed on many occasions in the last five years, and a long series of observations obtained this spring has made it possible to calculate the orbit, and predict the satellite's motion accurately. The details of this are to be published in the *Harvard Annals,* but have not yet reached us."

"The average life of the uranium atom is calculated by J. Joly to be 10^{10} years

The pole that need not be climbed

Fastening wires with new tool.



Since telephony began, there has been just one way to install telephone wires on poles: have a trained man climb up and fasten them there. Now Bell Laboratories engineers have developed a special pole line for rural areas. The entire line can be erected without climbing a pole.

The whole job is done from the ground. Light-weight poles are quickly and easily erected. Newly created tools enable men to fasten wires to crossarms 10 to 25 feet over their heads.

This inexpensive line promises more service in sparsely populated places. From original design to testing, it exemplifies a Bell Telephone Laboratories team operation in widening telephone service and keeping costs down.

Key to the new "climbless" pole is this insulator. Ground crews use long-handled tools to place the wire in position and then lock it fast.

Bell Telephone Laboratories

IMPROVING TELEPHONE SERVICE FOR AMERICA PROVIDES CAREERS FOR CREATIVE MEN IN SCIENTIFIC AND TECHNICAL FIELDS

—a period one hundred times greater than the period allowed for the development of the geological strata."

"Many new thrills and novel sensations are being experienced by the guests at the St. Louis Exposition, and a company has undertaken to put up the great American refreshment, ice cream, in the most novel and convenient form which has ever been devised. This company utilizes the collapsible tube in which paint has been so long sold for the use of artists. This tube was used first for this purpose and later came into favor for tooth paste, some forms of soap and similar commodities. The inventor is of the opinion that this invention will appeal to the great majority of visitors to the fair, for the reason that it will be a timesaver."

"Robert E. Peary has announced that he will again attempt to reach the North Pole in a specially constructed vessel, in which he will embark next summer. 'My plan of campaign, in a very few words,' Peary said, 'is to force this ship to the north shores of Grant Land, taking on board at Whale Sound the pick and flower of the Esquimau tribe with whom I have worked and lived so long, to go into winter quarters on that shore, and to start with the earliest returning light on the sledge journey across the central polar pack. Never before has it been in the power of a white man to command the utmost efforts and fullest resources of this little tribe of people, as I can do.' "

"A. J. Balfour, Chancellor of the University of Edinburgh, recently addressed the British Association for the Advancement of Science on the new electrical theory of the atom. Speaking of atomic forces he said, 'In common with all other living things, we seem to be practically concerned chiefly with the feebler forces of Nature, and with energy in its least powerful manifestations. Chemical affinity and cohesion are on this theory no more than the slight residual effects of the internal electrical forces which keep the atom in being. Gravitation, though it be the shaping force which concentrates nebulae into organized systems of suns and satellites, is trifling compared with the attractions and repulsions with which we are familiar between electrically charged bodies; while these again sink into insignificance beside the attractions and repulsions between the electric monads themselves. This prodigious mechanism seems outside the range of our immediate inter-

X-RAY--invisible guide to industrial progress

General Electric apparatus gives you fast, accurate, low-cost inspection, analysis, quality control, gaging

FOUNDRIES, welding shops, metallurgical and research laboratories, mines, fabrication and assembly plants — even dairies, breweries, confection and milling plants — consider x-ray a working partner in producing better products at lower costs.

There are four main groups of x-ray apparatus: Radiographic, Fluoroscopic, Diffraction and Gaging. In each, G. E. offers you a broad range of quality equipment backed by application, sales and service engineers whose job is to make this equipment best serve you and your needs.

X-ray radiography is a proven quality control device, helping to produce better products of known quality in less time, at lower cost. It is presently used in hundreds of foundry and welding shops, as well as in various assembly and other manufacturing operations.

The proper application of a specific piece of x-ray radiographic apparatus is governed by several factors:

1. Thickness of part to be inspected.
2. Latitude (relationship of thick and thin parts of same object being radiographed).
3. Number of parts, feet of welds, etc., to be inspected in any given period.
4. The size of the defect which must be seen.

There is a G-E radiographic unit which will best fit the above factors, and which in turn can be translated in terms of your quality control and inspection requirements. Available in over 25 different models, the units which comprise this full range of equipment are presently offered at these voltages: 140 kvp, 250 kvp, 400 kvp, 1000 kvp, 2000 kvp, and 15 mev.

New radiographic method produces great savings — "inside-out radiography." New equipment of small, lightweight design and 360-degree radiation fields has revolutionized the method of radiographing cylindrical vessels. With this equipment, an entire circumferential weld can be radiographed in one exposure. Even radiography of lateral welds is speeded up and simplified. Protection problems are greatly reduced with inside-out radiography since the vessel itself acts as a protective barrier against stray radiation. As a result, radiography normally can be conducted in the middle of the shop.

X-ray fluoroscopy is a rapid, inexpensive method of inspection used to scan a product for gross internal defects or abnormal conditions. Industrial users are generally grouped into three categories: light alloy castings, miscellaneous assemblies and food products. Among the specific items now being inspected are aircraft castings, shoes, rubber heels, electrical and ordnance components, confectionery products, citrus fruits and other manufactured items. This inspection assures a uniform product and prevents defective material from reaching the customer.

Quality control, as exemplified by x-ray fluoroscopy, assists in the reduction of product cost, elimination of the cause of rejects and improvement of the product.

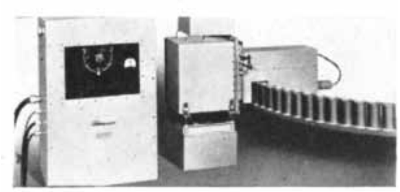
In the light alloy field, the major users of fluoroscopy are in the aircraft industry. They use fluoroscopy to screen certain aluminum castings before submitting the lot to the radiographic test prescribed by the aircraft inspection code. This screening eliminates castings with gross defects and assures the casting supplier of meeting the acceptance test. Light alloy foundries and die casters also use fluoroscopy for quality control on casting technics.

Size of the defect which can be seen fluoroscopically is about 6 to 8 percent of the total thickness... with standard commercial equipment. With special screens now available and small focal spot tubes (less than 1 mm) sensitivities of 3 percent have been reported.

General Electric has fluoroscopic equipment available in both conveyor and cabinet type housings. Completely self-protected, these units can be used anywhere in the shop or plant.

X-ray diffraction methods are time-saving, accurate and non-destructive. In conjunction with fluorescence instruments, they are capable of solving a multitude of analytical problems. Organic and inorganic compounds can be studied qualitatively and quantitatively. Arrangement of atoms and molecules in a crystal can be determined. The behavior of compounds under various temperatures can be examined. Orientation of particles in drawn wires and rolled metal sheet is examined by diffraction, as are phases in alloys.

The use of x-ray diffraction is becoming increasingly widespread. The chemical, steel, mining, oil, glass and automobile industries — to name just a few — are presently using x-ray diffraction.



Automatic gaging — To speed up inspection and keep pace with ever-increasing production rates, automatic gaging — using x-rays or similar radiation — is providing the answer to many production problems. It eliminates the need for visual inspection and the coincident possibility of operator error.

Successful application of this method has been made in a wide variety of fields, including: Thickness or density monitoring; checking the fill of liquids or free-flowing solids in opaque containers; indicating the concentricity of coated wires or rods, the presence or absence of a component in an assembly.

X-ray is doing so many things for so many industries. To find out how it can help you, call the G-E x-ray representative near you, or write X-Ray Department, General Electric Company, Milwaukee 1, Wisconsin, Room TT94.

Progress is our most important product

GENERAL ELECTRIC

ests. We live, so to speak, merely on its fringe. It has for us no promise of utilitarian value. It will not drive our mills; we cannot harness it to our trains. Yet not less on that account does it stir the intellectual imagination.' "

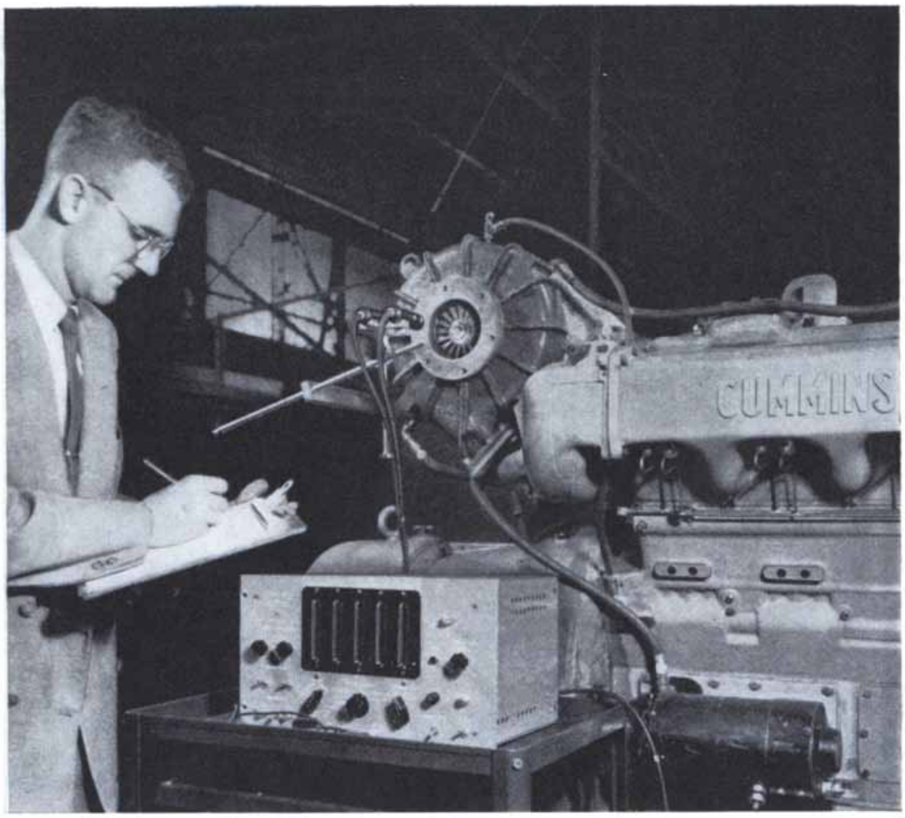
"In a recent number of *Harper's Magazine* Sir Oliver Lodge presents a popular account of the electronic theory, which is well worth quoting: 'Our present view of an atom of matter,' says Sir Oliver, 'is something like the following: Picture to oneself an individualized mass of positive electricity, diffused uniformly over a space as big as an atom—say a sphere of which 200,000,000 could lie edge to edge in an inch. Then imagine disseminated throughout this small spherical region a number of minute specks of negative electricity, all exactly alike, and all flying about vigorously, each of them repelling every other, but all attracted and kept in their orbits by the mass of positive electricity in which they are embedded and flying about. Insofar as an atom is impenetrable to other atoms, its parts act on the sentinel principle, not on the crowd principle!' "

SCIENTIFIC AMERICAN

SEPTEMBER, 1854: "We hope the four new government steam frigates which are to be built, according to the bill passed at the last session of Congress, will not make us ashamed of our country with respect to the way things have hitherto been managed in the Navy Department. Our readers will remember our famous steam frigate *San Jacinto*, for its desperate performances have been described more than once in our columns. If we are not much mistaken, this steam frigate has already had two new sets of machinery, and she is but yet in her trial trips, having done no service worth naming. Is not this a shame? It is. Engineers of the Navy, take care of the new steam frigates! Your reputation is at stake in their construction. You have much to lose if they prove unsuccessful."

"It is said there are now in Pittsburg thirty-eight iron foundries; of which nine are almost exclusively employed in the manufacture of steam engines, and twenty-nine in the manufacture of various kinds of hollow ware, machinery, &c. The foundries which are employed in

Your business is in the Age of Electronics



Cummins Engine Company, Inc. employs *-hp-* electronic counters in numerous ways. One is precision measurement of R.P.M. in new diesel engine turbo supercharger. The *-hp-* counter will measure accurately to 6,000,000 R.P.M.

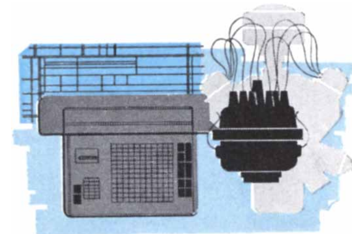
Electronic Counters—new, easy way industry makes precision measurements better, faster

Pressure, flow, velocity, r.p.m., quantity, viscosity, time interval—these are but a few production and research measurements new electronic counters make with hitherto unattainable speed and accuracy.

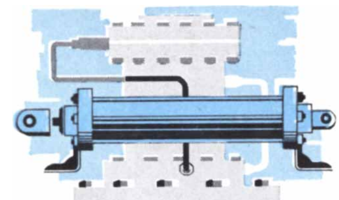
You do not need highly trained technicians to operate *-hp-* electronic counters. Nor is an elaborate and expensive instrument setup required. Reading an *-hp-* counter is like reading numbers on a license plate. Results appear in direct numerical form, complete even to automatic illuminated decimal.

-hp- 522B Electronic Counter shown here is but one of 10 *-hp-* counters, scalers or converters for research and industrial use, and one of over 250 different electronic test instruments Hewlett-Packard builds. Throughout industry and science, men are finding these instruments a better, faster way of obtaining engineering and manufacturing information.

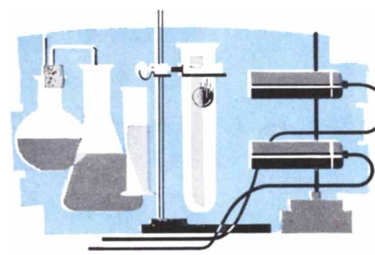
Correct application is of course of first importance; and this is where your *-hp-* field engineer can help most. If there are measurements you would like made more swiftly, simply or accurately, please write us about them.



Time interval. Time measurement of extreme accuracy is required in design and manufacture of automotive electrical systems, calculation equipment, automatic devices, etc. *-hp-* electronic counters measure intervals as microscopic as 1/1,000,000 second, as long as 100 days.



Pressure. In hydraulic and pneumatic equipment, pressures must be known exactly. Together with a simple transducer converting pressure to electric signals, *-hp-* counters read even most minute pressures directly, instantly; determine pressures at remote or hazardous points.



Viscosity. *-hp-* electronic counters and *-hp-* photo tubes work as a team to give instant viscosity data. Measurements are made by reading time of fall of free object through liquid under test. Counter reads time directly in seconds or milliseconds. Velocity measurements are also made this easy, accurate way.

WORLD LEADER IN ELECTRONIC MEASURING INSTRUMENTS

FIELD ENGINEERS SERVING ALL PRINCIPAL CITIES

HEWLETT-PACKARD COMPANY

275 PAGE MILL ROAD • PALO ALTO, CALIFORNIA

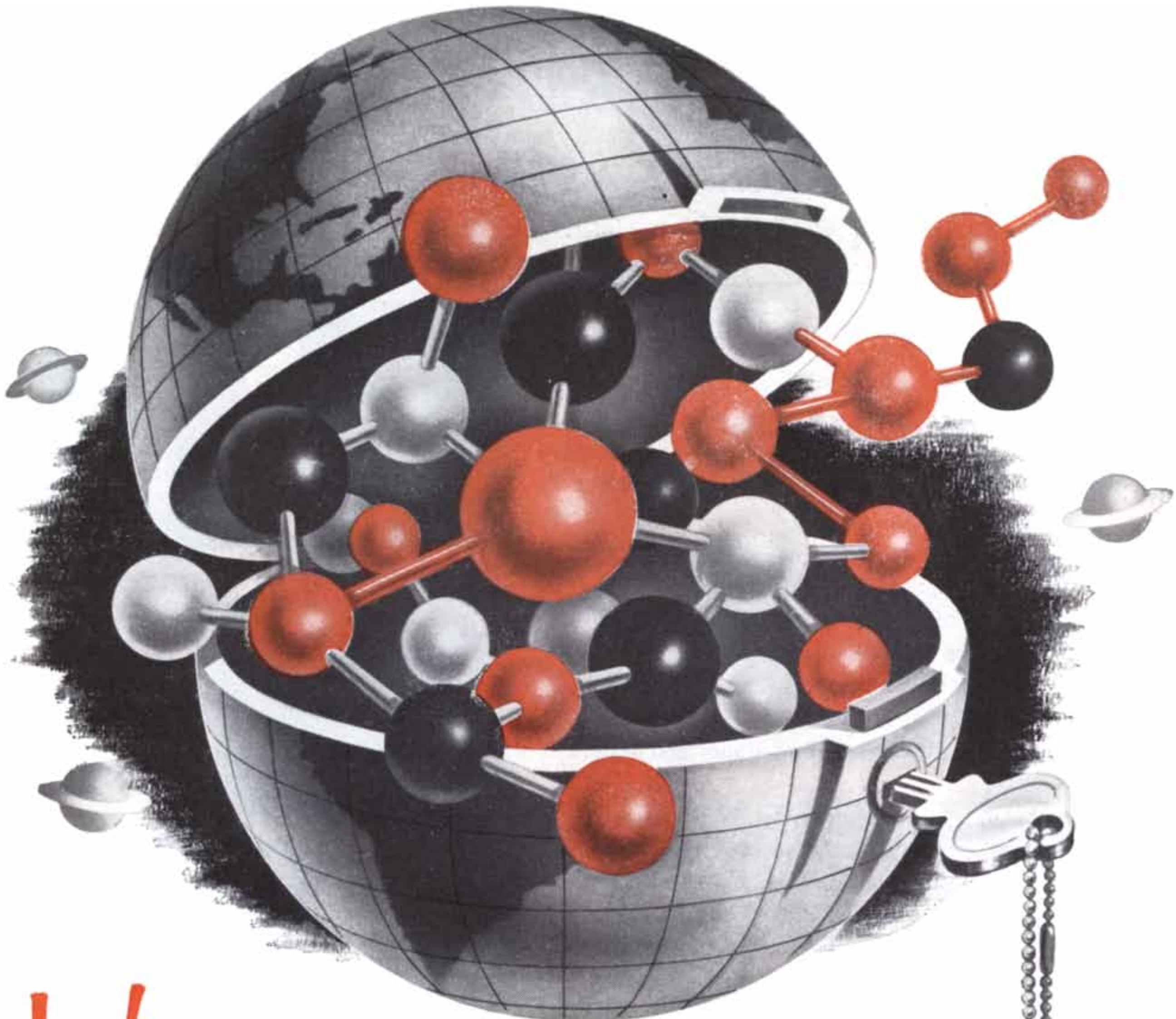
3101

the manufacture of steam engines consume yearly 3,200 tuns of wrought iron, 9,200 tuns of pig, employ 640 men and produce 120 steam engines every year. Their net capital is $549,000."

"M. Regnault, director of the Rouen telegraph in France, has produced light by electricity for four consecutive months for the Napoleon Docks, accommodating 300 workmen. His report of the experiment is interesting. Two large-sized batteries were used, and the expense of each per evening was: wages of workmen 4.50 francs; mercury 5 francs; zinc 4.50 francs; charcoal points 1.40 francs; nitric acid 1.80 francs; sulphuric acid 1.84 francs. This adds up to 19.04 francs per battery, or $7.62 per evening for both batteries, or about one mill per man. The work can be done without danger. The report remarks that electro-lighting can be cheaply established on ship board and is not like other light liable to be extinguished in a storm."

"No country in the world is so much affected by extensive conflagrations as ours. We presume that no less than $20,000,000 of property has been consumed by fire in the past year. This is all a dead loss to the country, and tends greatly to retard its prosperity. In France and England not one house is destroyed by fire for a hundred in the United States. Indeed, we are assured that in the city of Paris not more than one building is burned in three years, while in New York it is rather a wonderful thing if one is not burned down every day."

"The Albany *Knickerbocker* re-echoes the sentiments of the Hartford *Times*, and abuses the managers of the Smithsonian Institution because they discountenance a large and extensive library in Washington, they believing that it would be in opposition to the expressed sentiments in the will of James Smithson. It calls them 'a lazy set of professors; too deficient in talent and industry to obtain situations in colleges.' This is not true; no well-informed American would make such charges against the Secretary, Professor Henry, whose discoveries in science have conferred honors on his country, and whose reputation is world-wide and above reproach. While Professor of Natural Philosophy, &c., in Princeton College, he was solicited to take the secretaryship of the Smithsonian Institution, and conferred honor upon those who solicited him by accepting their offer, not they upon him."



Who are energy's "locksmiths?"

THE BABCOCK & WILCOX COMPANY

Locked within the Earth is ample provision for man's need of an abundance of useful energy. The Earth is stocked with coal, oil, natural gas and uranium from which energy can be harnessed through scientific use of heat.

Man has the task of finding the key to unlock the door to Nature's treasurehouse. Over the centuries he has learned that he needs not one key, but many, if the Earth's bounty is to serve him well. He must *release* heat energy, *contain* it, *absorb* it, *convert* it and *transport* it. Americans enjoy the highest standard of living in the world because they have found the keys and are applying their knowledge to the production of energy on a vast scale.

For three-quarters of a century B&W has assumed the responsibility and enjoyed the privilege of being in the forefront of man's struggle to release heat energy and convert it to useable form.

The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, N. Y.

BABCOCK & WILCOX

I-1

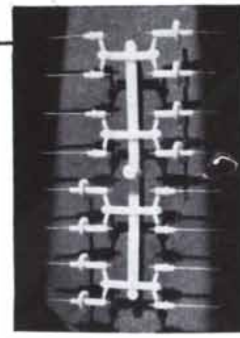
A *TECHNICAL REPORT* *from Du Pont*

• *Properties and uses of Du Pont "Zytel" nylon resin*

"Zytel" nylon resin is the name for a family of polyamide resins developed by the Du Pont Company, all of which are related in composition. This group of compounds features extreme toughness, abrasion resistance, form stability at high temperatures, strength in thin sections, lightness in weight, chemical resistance and easy moldability.

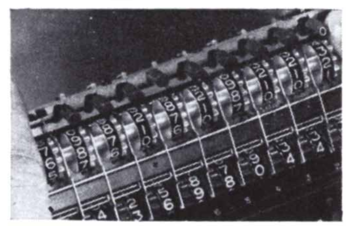
On the opposite page are detailed the outstanding properties of one of the Du Pont "Zytel" nylon molding powders, a general-purpose nylon. By using the unique combination of properties which "Zytel" offers, engineers and designers have been able to develop many new design and product improvements. Six of many thousands of applications, serving practically every industry, are shown here.

Have you and your company considered general-purpose Du Pont "Zytel" nylon resin in terms of your own product-design problems? For additional information on the properties, applications and processing of this unique engineering material, mail in the coupon today.



Blood-donor and receiver needles as they come from the mold illustrate how Du Pont "Zytel" is readily molded around metal inserts.

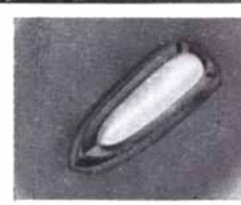
Gears molded from Du Pont "Zytel" have excellent resistance to abrasion, provide quiet operation, and may be produced economically by injection molding.



Counter dials with integral gear, and other parts of this calculating machine are molded of Du Pont "Zytel". The parts of "Zytel" nylon resin cost much less than parts replaced . . . give quiet, smooth operation.

Coil forms of "Zytel" offer an excellent example of the molding of thin and intricate yet tough sections. Du Pont "Zytel" nylon resin has good dielectric properties for electrical applications

This complex molding is the tension pulley on a yarn-tension brake for textile machinery. Du Pont "Zytel" nylon resin provides resiliency and strength in thin sections.



Du Pont "Zytel" is an ideal material for translucent lenses, such as this one. "Zytel" nylon resin is heat-resistant, won't discolor, eliminates breakage during assembly and use.

ZYTEL†
Nylon Resin
Tough, Abrasion-Resistant
Strong in Thin Sections
Form Stability

ALATHON*
Polyethylene Resin
Excellent Dielectric Properties
Flexibility and Toughness
Tasteless, Odorless, Non-Toxic
Excellent Water Resistance

LUCITE*
Acrylic Resin
Clear, Transparent
Outdoor Durability
Unlimited Range of Colors
Ability to Pipe Light

TEFLON*
Tetrafluoroethylene Resin
Heat Resistance
Chemical Inertness
Dielectric Properties
Non-Sticky Characteristics

†"Zytel" is the new trade-mark for Du Pont nylon resin
**Registered trade-mark of E. I. du Pont de Nemours & Co. (Inc.)*

DU PONT

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TYPICAL PROPERTIES* OF DU PONT "ZYTEL"

MECHANICAL

			METHOD
Tensile strength	—70°F.	15,700 p.s.i.	D-638-46T
	73°F.	10,900 p.s.i.	D-638-46T
	170°F.	7,600 p.s.i.	D-638-46T
Elongation	—70°F.	1.6%	D-638-46T
	73°F.	90%	D-638-46T
	170°F.	320%	D-638-46T
Modulus of elasticity	73°F.	400,000 p.s.i.	D-638-46T
Shear strength		9,600 p.s.i.	D-732-46
Impact strength, Izod	—40°F.	0.4 ft.-lb./in.	D-256-47T
	73°F.	1.0 ft.-lb./in.	D-256-47T
Stiffness	73°F.	250,000 p.s.i.	D-747-48T
Flexural strength	73°F.	13,800 p.s.i.	D-790-45T
Compressive stress at 1% deformation		4,900 p.s.i.	D-695-44T
Creep in flexure		90	**
Hardness, Rockwell		R 118	D-785-48T

THERMAL

Flow temperature	480°F.	D-569-48
Coefficient of linear thermal expansion per °F.	5.5×10^{-5}	D-696-44
Thermal conductivity	1.7 B.T.U./hr./sq.ft./°F./in.	—
Specific heat	0.4	—
Deformation under load at 122°F. and 2000 lb./sq.in.	1.4%	D-621-48T
Heat-distortion temperature 264 lb./sq.in.	150°F.	D-648-45T
Heat-distortion temperature 66 lb./sq.in.	360°F.	D-648-45T

ELECTRICAL

			METHOD
Dielectric strength, short-time		385 V/MIL	D-149-44
	step by step	340 V/MIL	D-149-44
Volume resistivity		4.5×10^{13} OHM-CM.	D-257-46
Dielectric constant,	60 cycles	4.1	D-150-47T
	10^3 cycles	4.0	D-150-47T
	10^6 cycles	3.4	D-150-47T
Power factor,	60 cycles	0.014	D-150-47T
	10^3 cycles	0.02	D-150-47T
	10^6 cycles	0.04	D-150-47T

MISCELLANEOUS

Water absorption	1.5%	D-570-42
Flammability	self-extinguishing	D-635-44
Specific gravity	1.14	D-792-48T
Average mold shrinkage	0.015 in./in.	—
Compression ratio	2.1	D-392-38
Resistance to weathering	good	—
Basic color	light cream, translucent	—
Resistant to:	esters, ketones, common solvents, alkalies, weak acids	
Not resistant to:	phenol, formic acid, concentrated mineral acids	

*Some of the physical properties are dependent on the moisture content of the nylon which may be as high as 2-2.5% under normal exposure.

**Term "creep in flexure" is a measure of the deformation under a prolonged standard load. Results here represent mils deflection in 24 hrs. of a 1/8" x 1/2" bar, 4" span, center-loaded flatwise to 1,000 lb./sq. in., minus the initial deflection.

Note: This table shows the typical property data for Du Pont "Zytel" nylon resin FM-10001.

THE AUTHORS

LOREN C. EISELEY ("Man the Fire-Maker"), professor of anthropology at the University of Pennsylvania, is well known to readers of SCIENTIFIC AMERICAN; his most recent article was "Fossil Man" in the December, 1953, issue. He has recently been commissioned by the American Philosophical Society to compile a bibliography of Charles Darwin.

FREEMAN J. DYSON ("What Is Heat?"), professor of physics at Cornell University, was born in England, where his father is president of the Royal College of Organists. After studies at Cambridge University that were mainly devoted to mathematics, he was assigned to operations research with the Royal Air Force bomber command during the last years of World War II. In 1947 he came to the U. S. on a Commonwealth Fund fellowship and turned his attention to physics. He has made valuable contributions in field theory—see his article on the subject in the April, 1953, issue. Before his present appointment at Cornell he spent some time at the Institute for Advanced Study at Princeton and married one of the mathematicians there. He was elected a fellow of the Royal Society in 1952.

I. BERNARD COHEN ("Pioneers in the Theory of Heat") is associate professor of the history of science and of general education at Harvard University and editor of *Isis*, the history of science journal. Cohen graduated from Harvard College in 1937 and has taught there ever since. His conscientious labors in the history of science have brought forth a number of books and articles, including several for SCIENTIFIC AMERICAN, among them a biographical sketch of Benjamin Franklin in the issue of August, 1948, and one of Galileo in August, 1949. His particular specialties are the history of physics and the development of scientific ideas in the 18th century. He is an authority on Benjamin Franklin. The best known of his books is *Science, Servant of Man*.

FRANK H. JOHNSON ("Heat and Life") is a biologist whose main interest has been the study of biological reaction rates. He says that he has been "trying to be a biologist" since early high school days. He graduated from high school at 15, did his undergraduate work

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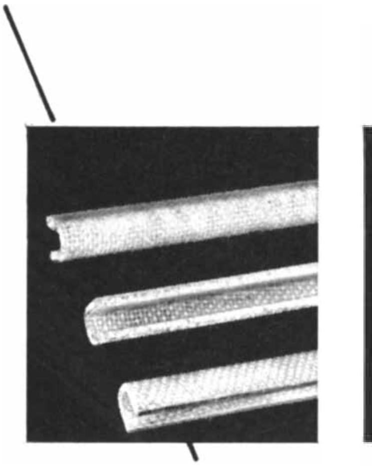

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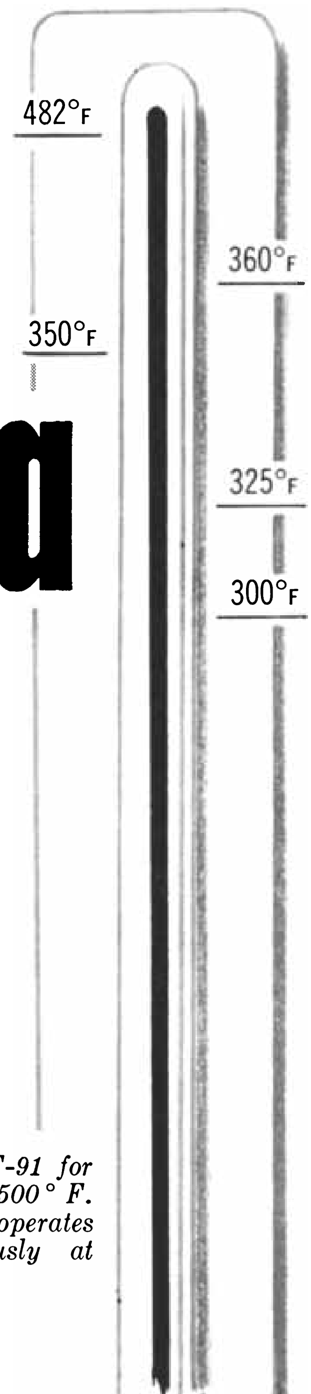

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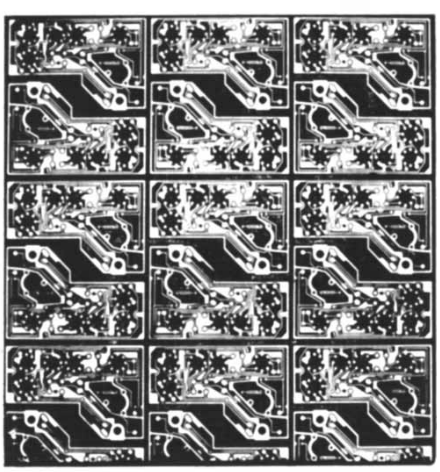

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☐ FF-91 (360° F.)	☐ A (300° F

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at Princeton University, obtained a Ph.D. in 1936 and has been there, on and off, ever since. In 1942 he, Dugald Brown and Douglas Marsland of New York University won the $1,000 prize of the American Association for the Advancement of Science for their joint study of the action of various environmental pressures on the luminescence of bacteria. In much of his work on luminescence Johnson has collaborated with Henry Eyring, the eminent authority on chemical reaction rates. Johnson has worked in several fields of biochemistry, including respiration, proteins, bacteriophage and enzymes. A painter in his spare time, Johnson spends Saturdays at the Art Students League in New York whenever he can get away from the laboratory.

BERNARD LEWIS ("High Temperatures: Flame") is a leading physical chemist who for many years was chief of the explosives branch of the U. S. Bureau of Mines. Born in London, he took his B.S. at Massachusetts Institute of Technology and his M.A. at Harvard University. He returned to England for his Ph.D. at Cambridge University, where he was demonstrator in physical chemistry for a year. After an interval of research in Minnesota and Berlin, he embarked on a long career in the Bureau of Mines. He has studied flames and explosions for 25 years and has written a great deal on these subjects. Recently he left the Bureau along with three colleagues to form a consulting organization in Pittsburgh called Combustion and Explosives Research, Inc. Last December he was awarded an honorary D.Sc. degree by Cambridge University in recognition of his outstanding work in his field. With his wife, the concert pianist Eunice Norton, Lewis takes an active part in the musical life of Pittsburgh; he is a founder and president of the Pittsburgh New Friends of Music.

POL DUWEZ ("High Temperatures: Materials") is a metallurgist whose career has oscillated between Belgium and the U. S. Born in the town of Mons, in the coal-mining area not far from the French border, he took his D.Sc. at the University of Brussels in 1933, then went to California Institute of Technology for two years on a fellowship from the Belgian-American Educational Foundation. His fellowship studies were physics and aeronautics. He then returned to teach physics in the school of mines of his home town, until the German invasion of 1940 bounced him back to Cal Tech, where he is now associate

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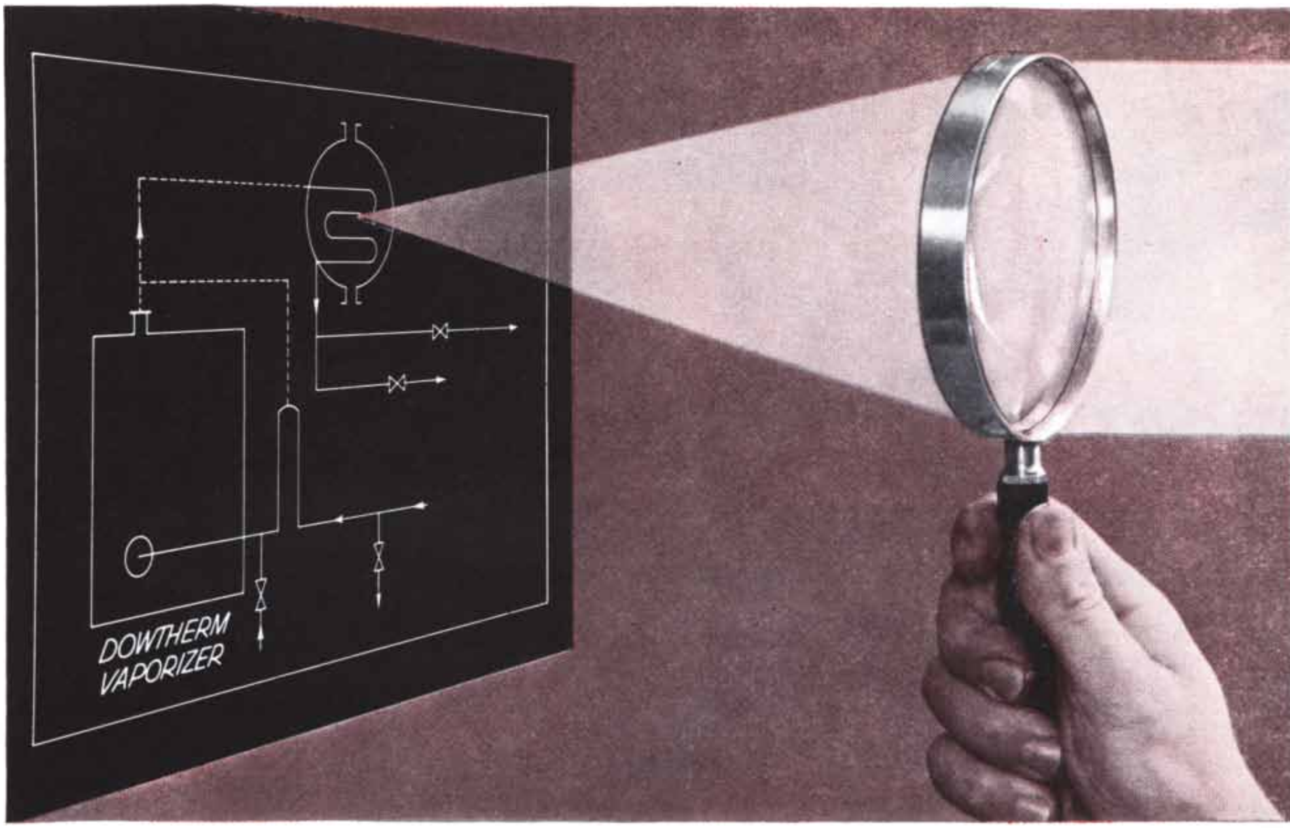
professor of mechanical engineering. His research has been in the physics of metals, in ceramic materials and in the plasticity of crystals. He has been a consultant to the U. S. armed forces on several technical committees and is now a U. S. citizen. Duwez' interest in materials to withstand high temperatures was originally awakened by researches in Belgium on alloys for steam turbines, and it was sharpened after his return to Cal Tech by the fact that the Institute is a center of research on jet propulsion.

FARRINGTON DANIELS ("High Temperatures: Chemistry") has served the chemical profession and the U. S. Government with distinction for many years. After taking his Ph.D. in physical chemistry at Harvard University in 1914, he taught for a while, then served in turn the Chemical Warfare Service and the Fixed Nitrogen Research Laboratory of the Department of Agriculture. He joined the University of Wisconsin in 1920 and in 1928 was appointed professor of chemistry, a title he has held ever since. He is the author of five books in physical chemistry and for some years was associate editor of *The Journal of the American Chemical Society*, as well as of two other journals. In 1941 he became consultant to the National Defense Research Committee and, in 1943, to the War Production Board. He is best known as the wartime director of the famous Metallurgical Laboratory at the University of Chicago, where the first uranium chain reaction was achieved. Daniels was president of the American Chemical Society in 1953.

MARTIN SUMMERFIELD ("High Temperatures: Propulsion") is a physicist who has been interested in rockets since his days as a graduate student at California Institute of Technology. He had begun to study infrared spectroscopy, but a roommate attracted his attention to the cooling problem in rocket motors, which reoriented his career. After taking his Ph.D. at Cal Tech, he worked on the Institute's jet-propulsion project as assistant chief engineer. In 1943 he joined the newly formed Aerojet Engineering Corporation. Later he returned to Cal Tech as chief of rockets and materials in the jet propulsion laboratory. Since 1949 he has been at Princeton University, now with the title of professor of jet propulsion. He has served on two subcommittees of the National Advisory Committee for Aeronautics and holds several patents on rocket motors and related devices. He is currently editing a 12-volume series on *High*



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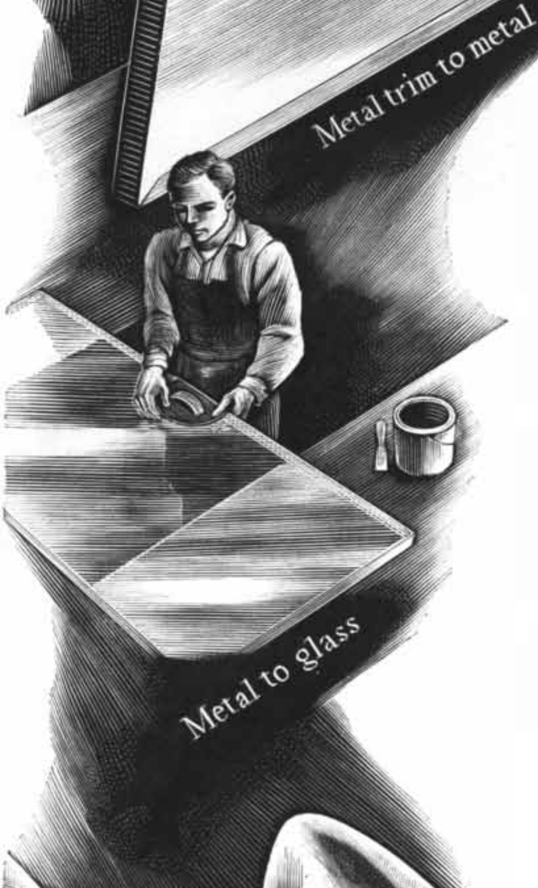
Speed and Jet Propulsion. This huge compilation, gathering the knowledge of some 100 specialists, will be published by the Princeton University Press over the next six years. The first two volumes are now in press.

ARTHUR KANTROWITZ ("Very High Temperatures") is associate professor of aeronautical engineering at Cornell University, where he specializes in gas dynamics and neighboring fields. After doing graduate work at Columbia University he became a physicist with the National Advisory Committee on Aeronautics at Langley Field, where he worked from 1935 to 1946. He was head of the gas-dynamics section, in charge of developing the supersonic axial-flow compressor. Kantrowitz was a lecturer at the Eighth International Congress of Theoretical and Applied Mechanics at Istanbul two years ago and is at present a Fulbright scholar at Cambridge and Manchester universities. He also holds a Guggenheim fellowship this year.

FRED HOYLE ("Ultrahigh Temperatures"), university lecturer in mathematics in St. John's College of Cambridge University, is widely known as the author of *The Nature of the Universe.* In this slim little book, which appeared in 1950, he outlined a new cosmology, founded mainly on his own researches and those of his friend R. A. Lyttleton. Their work had previously been described in a more technical book, *Some Recent Researches in Solar Physics.* Much of Hoyle's success in working out cosmological puzzles is due to his agility in mathematics, in which he won several prizes in his student days at Cambridge. Hoyle is 39, is married and has a son and a daughter. For relaxation he likes music, mountaineering and cricket.

JESSE L. GREENSTEIN, author of the lead book review on *The Sun* in this issue, is professor of astrophysics at California Institute of Technology and a staff member of Mount Wilson and Palomar Observatories. He took his master's degree at Harvard in 1930, then for four years tried the real estate and investment business in New York City. Although he became a director of several corporations, he decided to return to his boyhood passion—astronomy. He went back to Harvard for a Ph.D. and in 1937 joined the Yerkes Observatory, where he remained 11 years. After the war he joined the migration to the clear skies, and huge telescopes, of California.



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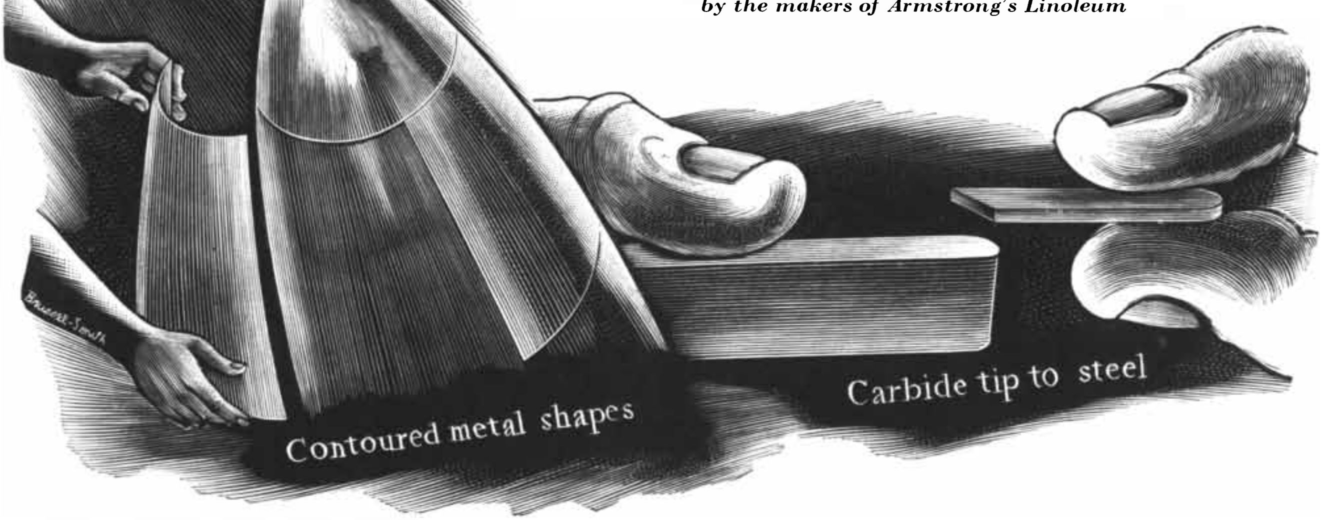

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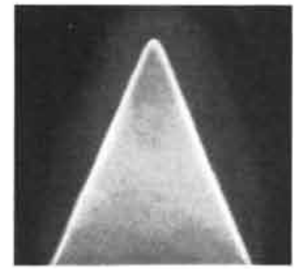

THE COVER

The photograph on the cover shows the inner cone of a flame burning on a nozzle in the National Bureau of Standards. To the naked eye the whole flame would be the same shade of blue seen around the edges of the cone. The red image was produced by the schlieren technique, which makes visible variations in the temperature and density of the gas. The distance between the red and blue images is related to the thickness of the zone in which the actual burning occurs.

THE ILLUSTRATIONS

Cover photograph by Paul Weller

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Silicone News

No. 9 of a series • FOR DESIGN ENGINEERS

HYBRID HOPS HEAT HURDLE

SILICONES RAISE TEMPERATURE LIMITS; OFFER PRODUCT DESIGNERS NEW FREEDOM

After 11 years of commercial production, Dow Corning silicones continue to make news in heat-resistant uses. This new class of semi-inorganic materials, with its basic structure of silicon and oxygen atoms, has proven useful in every industrial field where greater heat resistance is required of non-volatile fluids, flexible insulating varnishes, lubricants, laminates and rubbers.

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As a result, troublesome maintenance and production problems have been solved with Dow Corning silicones. And by freeing designers from the temperature limitations of organic materials, Dow Corning silicones have given rise to hundreds of new and improved products. A few examples are shown and described on these pages. Many of them would have been impractical or even impossible without silicones.

Dow Corning silicones have, in fact, penetrated industry to a degree which is hard to believe. Housing, transportation, clothing, the very food we eat — all have

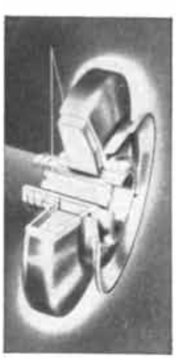
(continued pg. 2)

COURTESY WESTINGHOUSE ELECTRIC CORP.

The heart of the Westinghouse "Electronic Eye" heat control system for electric range surface units is a thermistor embedded in Silastic paste. Flexible Silastic insulated cable connects the thermistor to exterior wiring, and the Electronic Eye itself is isolated in the center of a flexible Silastic diaphragm. The Silastic components have stood up under boiling water, oil, grease, coffee, and syrup, as well as accelerated life testing equivalent to 15 years of actual service.* No. 77

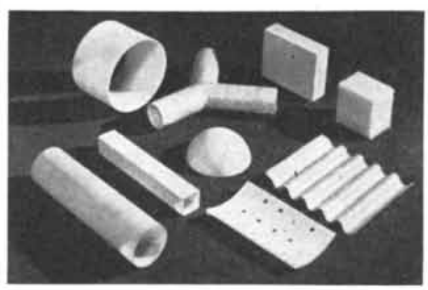
COURTESY PRATT & WHITNEY AIRCRAFT

Silastic-coated glass cloth gaskets have been the standard seal for rocker boxes on the giant P&W Wasp Major aircraft engines for over 8 years. No other material has ever been found with an equal ability to make and hold a tight, resilient seal in contact with hot oil at operating temperatures in the order of 450 F. No. 78



COURTESY HOUDAILLE-HERSHEY CORP.

High viscosity Dow Corning 200 Fluids are used in this torsional vibration damper designed for crankshafts of diesel and automobile engines. The relatively constant viscosity of silicone fluids over a wide temperature range and their ability to withstand constant shearing without breaking down make the principle of viscous damping practical in this device. No. 79



Silicone and its chemical cousin glass combine here in lightweight structural parts for hot jobs. Dow Corning 2106 is used to bond glass cloth to form laminated tubes, ducts, plates and honeycomb structures. Light, strong and arc-resistant, these parts stand 500 F continuously and short time exposures as high as 700 F. No. 80

Relative inertness and incompatibility coupled with a high degree of resistance to breakdown at molding temperatures have made silicone mold release agents standard equipment in the rubber and plastics industries. Unlike organic mold lubricants, silicones cannot decompose at operating temperatures to form a carbonaceous residue on mold surfaces. No. 81

COURTESY THE REDMOND CO.

Spraying dies with Dow Corning Mold Release Fluid provides easy release of aluminum or zinc die castings. Molten aluminum does not cause the silicone film on the die to smoke, fume or leave a hard, carbonaceous deposit. No. 82

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

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Silicone News

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Silicone pressure sensitive adhesives that stick to almost any material, retain useful bond strengths at temperatures from —67 to 480 F. Uses include bonding silicone treated electrical insulating materials, sealing and wrapping tapes and assembly of small electronic parts prior to mechanical installation. *No. 90*

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Heat-stable, nonflammable, foamed structures can be produced from two new Dow Corning expansible resins. Such structures resist direct flame and thermal shock; undergo practically no structural or dimensional change at 700 F; show less than 0.05 percent moisture absorption after 7 days at 96 percent relative humidity. Both resins can be expanded to densities of 6 to 24 pounds per cubic foot. *No. 91*

▽

The Reference Guide to Dow Corning Silicone Products briefly describes the properties and applications of all the most commonly used silicone products. Many manufacturing plants have requested copies for distribution to each of their design and material engineers. *No. 92*

▽

"What's a Silicone?" is the title of a 32 page booklet which answers that often asked question in semi-technical terms. Indexed and illustrated, this booklet has earned an international reputation as the most interesting and informative description of silicones ever published. *No. 93*

HYBRID HOPS HEAT HURDLE *(continued)*

been either improved or processed faster and at less cost with silicones.

As their applications multiply, Dow Corning silicones are being produced in increasing variety and utility. First in commercial production, and backed by expert research and able product development, Dow Corning is producing more and better silicone products than ever before — and at less cost. In contrast to the trend of steadily rising prices these last few years, Dow Corning silicones steadily dropped in price as production mounted.

These are some of the reasons why more and more designers, engineers and maintenance men look first to Dow Corning silicones for the solution to their high temperature problems.

These stationary diesel exhaust mufflers were both finished with aluminum pigmented paint the same day. The coating on the stack at left was formulated with a silicone resin vehicle; that on the right with a high temperature organic resin. After a year of service at surface temperatures in the range of 500 F, the silicone-based finish is relatively unchanged. The organic coating has corroded almost completely away. No. 83

Providing 10 or more times the life of organic grease in high temperature motor bearings of the plain or shielded type, Dow Corning 44 Grease makes permanent lubrication a practical reality in sealed bearings operating at temperatures from —30 to 350 F. No. 84

The generator and motor drive of the "Dynamotive" lift trucks built by Automatic Transportation Co. of Chicago are wound with silicone (Class H) insulation for protection against heavy overloads and excessive moisture. Automatic Transportation engineers report that "silicone insulation is used because it contributes to longer life and can take harder abuse than other insulating materials. Since we adopted it 7 years ago, we have never, to our knowledge, lost a motor due to insulation failure." No. 85

The platinum grey, modified silicone finish on this space heater showed no discoloration, checking or powdering after 500 hours at 450F. The finish is hard (better than 5H) yet flexible (takes 180° bend on 20 gauge steel over 1/8 inch mandrel). No. 86

COURTESY DUOTHERM DIVISION, MOTOR WHEEL CORP.

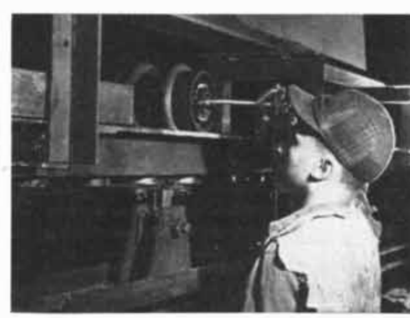

PHOTO COURTESY FORD MOTOR CO.

Over 7200 trolley bearings are used in the core oven conveyor system of the Ford foundry. Each bearing is exposed to oven temperatures ranging from 550 to 700 F several times daily. Dow Corning 41 Silicone Grease, refreshed occasionally with Dow Corning 710 Silicone Fluid, has been giving satisfactory service here for years. No. 87

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CONTENTS FOR SEPTEMBER, 1954 VOL. 191, NO. 3

ARTICLES

DEPARTMENTS

SCIENTIFIC AMERICAN
SEPTEMBER, 1954 VOL. 191, NO. 3

HEAT

This issue of Scientific American is solely concerned with the subject of heat.

Why heat? The answer is that we are in a period of quickening advance in our knowledge of higher temperatures and how to use them. It is a good time to reflect on the science and technology of heat.

The argument of the issue is as follows.

Heat has provided the energy by which man has shaped his own evolution. When man first made fire and cooked meat, he found a source of energy which liberated him from the mere struggle for survival. When he invented agriculture, fire softened his grain and baked the pots which enabled him to store it. With the storage of food he could found cities and specialize in technology, science and art. Fire further enabled him to smelt metals. The beginning of his industrial civilization came when he learned how to use metals and high-energy fuels to make engines converting heat into mechanical energy. This energy now frees a substantial fraction of mankind from its dependence on the muscular energy of men and animals.

With the development of the heat engine came an understanding of heat itself. Heat is a major feature of environment. In the immense range of temperature between absolute zero and the temperatures in the interiors of stars there lies a remarkably narrow zone where life has evolved. Flame, the same phenomenon that lighted the faces of primitive men around their campfires, is now seen as a subtle process wherein molecules are rearranged and give up radiant energy.

Today the pace of application accelerates. We seek unusual new materials to contain high temperatures so that they can do useful work. Chemical reactions that occur only at high temperatures are explored for their technological possibilities. Pure reaction motors such as the ramjet and rocket convert high temperatures directly into kinetic energy without the ingenious mechanical linkages of the past 150 years.

But for the moment man's knowledge of high temperatures outdistances his ability to turn them to his own benefit. In the atmospheres of stars we observe very high-temperature phenomena which are only beginning to be recreated in the laboratory. In the interiors of stars we deduce the highest temperatures and the thermonuclear reactions.

This issue contains no discussion of the hydrogen bomb. Its basic principles are found in the stars. The hydrogen bomb nonetheless represents the most significant advance in the release of heat. It has been said that thermonuclear reactions are only a source of destructive energy. The important thing is that they are a source of energy. Judging by man's past ingenuity, he will find a way to use them for nondestructive purposes. When he does, the energy at his command may so powerfully shape his development that its destructive potentialities will be forgotten.

MAN THE FIRE-MAKER

His unique evolution is largely due to his ability to turn heat to his own ends. Even before he learned to bake clay and smelt metals he used fire to change himself and the face of the earth

by Loren C. Eiseley

Man, it is well to remember, is the discoverer but not the inventor of fire. Long before this meddling little Prometheus took to experimenting with flints, then matches and finally (we hope not too finally) hydrogen bombs, fires had burned on this planet. Volcanoes had belched molten lava, lightning had struck in dry grass, winds had rubbed dead branches against each other until they burst into flame. There are evidences of fire in ancient fossil beds that lie deep below the time of man.

Man did not invent fire but he did make it one of the giant powers on the earth. He began this experiment long ago in the red morning of the human mind. Today he continues it in the midst of coruscating heat that is capable of rending the very fabric of his universe. Man's long adventure with knowledge has, to a very marked degree, been a climb up the heat ladder, for heat alone enables man to mold metals and glassware, to create his great chemical industries, to drive his swift machines. It is our intention in this article to trace man's manipulation of this force far back into its ice-age beginnings and to observe the part that fire has played in the human journey across the planet. The torch has been carried smoking through the ages of glacial advance. As we follow man on this journey, we shall learn another aspect of his nature: that he is himself a consuming fire.

At just what level in his intellectual development man mastered the art of making fire is still unknown. Neanderthal man of 50,000 years ago certainly knew the art. Traces of the use of fire have turned up in a cave of Peking man, the primitive human being of at least 250,000 years ago who had a brain only about two thirds the size of modern man's. And seven years ago Raymond Dart of Witwatersrand University announced the discovery in South Africa of *Australopithecus prometheus,* a man-ape cranium recovered from deposits which he believed showed traces of burned bone.

This startling announcement of the possible use of fire by a subhuman creature raised a considerable storm in anthropological circles. The chemical identifications purporting to indicate evidence of fire are now considered highly questionable. It has also been intimated that the evidence may represent only traces of a natural brush fire. Certainly, so long as the South African man-apes have not been clearly shown to be tool users, wide doubts about their use of fire will remain. There are later sites of tool-using human beings which do not show traces of fire.

Until there is proof to the contrary, it would seem wise to date the earliest use of fire to Peking man—*Sinanthropus.* Other human sites of the same antiquity have not yielded evidence of ash, but this is not surprising, for as a new discovery the use of fire would have taken time to diffuse from one group to another. Whether it was discovered once or several times we have no way of knowing. The fact that fire was in worldwide use at the beginning of man's civilized history enables us to infer that it is an old human culture trait—doubtless one of the earliest. Furthermore, it is likely that man used fire long before he became sophisticated enough to produce it himself.

In 1865 Sir John Lubbock, a British banker who made a hobby of popular writing on science, observed: "There can be no doubt that man originally crept over the earth's surface, little by little, year by year, just, for instance, as the weeds of Europe are now gradually but surely creeping over the surface of Australia." This remark was, in its time, a very shrewd and sensible observation. We know today, however, that there have been times when man suddenly made great strides across the face of the earth. I want to review here one of those startling expansions—a lost episode in which fire played a tremendous part. To make its outlines clear we shall have to review the human drama in three acts.

The earliest human-like animals we can discern are the man-apes of South Africa. Perhaps walking upright on two feet, this creature seems to have been roaming the East African grasslands about one million years ago. Our ancestor, "proto-man," probably emerged from the tropics and diffused over the region of warm climate in Eurasia and North Africa. He must have been dependent upon small game, insects, wild seeds and fruits. His life was hard, his search for food incessant, his numbers were small.

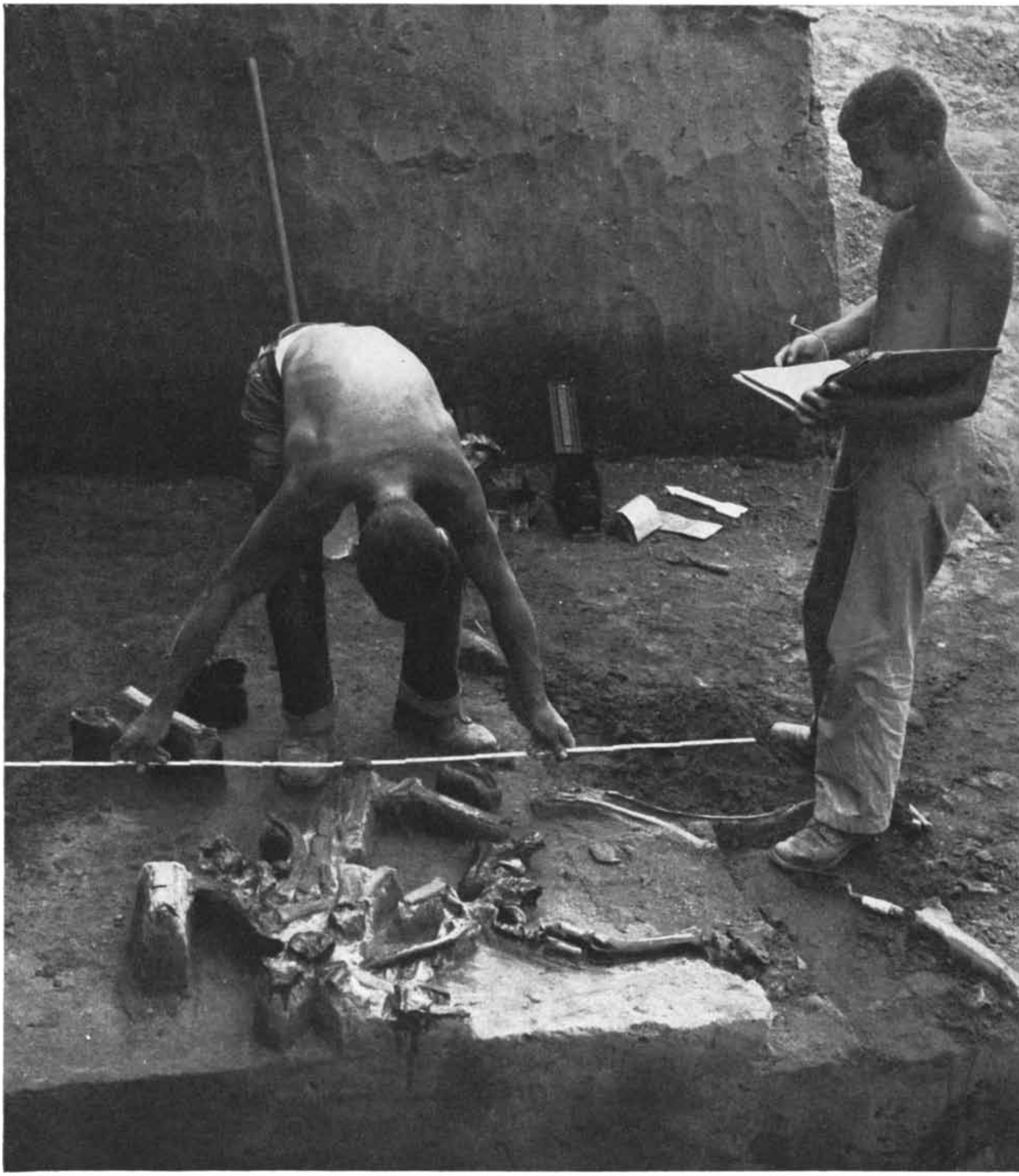
The second stage in human history is represented by the first true men. Paleoanthropic man is clearly a tool user, a worker in stone and bone, but there is still something of the isolated tinkerer and fumbler about him. His numbers are still sparse, judging from the paucity of skeletal remains. Short, stocky and powerful, he spread over the most temperate portions of the Afro-Eurasiatic land mass but never attempted the passage through the high Arctic to America. Through scores of millennia he drifted with the seasons, seemingly content with his troglodyte existence, making little serious change in his array of flint tools. It is quite clear that some of these men knew the use of fire, but many may not have.

The third act begins some 15,000 or

EVIDENCE OF FIRE made by man goes back to the Second Glacial Period. Shown here is the Red Smoke site in the Medicine Creek Reservoir area of Nebraska, where E. Mott Dávis and his colleagues have found such evidence for the later Fourth Glacial.

FIRE PIT (*lower left*) at the Red Smoke site contained charcoal, charred bone fragments and fired earth. A sample of charcoal from a slightly later fireplace above the blackboard in the rear was found by the radiocarbon method to have an age of 8,862 ± 230 years.

20,000 years ago. The last great ice sheet still lies across northern Europe and North America. Roving on the open tundra and grasslands below those ice sheets is the best-fed and most varied assemblage of grass-eating animals the world has ever seen. Giant long-horned bison, the huge wild cattle of the Pleistocene, graze on both continents. Mammoth and mastodon wander about in such numbers that their bones are later to astonish the first American colonists. Suddenly, into this late paradise of game, there erupts our own species of man—*Homo sapiens*. Just where he came from we do not know. Tall, lithe, long-limbed, he is destined to overrun the continents in the blink of a geological eye. He has an excellent projectile weapon in the shape of the spear thrower. His flint work is meticulous and



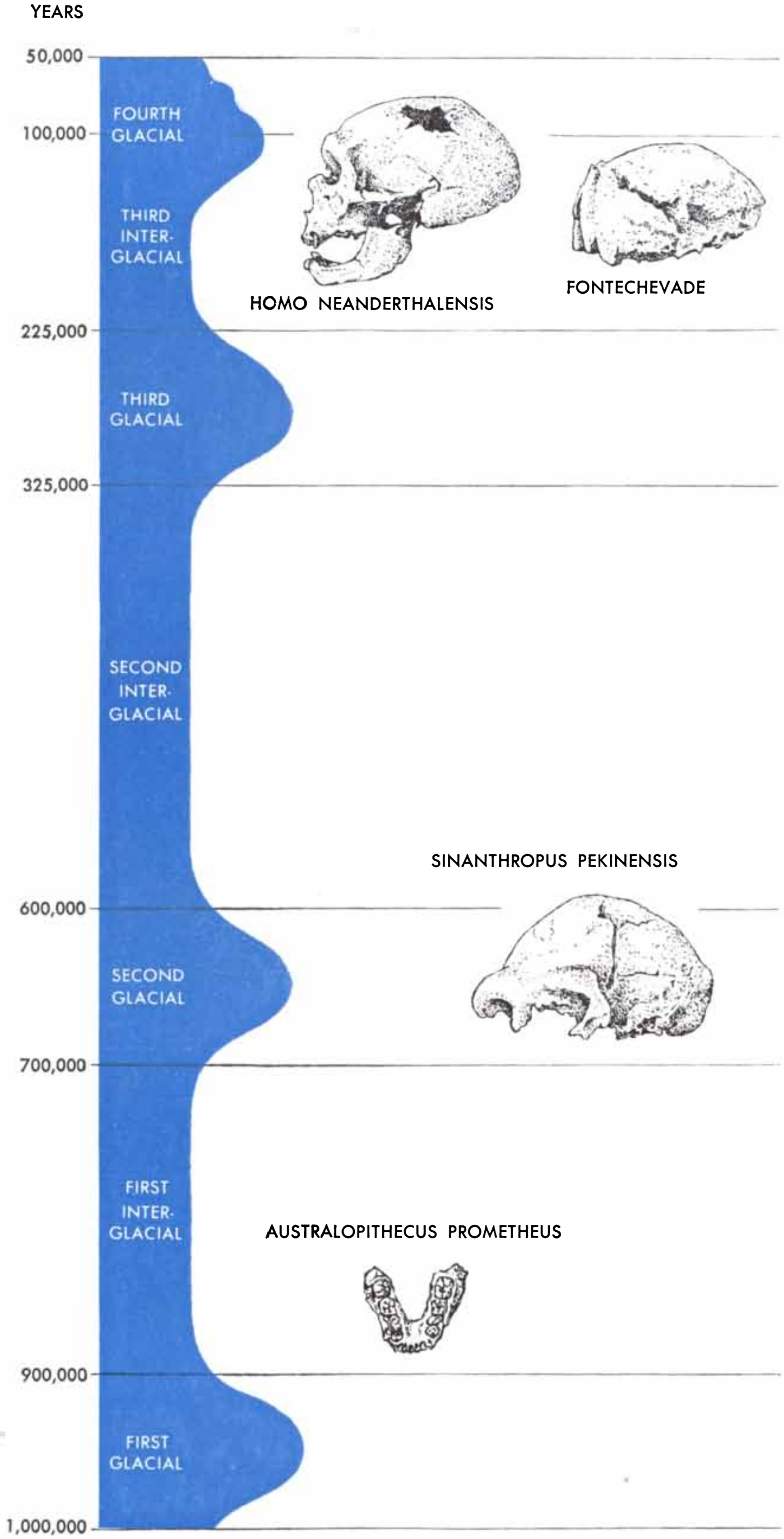
BURNED BISON BONES were found at the Red Smoke site 10 feet below the fire pit shown at the bottom of the preceding page. Near the bones lay a stone knife. Here two workers from the University of Nebraska State Museum measure the bones and map their location. The bones, which are shiny because they were protected with shellac, included ribs, vertebrae, a pelvis and most of a lower hind leg. They represent the earliest of eight levels of habitation at the site; the dated fireplace represents the latest.

sharp. And the most aggressive carnivore the world has ever seen comes at a time made for his success: the grasslands are alive with seemingly inexhaustible herds of game.

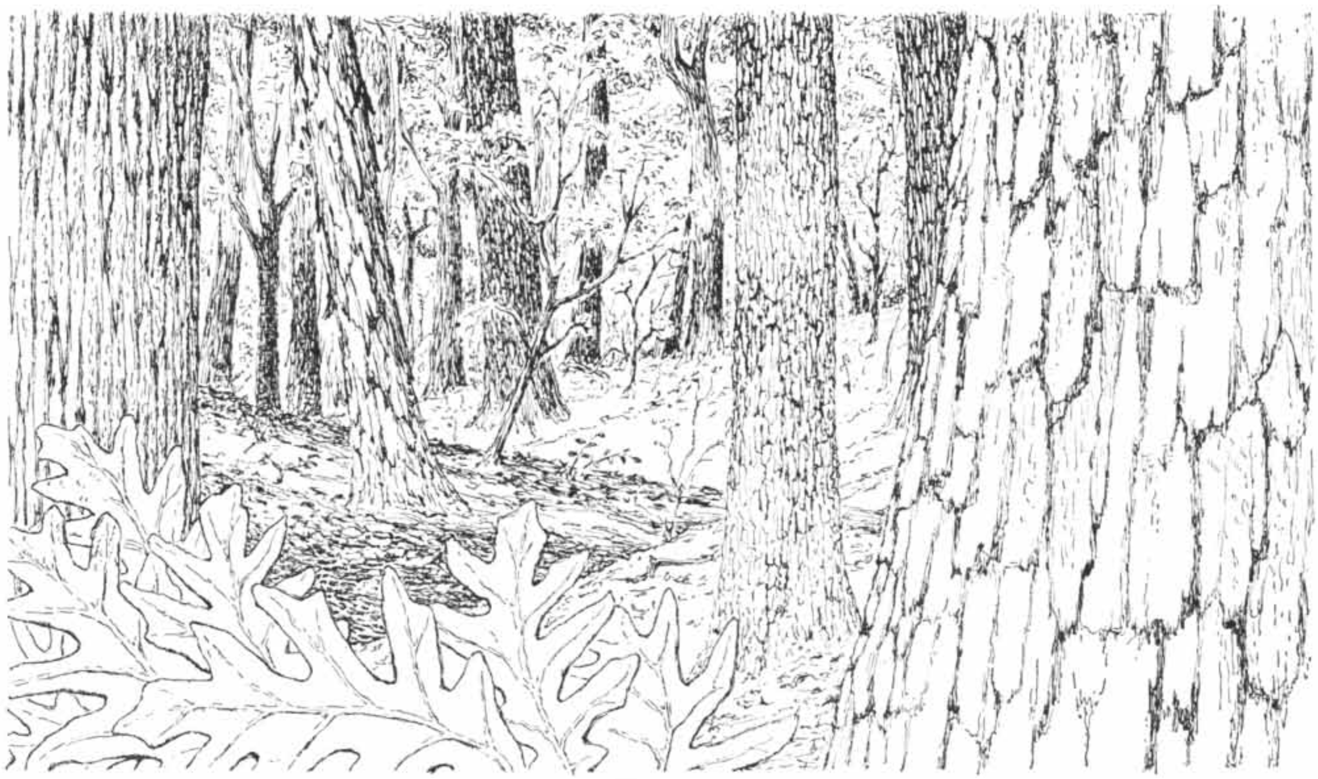
Yet fire as much as flesh was the magic that opened the way for the supremacy of *Homo sapiens*. We know that he was already the master of fire, for the track of it runs from camp to buried camp: the blackened bones of the animals he killed, mute testimony to the relentless step of man across the continents, lie in hundreds of sites in the Old and the New Worlds. Meat, more precious than the gold for which men later struggled, supplied the energy that carried man across the world. Had it not been for fire, however, all that enormous source of life would have been denied to him: he would have gone on drinking the blood from small kills, chewing wearily at uncooked bone ends or masticating the crackling bodies of grasshoppers.

Fire shortens the digestive process. It breaks down tough masses of flesh into food that the human stomach can easily assimilate. Fire made the difference that enabled man to expand his numbers rapidly and to press on from hunting to more advanced cultures. Yet we take fire so much for granted that this first great upswing in human numbers, this first real gain in the seizure of vast quantities of free energy, has to a remarkable degree eluded our attention.

With fire primitive man did more than cook his meat. He extended the pasture for grazing herds. A considerable school of thought, represented by such men as the geographer Carl Sauer and the anthropologist Omer Stewart, believes that the early use of fire by the aborigines of the New World greatly expanded the grassland areas. Stewart says: "The number of tribes reported using fire leads one to the conclusion that burning of vegetation was a universal culture pattern among the Indians of the U. S. Furthermore, the amount of burning leads to the deduction that nearly all vegetation in America at the time of discovery and exploration was what ecologists would call fire vegetation. That is to say, fire was a major factor, along with soil, moisture, temperature, wind, animals, etc., in determining the types of plants occurring in any region. It follows then, that the vegetation of the Great Plains was a fire vegetation." In short, the so-called primeval wilderness which awed our forefathers had already felt the fire of the Indian



FOSSIL FIRE-MAKERS are located in time. At the left is an approximate scale of years. The colored band beside it indicates the advance and retreat of the ice in the glacial and interglacial periods. The early modern man of Fontèchevade made fire, as did Neanderthal man. *Sinanthropus* probably made fire, and it is possible that *Australopithecus* did.



PRE-FIRE VEGETATION in Pennsylvania is reconstructed from an early description. The four closest trees are a tulip (*left*), a shagbark hickory (*second from left*), a sugar maple (*third*) and a white oak (*fourth*). In the foreground are white oak leaves.

hunter. Here, as in many other regions, man's fire altered the ecology of the earth.

It had its effect not only on the flora but also on the fauna. Of the great herds of grazing animals that flourished in America in the last Ice Age, not a single trace remains—the American elephants, camels, long-horned bison are all gone. Not all of them were struck down by the hunters' weapons. Sauer argues that a major explanation of the extinction of the great American mammals may be fire. He says that the aborigines used fire drives to stampede game, and he contends that this weapon would have worked with peculiar effectiveness to exterminate such lumbering creatures as the mammoth. I have stood in a gully in western Kansas and seen outlined in the earth the fragmented black bones of scores of bison who had perished in what was probably a man-made conflagration. If, at the end of Pleistocene times, vast ecological changes occurred, if climates shifted, if lakes dried and in other places forests sprang up, and if, in this uncertain and unsteady time, man came with flint and fire upon the animal world about him, he may well have triggered a catastrophic decline and extinction. Five thousand years of man and his smoking weapon rolling down the wind may have finished the story for many a slow-witted animal species. In the great scale of geological time this act of destruction amounts to but one brief hunt.

Man, as I have said, is himself a flame. He has burned through the animal world and appropriated its vast stores of protein for his own. When the great herds failed over many areas, he had to devise new ways to feed his increase or drop back himself into a precarious balance with nature. Here and there on the world's margins there have survived into modern times men who were forced into just such local adjustments. Simple hunters and collectors of small game in impoverished areas, they maintain themselves with difficulty. Their numbers remain the same through generations. Their economy permits no bursts of energy beyond what is necessary for the simple age-old struggle with nature. Perhaps, as we view the looming shadow of atomic disaster, this way of life takes on a certain dignity today.

Nevertheless there is no road back; the primitive way is no longer our way. We are the inheritors of an aggressive culture which, when the great herds disappeared, turned to agriculture. Here again the magic of fire fed the great human wave and built up man's numbers and civilization.

Man's first chemical experiment involving the use of heat was to make foods digestible. He had cooked his meat; now he used fire to crack his grain. In the process of adopting the agricultural way of life he made his second chemical experiment with heat: baking pottery. Ceramics may have sprung in part from the need for storage vessels to protect harvested grain from the incursions of rats and mice and moisture. At any rate the potter's art spread with the revolutionary shift in food production in early Neolithic times.

People who have only played with mud pies or made little sun-dried vessels of clay are apt to think of ceramics as a simple art. Actually it is not. The sun-dried vessels of our childhood experiments would melt in the first rain that struck them. To produce true pottery one must destroy the elasticity of clay through a chemical process which can only be induced by subjecting the clay to an intense baking at a temperature of at least 400 or 500 degrees centigrade. The baking drives out the so-called water of constitution from the aluminum silicate in the clay. Thereafter the clay will no longer dissolve in water; a truly fired vessel will survive in the ground for centuries. This is why pottery is so important to the archaeologist. It is impervious to the decay that overtakes

FIRE VEGETATION in an area deliberately burned over by the Indians is similarly reconstructed from an early account. The forest has been replaced by grassland. The three trees are young oaks. In the foreground are grassland plants such as strawberry.

many other substances, and, since it was manufactured in quantity, it may tell tales of the past when other clues fail us.

Pottery can be hardened in an open campfire, but the results can never be so excellent as in a kiln. At some point the early potter must have learned that he could concentrate and conserve heat by covering his fire—perhaps making it in a hole or trench. From this it was a step to the true closed kiln, in which there was a lower chamber for the fire and an upper one for the pottery. Most of the earthenware of simple cultures was fired at temperatures around 500 degrees centigrade, but really thorough firing demands temperatures in the neighborhood of 900 degrees.

After man had learned to change the chemical nature of clay, he began to use fire to transform other raw materials—ores into metals, for instance. One measure of civilization is the number of materials manipulated. The savage contents himself with a few raw materials which can be shaped without the application of high temperatures. Civilized man uses fire to extract, alter or synthesize a multitude of substances.

By the time metals came into extended use, the precious flame no longer burned in the open campfire, radiating its heat away into the dark or flickering on the bronzed faces of the hunters. Instead it roared in confined furnaces and was fed oxygen through crude bellows. One of the by-products of more intensified experiments with heat was glass—the strange, impassive substance which, in the form of the chemist's flask, the astronomer's telescope, the biologist's microscope and the mirror, has contributed so vastly to our knowledge of ourselves and the universe.

We hear a good deal about the "Iron Age," or age of metals, as a great jump forward in man's history; actually the metals themselves played a comparatively small part in the rise of the first great civilizations. While men learned to use bronze, which demands little more heat than is necessary to produce good ceramics, and later iron for tools and ornaments, the use of metal did not make a really massive change in civilization for well over 1,500 years. It was what Leslie White of the University of Michigan calls the "Fuel Revolution" that brought the metals into their own. Coal, oil and gas, new sources of energy, combined with the invention of the steam and combustion engines, ushered in the new age. It was not metals as tools, but metals combined with heat in new furnaces and power machinery that took human society off its thousand-year plateau and made possible another enormous upswing in human numbers, with all the social repercussions.

Today the flames grow hotter in the furnaces. Man has come far up the heat ladder. The creature that crept furred through the glitter of blue glacial nights lives surrounded by the hiss of steam, the roar of engines and the bubbling of vats. Like a long-armed crab, he manipulates the tongs in dangerous atomic furnaces. In asbestos suits he plunges into the flaming debris of hideous accidents. With intricate heat-measuring instruments he investigates the secrets of the stars, and he is already searching for heat-resistant alloys that will enable him to hurl himself into space.

How far will he go? Three hundred years of the scientific method have built the great sky-touching buildings and nourished the incalculable fertility of the human species. But man is also *Homo duplex,* as they knew in the darker ages. He partakes of evil and of good, of God and of man. Both struggle in him perpetually. And he is himself a flame—a great, roaring, wasteful furnace devouring irreplaceable substances of the earth. Before this century is out either *Homo duplex* will have learned that knowledge without greatness of spirit is not enough for man, or there will remain only his calcined cities and the little charcoal of his bones.

What Is Heat?

We deal with it by means of mathematical abstractions which rest on the notions of disorder and energy. Presenting an explanation of these concepts together with a brief account of their origins

by Freeman J. Dyson

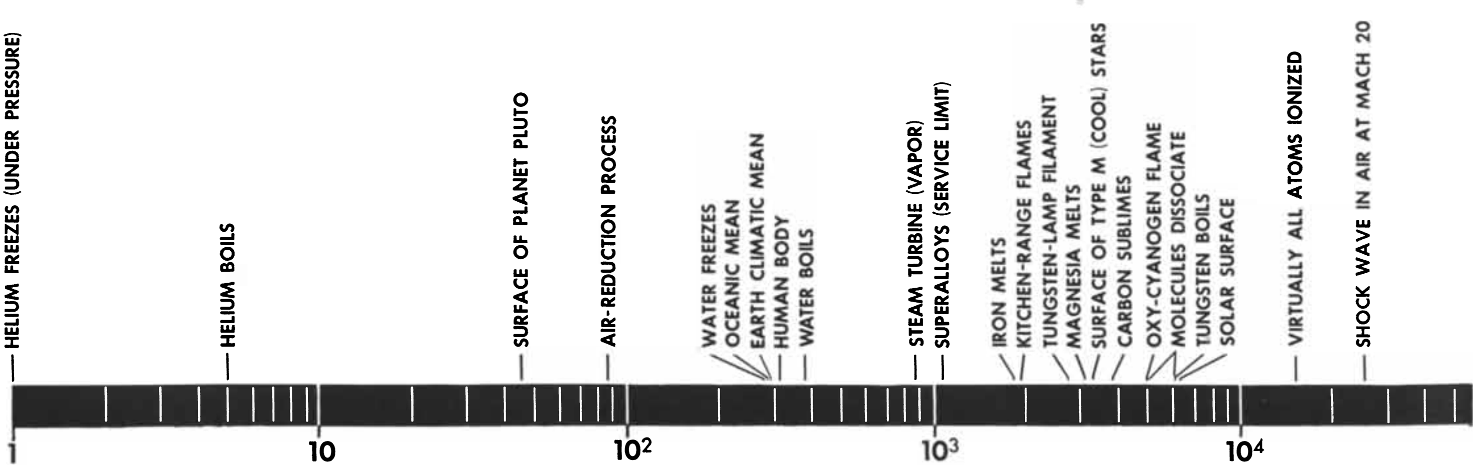
Heat is disordered energy. So with two words the nature of heat is explained. The rest of this article will be an attempt to explain the explanation.

Energy can exist without disorder. For example, a flying rifle bullet or an atom of uranium 235 carries ordered energy. The motion of the bullet is the kind of energy we call kinetic. When the bullet hits a steel plate and is stopped, the energy of its motion is transferred to random motions of the atoms in the bullet and the plate. This disordered energy makes itself felt in the form of heat; parts of the bullet and plate may get so hot that they momentarily melt. The energy dwelling in the uranium atom is the kind we call potential; it consists of the electric forces which tend to push the constituent protons apart. When the atom fissions, the energy of motion of the flying fragments is converted by collisions into random motions of the electrons and other atoms nearby in the surrounding matter—that is to say, into heat. This conversion of potential energy into heat is the working principle of nuclear reactors.

These two examples illustrate the general principle that energy becomes heat as soon as it is disordered. It is conversely true that disorder can exist without energy, and that disorder becomes heat as soon as it is energized. The atoms of uranium 235 and 238 in a piece of ordinary uranium are mixed in a random way, but this disorder carries no energy. To see how heat is produced by adding energy to disorder, consider the air in a bicycle pump. Before compression the air atoms are already moving at random in all directions; in other words this is a disordered system, and its energy is in the form of heat, though we do not feel it because the air is only at room temperature. Now if you pump vigorously, compressing the air rapidly, it heats up; the pump becomes hot to the touch. The air has the same disorder it had before, but more energy. By doing work you have pushed more energy into the air, and the observed production of heat is just the effect of this addition of energy to the pre-existing disorder.

The same operation in reverse provides a practical method of reaching low temperatures. After compressing the air in a pump, we may allow the compressed air to stand until it cools to room temperature. (For this experiment we need a pump with a tighter seal around the piston than that in a bicycle pump.) When the compressed air has cooled to room temperature, we let it expand and push the piston out of the cylinder. By applying work to the piston, the air loses energy and hence becomes colder. With this principle of refrigeration, using repeated expansions and self-cooling during the compression phase, it is possible to reach temperatures low enough to liquefy helium.

The foregoing illustrations give a qualitative picture of the nature of heat.



RANGE OF TEMPERATURES runs from absolute zero to those that are encountered in the interiors of the hottest stars. This logarithmic scale is in degrees absolute or Kelvin, the units of which are the same as degrees centigrade but start from absolute

In order to go further it is necessary to talk quantitatively. We must measure heat precisely in terms of numbers. Only when we have an exact language for describing quantities of heat can we formulate the physical laws that heat obeys.

First, it is clear that to specify heat we must use at least two numbers: one to measure the quantity of energy, the other to measure the quantity of disorder. The quantity of energy is measured in terms of a practical unit called the calorie, which is the amount of heat required to heat a gram of water through one degree centigrade under standard conditions. The ultimate unit to which we relate all forms of energy is the unit of kinetic energy, called the erg. This is defined as the energy of a mass of two grams moving with a velocity of one centimeter per second. By conversion of kinetic energy to heat energy we determine that one calorie equals 42 million ergs.

The quantity of disorder is measured in terms of the mathematical concept called entropy. This concept goes to the heart of all theoretical ideas about heat (and about certain other phenomena as well, notably information). Entropy, usually represented by the letter S, is defined as a number which indicates how many states are possible in a system in a given situation. The system has an equal probability of being in any one of these states. The disorder consists in the fact that we do not know which state the system is in. In other words, disorder is essentially the same thing as ignorance (this is where the connection with information theory comes in). Roughly speaking, entropy measures the number of independent degrees of freedom possessed by a system. A high-entropy system is free to be in many different states. An example of such a system is a liquid: its atoms may arrange themselves in a huge variety of ways. At the other extreme, an example of a low-entropy system is a crystal lattice: its atoms are arranged in a highly ordered way and we usually know precisely which atom goes where.

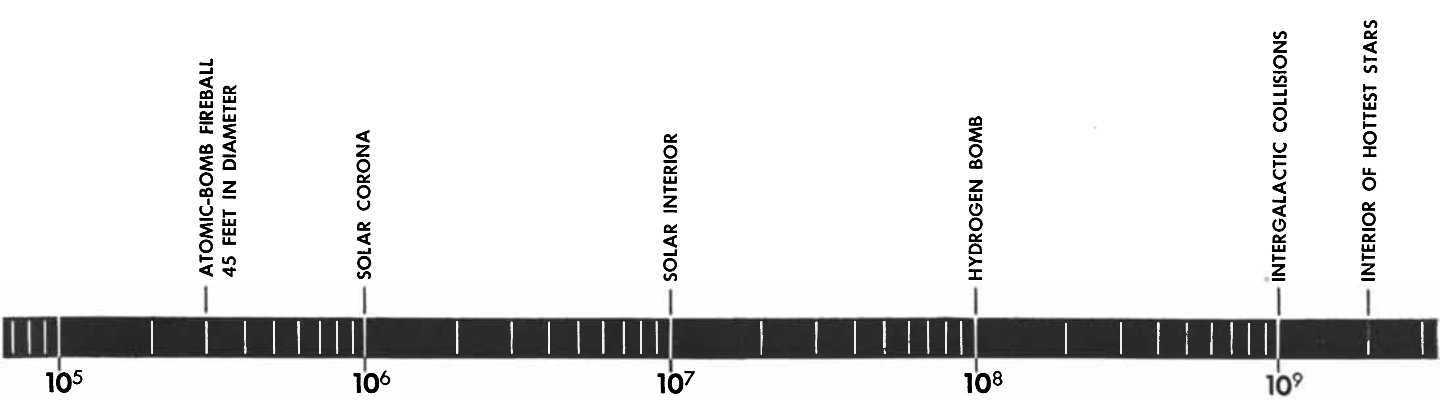
The mathematical definition of entropy is simply a precise statement of what we mean by the intuitive idea of disorder. We define S by the equation $M = 2^S$, with *M* representing the number of equally probable states a system may be in. The main reason for using this definition is that it makes entropy additive. If object 1 has entropy S_1 and object 2 has entropy S_2, then the two objects placed side by side and considered as a single system have entropy $S_1 + S_2$. The notion of entropy, as a quantity which measures the "amount of disorder" in a system, is useful only because it has the additive property.

When we speak of the entropy of a volume of air, we have to consider how many possible states of motion are available to the molecules in the volume. To a good approximation the molecules may be considered as particles moving freely and without disturbing each other. In the classical mechanics of Newton, the state of each molecule would be described by specifying its position and velocity, and there would be a continuously infinite number of possible states. For this reason it was not possible in Newtonian mechanics to define entropy in absolute terms; one could only define the change in entropy produced by changing the air from one set of conditions to another. However, in quantum mechanics, which we now know to be the correct mechanics for describing the movement of atoms, the air has only a finite number of possible states inside a given volume and with a given total energy. With the help of quantum mechanics the definition of entropy can be given a meaning for any type of heat motion whatever.

Having defined what we mean by the quantity of energy and the quantity of disorder, let us see how these two numbers describe the observable properties of heat.

Thermodynamics is based on two simple laws. The First Law is just the Law of Conservation of Energy: the total energy, including heat, of any closed system remains constant. The Second Law is a kind of law of "conservation of disorder": the total entropy of any closed system must either remain constant or increase as time goes on—it can never decrease. It is clear that disorder cannot strictly remain constant. When a rifle bullet stops and converts its energy of motion into heat, disorder is created and the total entropy is increased. Whenever any process of mixing-up or dissipation of energy occurs, entropy is created. The point of the Second Law is that such mixing processes are in their nature irreversible. A spent rifle bullet will not convert its heat energy into energy of motion and travel back to the gun the way it came. A mixture of atoms of uranium 238 and 235 will not unmix itself spontaneously. We can unmix a mixture (reduce its entropy) only by producing an equal or greater quantity of entropy in some other part of our apparatus.

The effect of the Second Law is that, if two bodies are in contact, heat will always flow from one to the other in such a direction as to increase the total entropy. In which direction will this



zero. On this scale the freezing point of water is 273.16 degrees and the boiling point 373.16 degrees. In each of the next seven articles this Kelvin scale is repeated together with an enlarged section in the appropriate degrees: Kelvin, centigrade, or Fahrenheit.

PIONEERS IN THE THEORY OF HEAT

The nature of heat was a major subject of investigation from the very beginning of modern science. Bacon, Galileo, Boyle, Leibnitz, Hooke, Newton—all these men sought to explain heat in terms of motions of the tiny corpuscles of which bodies are made. It was difficult to see how this idea could be applied to account for fire, and it failed to explain how heat could move through a vacuum. Newton suggested that radiant heat might be due to vibrations in a subtle medium, the aether, which fills all of space, but this theory raised more questions than it answered.

In the 18th century Benjamin Franklin and the Dutch chemist Hermann Boerhaave helped to advance understanding by concentrating on the flow of heat. They thought of it as a fluid, and Franklin experimented on the heat conductivity of various metals, just as he studied electrical conductivity. He was unable to measure heat conductivity, but toward the end of the century the Scottish physicist and chemist Joseph Black made it possible to do so by discovering the specific or latent heats of different substances. Black used the amount of ice melted as his measure of the heat liberated by a material in connection with a given change in temperature.

Carnot (1796-1832)

The way was now open to develop a quantitative theory of heat, and this was begun by Antoine Lavoisier, the father of modern chemistry. Together with the mathematician Pierre Simon de Laplace he determined the specific heats of a large number of materials and also showed that the heat evolved in chemical reactions could be studied quantitatively. From the concept of the heat fluid, which he named "caloric," Lavoisier developed an exact chemical thermodynamics. If we smile today at this notion of heat as a substance, we overlook the fact that in everyday usages we still regard heat as a fluid—something carried, acquired or released by bodies. This is evident in the language we use: *e.g.*, heat flow, thermal conduction, thermal capacity, latent heat.

It was Benjamin Thompson, Count Rumford, who at the beginning of the 19th century revived the kinetic theory of heat and laid the basis for modern thermodynamics. Rumford, a self-taught scientist [*see book review on page 163*], came to his studies of this subject by observing the vast quantities of heat produced by friction during the boring of cannon, an activity which he was supervising for the Elector of Bavaria in Munich. Rumford decided that the "inexhaustible" heat issuing from the metal "cannot possibly be a material substance;" he could conceive of nothing "capable of being excited and communicated in the manner heat was excited and communicated in these experiments, except it be motion." He proceeded to experiments designed to show that there could be no such substance as caloric. He wrote brilliantly on the kinetic theory and suggested the principle of the conservation of energy, but his work gained few converts. The demolition of the caloric theory and the proof that heat was only a form of energy came some four decades later, chiefly through the labors of a British physicist, James Prescott Joule, and a German physician, Julius Robert von Mayer.

Rumford (1753-1814)

Joule, like Rumford, was a scientific amateur. He had been rejected for a professorship at St. Andrew's because of a slight physical deformity and made his living as the proprietor of a large brewery, but he spent much of his life on physical experiments, which he performed with meticulous care. His measurements of heat and energy showed that the heat produced was always proportional to the mechanical energy expended and *vice versa*. This great discovery of the equivalence of mechanical energy and heat became known as the First Law of Thermodynamics.

The so-called Second Law of Thermodynamics had been discovered before the First Law. It was indicated in a small book published in 1824 by Sadi Carnot, a brilliant young French physicist who had been a captain in the engineering corps of the army but had resigned his commission to devote his time to scientific research. His central idea was that the efficiency of a heat engine is greatest when the cycle of the engine is reversible, and that the transformation of heat into work requires a source of heat and a sink of heat at different temperatures. The import of Carnot's work was not at first clear, but by the middle of the century two men had developed its implications. They were Rudolf Clausius of Germany, who enunciated the Second Law and invented the concept of entropy, and Lord Kelvin of Great Britain, who showed how Carnot's concepts led to an absolute thermodynamic temperature scale.

It remained only for two giants of the end of the 19th century, Willard Gibbs and Ludwig Boltzmann, to apply the principles of statistical mechanics and establish thermodynamics as an exact science.

I. Bernard Cohen

Joule (1818-1889)

be? That will depend on the amount of energy and entropy the two bodies already contain. The Second Law implies that heat must flow toward the region of lower temperature, for the following reasons. As we lower the temperature of anything, the amount of energy and disorder in it both get smaller. But the energy always decreases more rapidly than the disorder, so that the amount of disorder per unit of energy grows larger as the temperature falls. A given amount of energy carries more disorder when it is at a lower temperature. This is why heat always likes to move from a higher temperature to a lower; as it moves, each unit of heat energy acquires greater disorder.

Note that we have here implied a definition of temperature: the temperature of any object is the amount of heat energy that must be added to it to increase its entropy by one unit. This definition gives us a precise notion of the meaning of temperature, not depending on the particular properties of the thermometers that are used to measure it in practice. A mercury thermometer of course measures temperature in terms of the specific thermodynamic properties of mercury, on a scale which arbitrarily divides the range between the freezing and boiling points of water into a certain number of units—100 units in the case of the centigrade scale.

To complete the science of thermodynamics we need to know not only the two general laws but also the behavior of particular substances so far as heat-carrying capacity is concerned. The information concerning a particular substance is contained in the so-called "equation of state" of the substance. The equation of state of air, for example, tells us how much disorder is present when one gram of air is carrying a given amount of heat energy. From this we can deduce by simple mathematics the amount of energy and entropy that air will contain at a given temperature. The equation of state of air is not a consequence of the general laws of thermodynamics. It depends on the detailed properties of air molecules—their size and shape and rigidity and so on. It is possible in simple cases to calculate the equation of state from the theoretical behavior of the molecules, but in general it is easier and more accurate to measure it experimentally.

One situation of great practical importance, where equations of state cannot be measured but must be calculated from theory, is in studying the behavior of matter at really high temperatures, say from a million degrees up. Such temperatures are found in stars and in exploding atomic bombs. Theoretical calculations are simplified by the fact that at these temperatures chemical molecules no longer exist, the matter consisting entirely of single atoms, ions and electrons. The thermodynamical behavior of stars, as observed by astronomers, can be very well understood on this basis, and from the observed behavior we can also deduce facts about the chemical composition of the stars' deep interior.

Electromagnetic waves, which include light, infrared and radio waves, are a form of energy. They are like other forms of energy, except that they can exist in empty space in the absence of matter. They may be disordered, like the irregular waves on the water in mid-ocean. Like other forms of energy, when electromagnetic waves are disordered they become heat. So disordered electromagnetic energy is a form of heat which belongs to empty space, just as disordered motion of atoms is a form of heat which belongs to matter. All the laws of thermodynamics apply as well to the one kind of heat as to the other. Heat in empty space we call heat radiation.

The existence of heat radiation implies that no material body is ever completely isolated. The space around every object will contain radiation; if there is a temperature difference between the object and the radiation, energy will move from the radiation into the object, or from the object into the radiation, so as to equalize the temperatures. So the radiation transfers energy from hotter objects to colder.

From a practical point of view we want not only to understand the fact that heat transfer by radiation can occur, but we want to know how fast and how efficient the process will be. Especially we want to understand why heat transfer by radiation is so enormously more effective at high temperatures than at low temperatures. To get a rough idea of how much difference temperature makes, consider this comparison: A 25-cent piece, at a distance of 10 feet from you, has about the same angular size as the sun. But compare the sensation of sitting in direct sunlight with that of sitting 10 feet from a red-hot quarter. The temperature of the coin (600 degrees C.) is only one tenth that of the sun's surface.

The main factor determining the rate of transfer of heat is the amount of radiation energy which a volume of space at a given temperature contains. To calculate this, we need to know the equation of state for empty space. The equation of state for empty space is a fundamental law of nature: it gives the relation between the quantities of energy and entropy for disordered radiation. The law is that the entropy varies with the three-quarters power of the energy, and this implies that the temperature varies only as the one-quarter power, or the fourth root, of the energy.

To understand the origin of the three-quarters power, one has to go deeply into the quantum nature of radiation, which we will not discuss here. But one can say in a general way that empty space has an exceptionally large number of degrees of freedom, in fact a continuously infinite number, since electromagnetic waves can exist with every possible wavelength. By contrast, a material object has a finite number of degrees of freedom, fixed by the number of atoms it contains. This means that a given quantity of energy can be spread out over more degrees of freedom, and therefore produce more disorder, in empty space than in matter. And the increase of temperature with energy is consequently much slower for empty space than for matter. While temperature varies as the fourth root of the energy for heat radiation, for ordinary gases the temperature is simply proportional to energy.

The practical effect of the fourth root is tremendous. Suppose that a piece of matter at 600 degrees C. can radiate away half its heat energy in an hour. The same piece of matter at 6,000 degrees C. would have only about 10 times as much energy, but it would radiate it away 10,000 times as fast—it would radiate away half its energy in about four seconds.

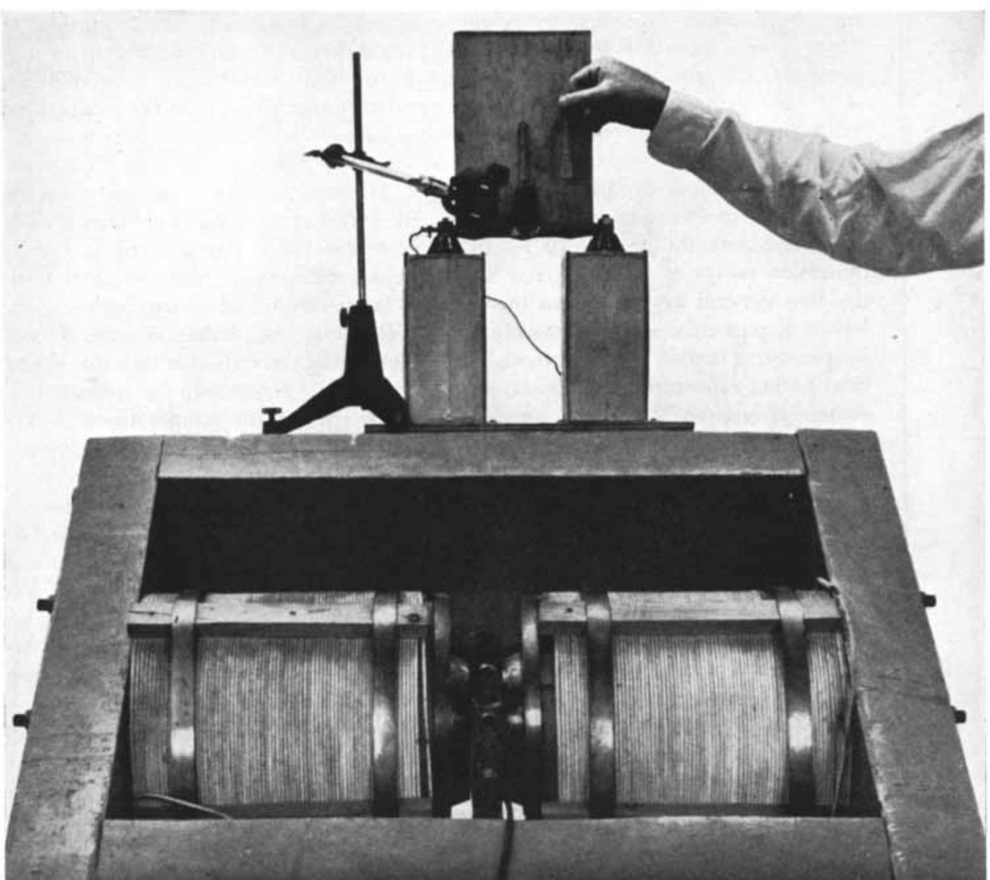
If we increase the temperature of matter further still, we finally reach a point, in the neighborhood of 10 million degrees, where the heat radiation which exists instantaneously in the spaces between the atoms carries as much energy as the atoms themselves. Matter at this temperature would radiate away its energy in a time as short as the time taken by light to travel from its center to the surface. It is practically impossible to heat matter to a temperature higher than this for any appreciable time except in regions of high density, such as the centers of stars. Above 10 million degrees empty space behaves like a wet sponge, having an inexhaustible capacity for absorbing energy without greatly increasing in temperature. Any matter at a temperature much above 10 million degrees will have its energy soaked up by the space between its atoms in a minute fraction of a second.

In recent years physicists have exploited a flexible new tool for studying the properties of heat and temperature. This is a certain type of salt crystal, some of whose atoms are magnets. Blue copper sulfate is one of these substances, but for good reasons the experimenters prefer to work with more esoteric compounds, such as dysprosium ethyl sulfate.

When a magnetic field is applied to such a crystal, the individual magnetic atoms acquire energy. Each little magnet is under pressure to line itself up along the applied field, and this tendency gives it a potential energy. Those atoms that are farthest out of line with the field, of course, will have the greatest energy.

Now the atomic magnets point in all directions and share the total energy in a random way. Thus the crystal as a whole possesses disordered energy—which we have seen is the definition of heat. The magnetic energy therefore can be considered a form of heat energy. It is not heat that we can feel, because the energy is potential, not kinetic (it causes no motion of molecules). But it should obey the laws of thermodynamics.

The beauty of this tool is that the energy of the system is directly under the control of the experimenter and can be varied just by varying the applied magnetic field. If the field is varied quickly, the entropy of the magnetic sys-



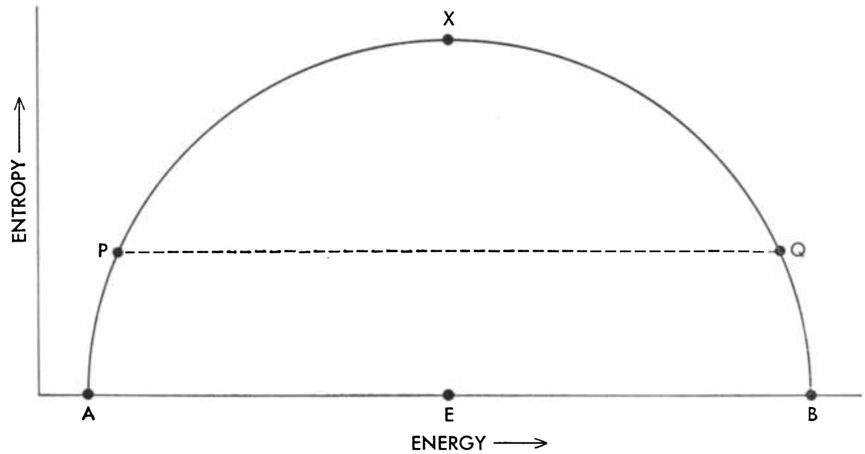
NEGATIVE TEMPERATURES were produced by Edward M. Purcell and Robert V. Pound in this apparatus at Harvard University. The arm at the upper right holds a small crystal of lithium fluoride on the end of a stick. The crystal is first magnetized between the poles of the large magnet at the bottom, which is part of a nuclear induction apparatus. It is then placed in a small coil mounted on the board at top center. When the magnetic field around the crystal is reversed by passing a strong current through the coil, a negative temperature results (*see diagram at the top of the opposite page*). The effect is detected by placing the crystal in the magnet of the nuclear induction apparatus again.

tem will not be affected. An increase in field produces an immediate rise in the temperature, and a decrease in field produces a fall in temperature. In this way one can reach temperatures of a few thousandths of a degree, the lowest so far achieved. With a single demagnetization the temperature may fall from 1 degree to .003 degrees absolute (Kelvin). Temperatures in this range can be measured surprisingly accurately, by observing directly the amount of energy required to produce a given increase in entropy. The accuracy is good because the magnetic field gives the observer a precise control of the quantities of energy involved.

There is a general rule that it is impossible by any method actually to reach zero temperature. To reach zero we would have to extract energy from a disordered system until there was absolutely no energy left, and this is a practical impossibility.

Paradoxically, although zero temperature cannot be reached it is rather easy, with a system of atomic magnets, to make an infinite temperature. What does this mean? It means simply that there is a state of maximum possible disorder of the magnets. When they are pointing at random in all directions with equal probability, they have more entropy than in any other state. Now suppose that the system in this state of maximum disorder is put into a magnetic field. It will then have a certain energy. At this energy any small decrease or increase of energy will produce practically no change in entropy. In other words, a small change in entropy would require a change of energy which is enormous compared to the change in entropy. This is all we mean by saying that the temperature is infinite. Since at maximum entropy the magnets can lose a small amount of energy without significant loss of disorder, heat will flow from the magnets into the surroundings, with a net increase of entropy in the total system, if the surroundings are at any finite temperature. In this sense the magnet system is hotter than any finite temperature.

The solid in which a nuclear magnet system lies will look and feel quite cool, even when the magnet temperature is infinite. The temperature we feel when we touch it is just the temperature of the mechanical motions of the atoms into which the magnetic heat is slowly translated. Just because the mechanical and magnetic energy are not rapidly interchanged, it is possible to control and measure the temperature of the magnet system by itself.



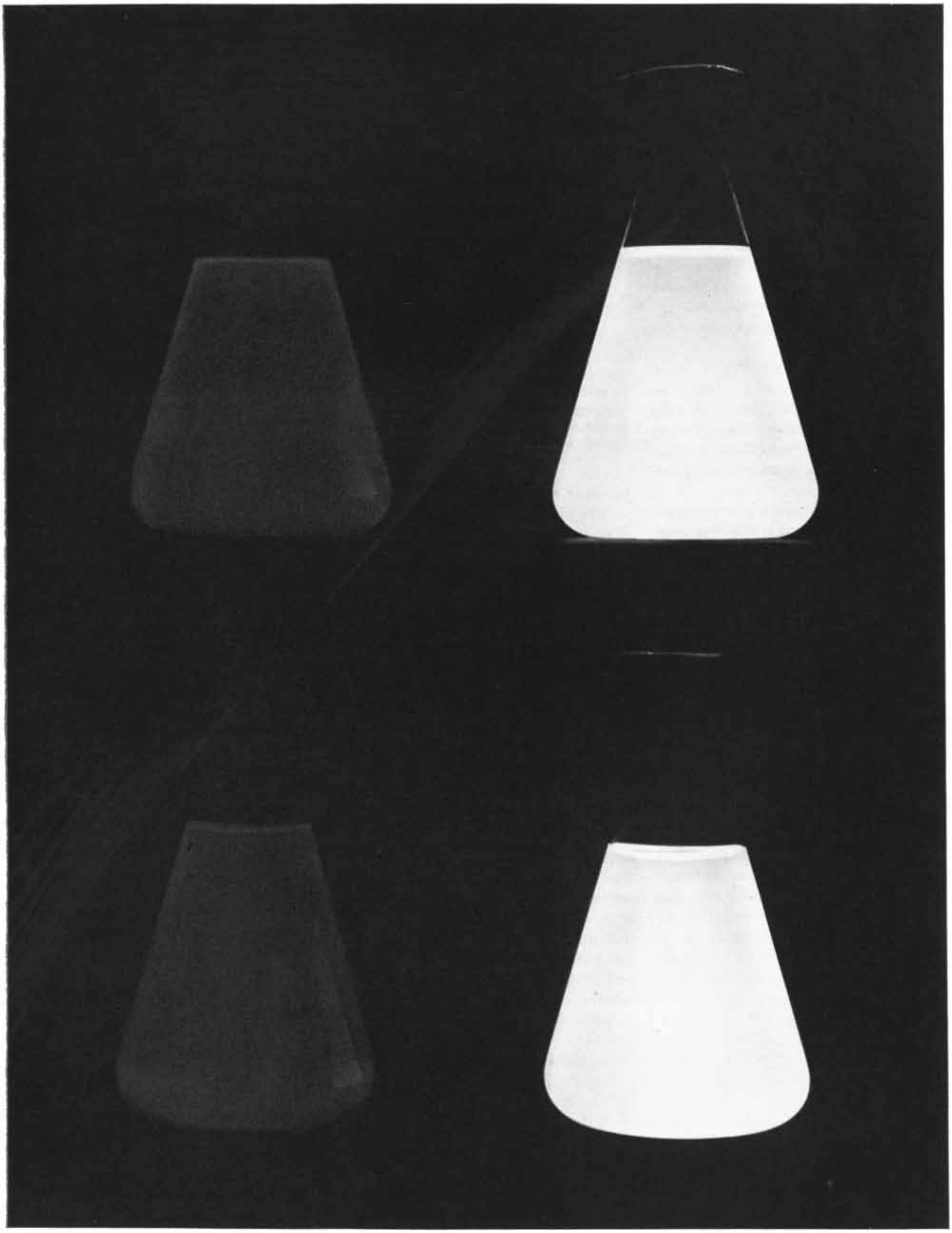
ENERGY AND ENTROPY RELATIONSHIP for a system of atomic magnets is depicted in this diagram. At the point X, where the entropy is maximum and the energy is E, the temperature is infinite. At A and B the temperature is zero. From A to X the temperature increases from zero to infinity. From X to B the temperature is negative. By suddenly reversing magnetic field we can jump from plus temperature (P) to minus temperature (Q).

The equation of state for a system of magnets is shown in the diagram above. In this semicircular curve, the top of the curve represents the point where the temperature is infinite. To the left of this point, X, a small increase in energy produces an increase in entropy, and the magnets have an ordinary finite temperature. What happens to the right of X, where the magnets on the average are pointing against the magnetic field? Here a small increase in energy produces a decrease in entropy: according to the definitions the temperature is minus. There is nothing wrong with the definitions; the temperature is in fact minus.

The only unexpected thing about minus temperatures is that every minus temperature is hotter, in the ordinary sense, than every plus temperature. That is to say, if a magnet system at minus temperature is put in contact with anything at a plus temperature, heat energy will flow from the minus to the plus temperature, both systems increasing their disorder in the process. Thus minus temperatures are not "below zero" but "above infinity."

Two Harvard University physicists, Edward M. Purcell and Robert V. Pound, first produced and detected a minus temperature in 1950. They used a crystal of lithium fluoride. It takes about five minutes for the lithium atomic magnets to share their energy with the atomic motions, and during this five minutes the magnet temperature can be measured many times. It turned out that the creation of a negative temperature is rather simple. All that is necessary is to reverse the direction of the magnetic field so quickly (in about one fifth of a microsecond) that the magnets do not have time to move during the reversal. The result is a jump from a plus-temperature point to one in the minus-temperature range. The difficult part of the experiment is to detect the minus temperature after it is created. This was done by observing the magnet system with the technique of nuclear induction. There is no space here to say anything about nuclear induction, except that it is a delicate electronic technique, and Purcell with Felix Bloch of Stanford University received a Nobel prize in 1952 for inventing it.

Why do we never experience minus temperatures (and I do not mean below zero Fahrenheit) in ordinary life? The reason is that a system can have a minus temperature only if it has a state of maximum entropy. For the movements of atoms in a piece of matter, or for heat radiation in empty space, there is no state of maximum entropy. As we supply more and more energy, the entropy goes on increasing forever. So for these familiar kinds of heat, the equation of state does not bend over like the curve in the diagram; it is an open curve climbing steadily from left to right all the way to infinity. As a result, we shall never know what a minus temperature feels or looks like. So far as I know, minus temperatures have no practical or economic importance. They are just a philosophical curiosity, but one which has added considerably to our understanding of the general notions of heat and temperature.



LUMINESCENT BACTERIA *Photobacterium phosphoreum*, suspended in saline solution, are photographed by their own light. The flask at upper left, at 5 degrees centigrade, is one fifth as luminous as the flask at upper right, which is at 22 degrees C. This is roughly the optimum temperature for luminosity in this species (*see graph on the opposite page*). The flask at lower left, at 32 degrees C., has gone past the optimum point and has returned to about the same intensity as the first flask. The flask at lower right has been heated to 32 degrees C. and then cooled to 22 degrees C., its equal intensity indicating the reversibility of the reaction.

HEAT AND LIFE

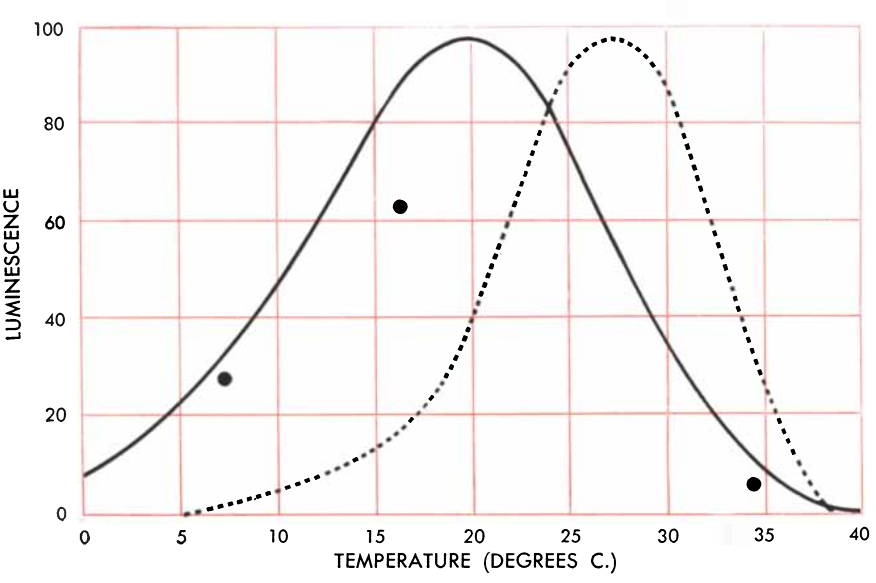
Between the lowest temperatures and the highest is a narrow zone in which living organisms have evolved. This is the range where enzymes can exist and speed the chemical reactions of metabolism

by Frank H. Johnson

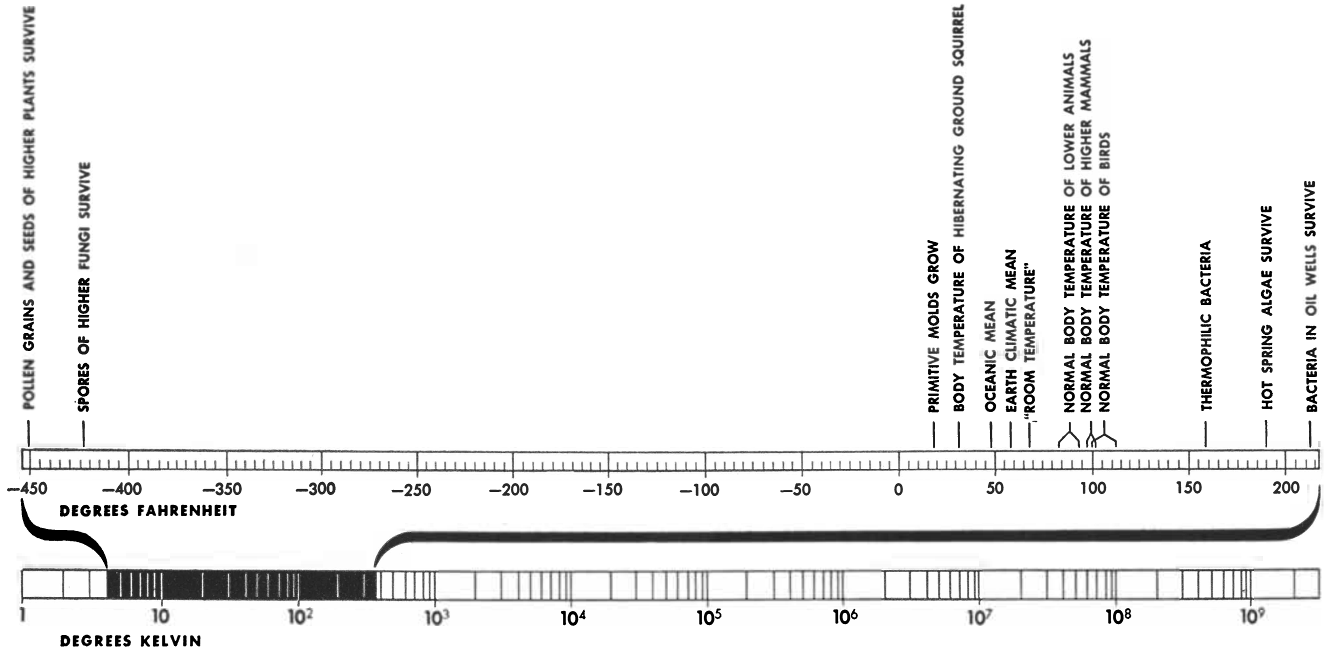
Without heat, all life processes cease. With a little too much heat, they cease just as surely. And the difference between too little and too much is only a hair's-breadth in the broad scale of temperature known to modern science. Life is pretty much confined to the range between about 0 and 50 degrees centigrade, or 32 to 122 degrees Fahrenheit. Very few organisms can live long at temperatures above or below those limits. It has been estimated that, if the average daily temperature on the face of the earth as a whole were suddenly raised or lowered by only 20 degrees, all life would perish. As a matter of fact, life could not adjust to any great change in temperature even with unlimited time for evolutionary adaptation, for the chemistry of organisms is subject to unchangeable limitations.

We might consider first some of the exceptional situations. At the cold end of the biological scale, there is, for example, the Alaskan stonefly, which apparently lives a normal life at freezing temperatures; it has been observed to mate on the frozen ceiling of ice caverns. Some species of bacteria and molds are able to grow slowly at temperatures several degrees below freezing. The polar codfish remains active at below-zero temperatures. Yet these few extremes only emphasize the central principle. As a general rule, at freezing or near-freezing temperatures living organisms can exist, if they survive at all, only because their normal living activities, including metabolism, come to a virtual standstill. Some species of bacteria can survive being kept for months at a time at temperatures around 300 degrees below zero F., and a remarkable array of living forms, including luminous bacteria, moss spores, pollen grains, seeds of higher plants and some lower animals, have recovered their normal activity after exposure to the temperature of liquid helium, within a couple of degrees of absolute zero. Among the more complex animals, a number can keep alive at low temperatures by hibernation, which is a state of suspended activity. Even among the higher mammals some can survive a drastic lowering of the body temperature; for example, young white rats have recovered after being chilled to 37 degrees F., when all perceptible signs of life, including the heartbeat and circulation of the blood, disappeared. The rats in effect underwent a general anesthesia. The anesthetic effects of refrigeration of course are well known; it has been used by surgeons for hundreds of years, and Napoleon's surgeon-in-chief, Larrey, is said to have performed 200 amputations in a single day with the assistance of freezing temperatures on the battlefield.

At the hot end of the biological scale, where the chemistry of life is speeded up rather than stalled, organisms are far more vulnerable to temperatures exceeding the limit. Here too, however, there are freaks. Perhaps the hottest of all animals is the "cold-blooded" fish *Barbus thermalis,* which lives in hot springs of Ceylon at a temperature of 122 degrees F. The albino mouse lives at a body temperature of 102.2 degrees, and the songbirds have a normal temperature of nearly 113 degrees. To find really warm organisms, however, we must turn to the world of primitive



LUMINESCENCE VARIATION occurs in two species of bacteria as the temperature of their environment changes. The solid line shows the increase and decrease of intensity of luminescence for *Photobacterium phosphoreum* as the temperature is increased. The dots show the reversibility of this reaction by readings taken after heating these bacteria to 40 degrees, then cooling. The dashed line shows the response of *Achromobacter fischeri.*



LIFE TEMPERATURES of organisms are largely confined to a narrow band on the thermometer. Such organisms as luminous bacteria and pollen grains can survive to about 450 degrees below zero by virtually suspending metabolic activity. Primitive plants, such as bacteria in oil wells, mark the upper end of the scale at 212 degrees. Most life processes occur between 32 and 122 degrees.

plants. Some species of bacteria thrive at 158 degrees or above. In some of the hot pools of the Yellowstone a blue-green alga carries on a simmering existence at 185 degrees. Certain bacteria indigenous to deep oil-well brines are believed to exist at a temperature of 212 degrees F. or higher.

We are concerned here with what temperatures are most favorable to life. The optimal temperature varies, of course, not only with the organism but also with the state of the organism. In a human being a rise in temperature, for instance, may help to fight an infection; fever therapy of syphilitic paresis depends on the fact that spirochetes cannot withstand as high a temperature as human cells can.

Growth and size have their optimal temperature, but here the relationship is not at all simple. Although cold retards biological processes, among lower animals it is not unusual to find larger body sizes associated with cold habitats. Many arctic species grow to a larger size than their near relatives in warm climates, and flies are larger in winter than in summer. On the other hand, relatively high temperatures may greatly increase the growth of cells. When cultures of the vinegar-forming bacterium *Acetobacter* are incubated at 104 degrees F., which exceeds the normal optimum for the rate of reproduction, cell division almost ceases but the cells themselves continue to grow—sometimes to as much as 150 times the normal size.

Even longevity has an optimum temperature. A study of the water flea *Moina* shows that it lives longest at a temperature of about 60 degrees F. No doubt there is a similar optimum for longevity among the warm-blooded animals, including man, but obviously it would be more difficult to determine.

Biologists would like to develop a precise theory of optimal temperatures for man and other animals, but the temperature relationships are many and complex. In living organisms so many distinct reactions take part in an end result—growth, cell division, respiration, reproduction, longevity and so on—that it is difficult, indeed, to identify which one or which ones may be most important in determining the observed response to temperature.

The crux of the whole problem of temperature and life lies in the effects of heat upon enzymes, the body's catalysts. Enzymes lower the temperature required for reactions to proceed at a given rate. Their activity increases with rise in temperature, just as the rates of chemical reactions in general do. But because they are large, complex proteins, they are unstable to any excess of heat. This dual effect of heat on enzymes accounts primarily for the narrow limits of temperature within which life is possible, and also for the varieties of temperatures at which different life processes and different organisms do best. In each organism there is a multiplicity of enzymes, each catalyzing a specific step or type of reaction, and heat affects both the activity and the stability of some enzymes more than of others. The net effect of temperature on the total process is conditioned by the specific enzymes involved and the characteristics of their response to heat; these characteristics in turn depend on the biological source of the enzymes and on the nature of the chemical environment in which they act.

Life is sensitive to many other environmental variables besides heat—salt concentration, acidity, alkalinity and so on. Ultimately, however, heat is still the fundamental factor; the optimal concentrations of salt, acid and other agents

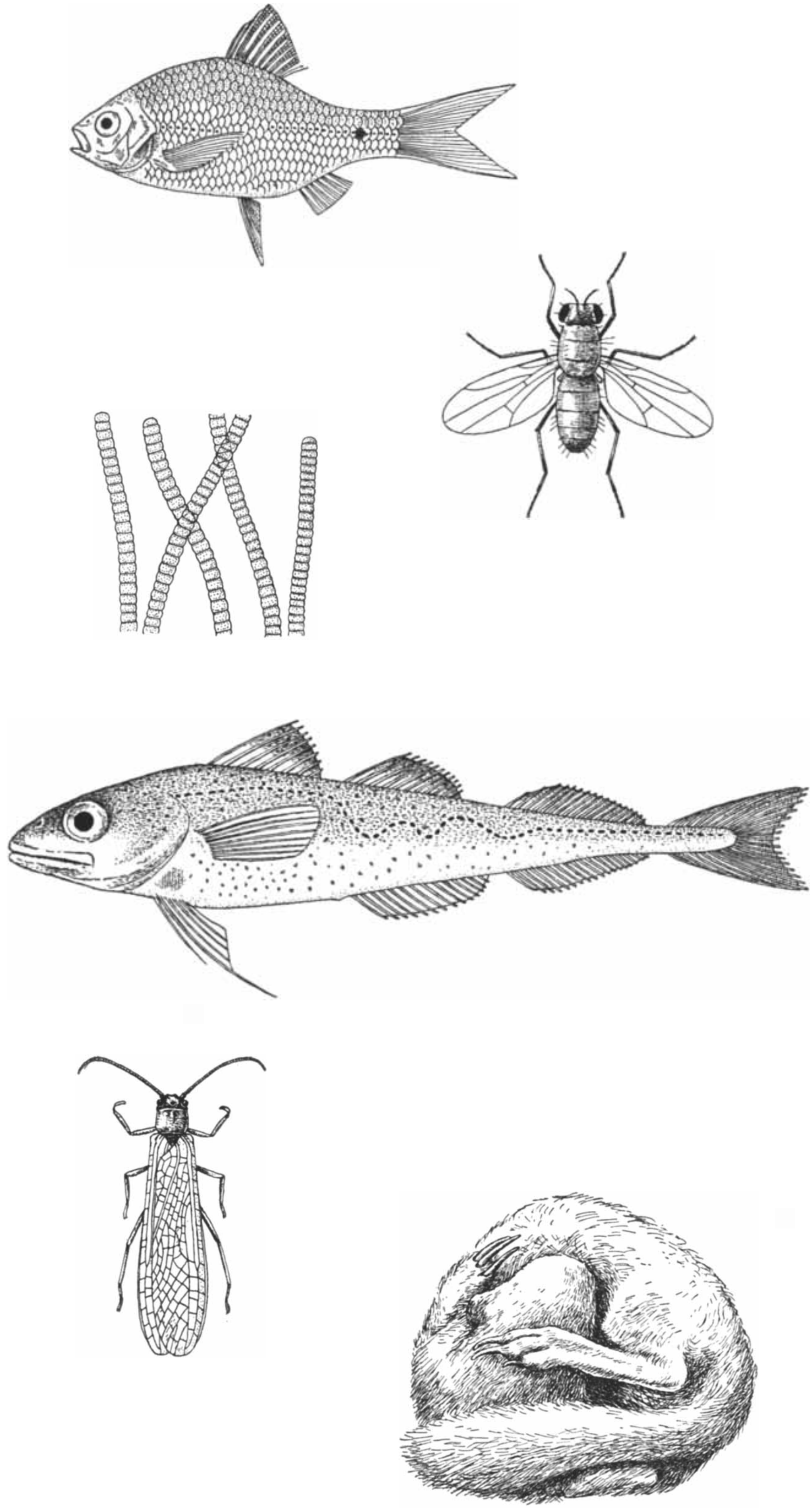
EDITOR'S NOTE

The subject of this article is more fully discussed in *The Kinetic Basis of Molecular Biology*, by Frank H. Johnson, Henry Eyring and Milton J. Polissar. This book has just been published by John Wiley & Sons, Inc.

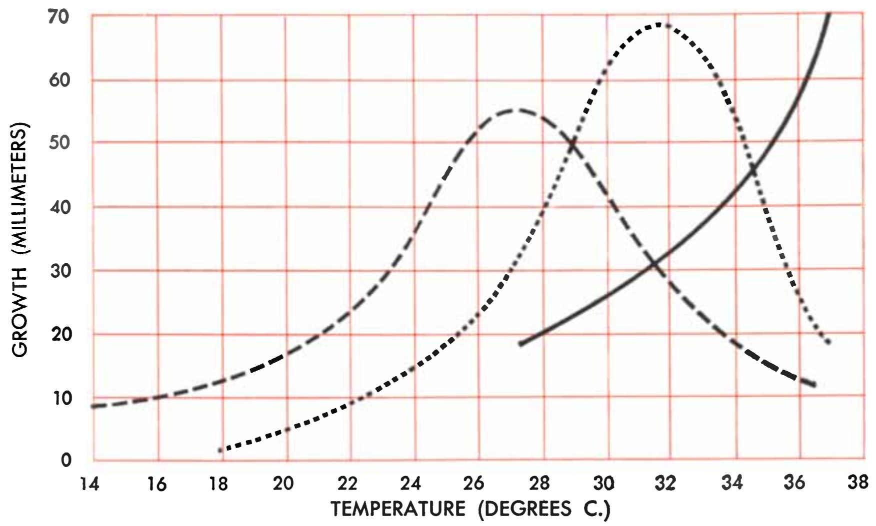
depend in part upon the temperature. Both the activity and the stability of enzymes and other essential constituents of living cells are influenced by the concentration of such agents, but temperature is still basically involved. An interesting illustration lies in the fact that when an egg is placed in alcohol or acid, it will coagulate at room temperature. Heat makes the reaction go, just as when the egg is boiled in water, but the catalytic action of the alcohol or acid lowers the required temperature. (In living organisms alcohol produces fundamentally similar effects, though its concentration is not usually high enough to cause coagulation; the alcohol reduces, by less drastic and usually reversible reactions, the activity of the sensitive enzymes.)

In view of the large number of different reactions that are responsible for the end result of a complex biological process, and in view of the equally large number of enzymes involved in these reactions, it would appear to be a well-nigh hopeless undertaking to attempt to analyze the total rate according to laws governing simple reactions. Surprisingly, however, some of the most complicated living processes respond to temperature as a whole in precisely the manner of a simple chemical reaction. Thus at temperatures below the normal optimum of the system the rate of a single enzyme reaction, or of the heartbeat, or of mental processes, may increase with temperature in the manner that the Swedish chemist Svante Arrhenius discovered is true of many simple reactions; *i.e.*, the logarithm of the rate is a linear function of the reciprocal of the absolute temperature. The reason is that the total rate is limited primarily by the slowest step in the group of reactions, and this slowest reaction, as well as all the others, obeys the same physicochemical laws that hold for all reactions.

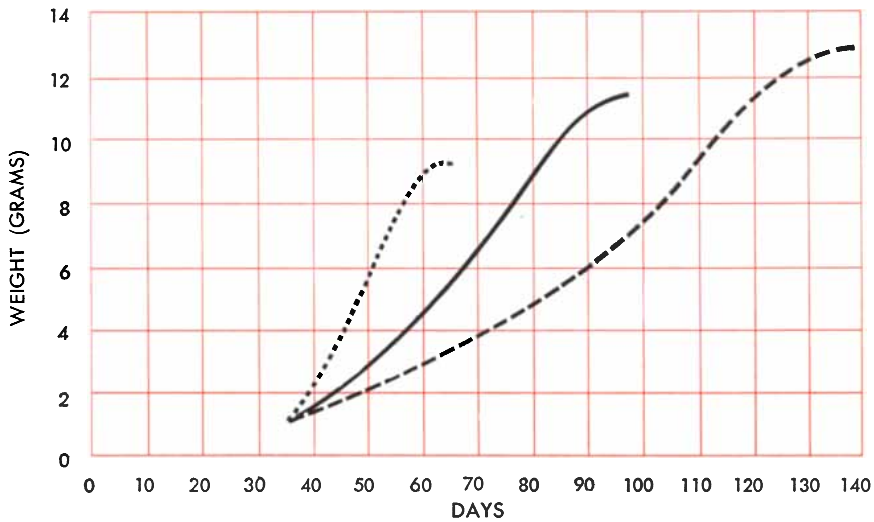
At a given temperature above the normal optimum, the rate of the process often decreases in a manner also in accord with the Arrhenius relation. The decrease suggests irreversible destruction of one or more of the essential enzymes. However, if the exposure to the above-optimum temperature is short, the rate in some cases recovers at once on cooling. This effect, which was first quantitatively demonstrated in living cells with bacterial luminescence, indicates an equilibrium change between catalytically active and inactive states of an essential enzyme. We are probably touching here on a general mechanism



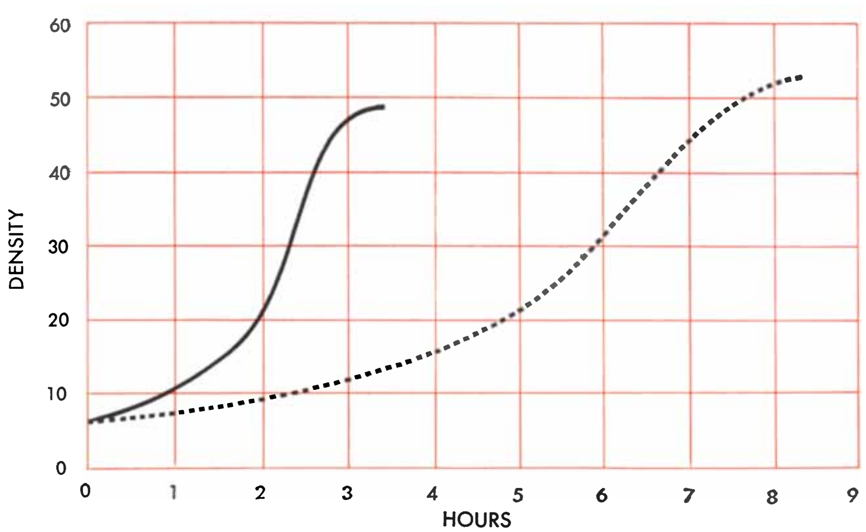
EXTREME DWELLERS in the realm of life temperatures are illustrated here. The fish *Barbus thermalis* (*top*) lives in the hot springs of Ceylon at 122 degrees F. The brine fly *Ephydra* can be found in hot salt pools at 115 degrees. The blue-green algae *Oscillatoria* are quite adaptable and live up to 190 degrees. The polar codfish *Boreogadus* is one of the coldest creatures at 29 degrees. The Alaskan stonefly *Nemoura columbiana* mates at 32 degrees. The ground squirrel *Citellus tridecemlineatus* hibernates in winter at 32 degrees.



PLANTS respond to temperatures differently according to species variations. Increments of growth for 48 hours are shown for a temperate climate plant, *Lupinus* (*long-dashed line*) and two plants of warmer climes, *Zea* (*short-dashed line*) and *Cucumis melo* (*solid*).



FISH EMBRYOS indicate a varying response of growth to temperature. One hundred trout larvae were raised at three temperatures: 16 degrees C. (*short-dashed line*), 10 degrees (*solid line*) and 5 degrees (*long-dashed line*). Weight increase was greatest for the coldest.



BACTERIA indicate a differential response of growth to temperature. Two cultures of *Escherichia coli* were kept at 37 degrees C. (*solid line*) and 23 degrees. The higher temperature caused an increase of rate in growth at the expense of total bacterial population.

in control of physiological rates, for this equilibrium is sensitive not only to temperature but also to many drugs, including alcohol, which lower the temperature at which the change in equilibrium occurs.

We suppose that the intensity of light emitted by luminescent bacteria depends on an oxidative enzyme, whose catalytic activity is reversibly increased with rise in temperature, but whose stability is reversibly decreased, to a different extent. On this assumption it is possible to account with considerable accuracy for the relation between temperature and light intensity over a broad range in temperature. Although many reactions are involved, the net result, as measured by luminescence, responds to temperature as if the whole process depended upon the reactivity of a single species of molecules, namely, the enzyme that limits the process of light emission. There are many other instances wherein a complex biological process as a whole responds to heat in the manner of a relatively simple chemical reaction.

No one knows, and no one is ever likely to know for certain, the temperature of the earth when life first appeared. There is reason to believe that the temperature was quite a bit hotter than it is today. Life probably arose from a single molecule or at most from a very few molecules having the same type of optical activity. It arose when this molecule, or these few molecules, reproduced themselves, possibly by acting as templates for the formation of their successors. The fact that left-handed (levo) optical forms predominate over right-handed (dextro) forms in the living world today, though the two forms have exactly the same chemical reactivity, is difficult to account for on any other hypothesis. The original molecules, with which life began, may have set the left-handed pattern, and the few dextro isomers can be explained as inversions without survival value.

The first self-duplicating molecules must have been relatively small and simple. Because of their simplicity they were more stable to heat. With the cooling of the earth it became possible for more complex molecules to survive, and evolution proceeded in every feasible direction. Out of it has emerged present-day life in all its magnificent array. Heat makes it go and heat makes it stop going. Whatever the future holds in store for us rests ultimately on heat—and on the compromise between too little and too much.

Kodak reports to laboratories on:

high speed film for high speed movies . . . where to look for organic chemicals . . . toughening up our fastest photorecording paper

High speed boon

In Paris this month at an international symposium on high speed photography, we are announcing 16mm *Cine-Kodak Tri-X Negative Film*. We are making a scholarly and dispassionate exposition of the factors governing choice of emulsion characteristics for high speed motion pictures and in due course of the argument we bring out that the new film has at least twice the speed of the valiant old "Super-XX," with about the same graininess. The happy implication to, say the man who is pointing a *Kodak High Speed Camera* at a malfunctioning centrifugal clutch, is that he can close down his lens to get more depth of field, or he needn't pour so much light on his subject, or he can combine the two boons.

Cine-Kodak Tri-X Negative Film is now obtainable from your Kodak dealer, not only spooled for the rigors of high speed cameras (and so labeled) but also for more orthodox 16mm movie cameras used in newsreel, industrial, and sports photography. ASA Exposure Indices for conventional work are 250 for daylight and 200 for tungsten. Actually, this film outstrips the vision of some exposure meter designers by often making possible a quite adequate picture under illumination so low that the photographer can't get any response out of his meter.

Cine-Kodak Tri-X Negative Film *is priced at $3.80 for a 100-foot roll on camera spool. The same emulsion is also available in 35mm form as 100-, 200-, 400-, and 1000-foot rolls of* Eastman Tri-X Negative Film *through our distributors, W. J. German, Inc., Fort Lee, N. J. For a technical data sheet on* Tri-X *motion picture film, write Eastman Kodak Company, 343 State Street, Rochester 4, N. Y. We do not process this film.*

List No. 39

This and every year, myriads of companies spawn numberless catalogs, each a jewel in the crown of some sales manager, each a brick in the edifices of the printing industry and the filing cabinet industry. Here *we* come with yet another and with the presumption to proclaim its advent an event. In support we

cite the reception accorded the 38 predecessors of the vivid turquoise *Eastman Organic Chemicals List No. 39*, which has just been mailed out to those who have told us in past years that they would want it.

We speculate sometimes on why the Eastman Organic catalog is in such high demand by working practitioners of science. Among the more tenable hypotheses, may be listed:

1. It's handy to have around a book weighing less than a pound that gives the *Chem Abstracts* names, laboratory-quantity prices, structural formulas, molecular weights, and melting or boiling ranges (observed, not just quoted) of a representative group of some 3500 organic compounds.

2. It provides a means of distinguishing between the hundreds of thousands of organic compounds known to exist and those actually obtainable by mail or phone order from a single, eminently responsible source (148 items have been added to the latter class in the new edition).

3. It provides routine but useful compilations on matters like pH indicator ranges; transparency regions of spectrophotometric solvents; reagents for a great host of analytical tests; liquids for refractive index determination; listings of sugars, vitamins, amino acids, alkaloids.

4 and most far-fetched. Its conspicuous possession lends tone to those who would know science better and, conversely, a pragmatic note to those whose scientific feats are of the intellect rather than of lab or field.

Now is the time for anyone who needs to know about the availability of organic compounds for the laboratory and who has not yet received List No. 39 *to demand it of Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y.* (*Division of Eastman Kodak Company*). *Though the catalog is free for the asking and the rate of its distribution has been accelerating at a mad pace for the past 35 years, we are always running into deserving people who want it but don't have it. Can't figure that.*

1127

Kodak Linagraph 1127 Paper is the fastest photorecording paper we know of for tungsten light. For technological reasons far too complex to trouble you with, it is very difficult to make a photographic paper that fast and still have a durable emulsion. We speak frankly of this because the difficulty, formidable as it may have appeared, has now been surmounted.

All shipments of *Linagraph 1127* for some months now have been going out with a physically hardened emulsion. Hereby withdrawn is the warning that this paper should be dried face out to avoid sticking. It can now be handled just the same as the slower *Linagraph* papers, but it still has the speed to record cathode-ray traces directly from green-emitting tube faces; and for moving mirror galvanometers this speed still permits wider trace amplitude, higher frequencies, and/or lower source intensity for less frequent electrical servicing.

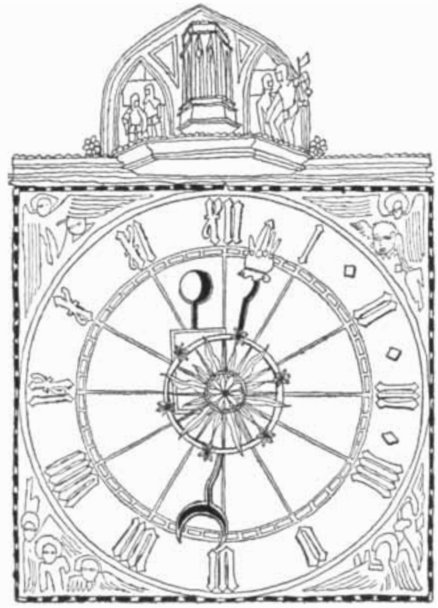
If the fact that such paper exists is a revelation to you, we are glad. It is sold by Kodak Industrial Dealers in a variety of widths and winding specifications.

Price is subject to change without notice.

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

Kodak
TRADE-MARK

SCIENCE AND



Science and the Military

An unsatisfactory relationship between civilian scientists and the Defense Department is jeopardizing the U. S. military research and development program. This is the conclusion of the House Committee on Government Operations after a month of closed hearings on the subject. The Committee found that senior scientists are leaving military projects in disturbing numbers; military leaders impose "irritations and frustrations" which hamper scientists' work; the high turnover of personnel has "disrupted continuity in the technical program."

Among the aspects of the problem which the Committee cited as needing further "extensive Congressional investigation" was the matter of security and clearance. Several leading scientists and administrators had testified on the point. James R. Killian, Jr., president of the Massachusetts Institute of Technology, told the Committee that "there has been, unhappily, a deterioration in recent months between government and science," and that scientists are "clearly discouraged and apprehensive" about the Government's "lack of understanding of scientific methods" and its "preoccupation with security procedures and policies at the expense of scientific progress."

Alice in Wonderland

The House Special Committee to Investigate Tax-Exempt Foundations, better known as the Reece Committee, was seeking last month "the least embarrassing way to gracefully bow off the stage," in the words of one of its own unsympathetic members. But it was not permitted to go quietly. The Committee's abortive investigation called forth the sharpest denunciation that has attended any recent Congressional investigation.

The Committee chairman, B. Carroll Reece, had put on a series of witnesses, mainly members of his staff, who testified that the rich foundations of the nation had been engaged for many years in a "conspiracy" to subvert U. S. education. Reece's witnesses accused the foundations of undermining "the principles underlying the American way of life" through the schools, and of financing many subversive researches, including such monumental projects as Gunnar Myrdal's study of the U. S. Negro problem.

The witnesses were cross-examined caustically by a Committee member, Democratic Representative Wayne L. Hays, who called the inquiry "an Alice in Wonderland investigation" and a "fantastic, nonfactual, nonsensical and slanderous attack on the great foundations." After hearing 11 witnesses against the foundations and one who defended them, Reece abruptly ended the public hearings.

The foundations, dumfounded, protested the denial of their day in court and made public detailed replies to the "charges." Charles Dollard, president of the Carnegie Corporation, called them a "shocking combination of innuendo and implication"; he observed that Myrdal's study *An American Dilemma* "stands and will stand as one of the great social documents of the century"; he noted incredulously that Reece had tried to attach sinister significance to all "empirical" research. Dollard concluded: "The doctrine that tax exemption justifies a political judgment as to soundness of ideas can be . . . the most devastating weapon ever invented for invading the private life of this nation."

H. Rowan Gaither, Jr., president of the Ford Foundation, observed that the Reece thesis that the social and economic changes of the past half-century were the product of "a giant conspiracy" engineered by the foundations was "the sheerest nonsense" and "an affront to the common sense of the American people."

Cornelis W. de Kiewiet, chairman of the American Council of Learned Societies, expressed its opinion of the Reece Committee in these terms: "To lay broad and loose charges against education can itself become a form of subversion against which it is the duty of intellectual leaders to speak emphatically."

Dean Rusk, president of the Rockefeller Foundation and the General Education Board, replied for the trustees of those organizations: "We believe that a free society grows in strength and in moral and intellectual capacity on the basis of free and responsible research and scholarship. We shall continue to support vigorously this concept . . . and we will oppose any effort by Government to use the tax-exempt status to accomplish indirectly what could not be done directly under the Constitution."

Atomic Energy Bill

After a 13-day filibuster against some of the proposed major changes in the Atomic Energy Act, the Senate last month passed the bill by a vote of 57 to 28. Despite the extended debate, the measure as passed differed little from the draft originally reported by the Joint Congressional Committee on Atomic Energy. As this issue of SCIENTIFIC AMERICAN went to press, House and Senate conferees were working on a final version.

The bill departs from the 1946 act chiefly in the fields of international cooperation and private industrial activity. It provides that the U. S. may conclude bilateral agreements with other countries to provide them with "special nuclear material" and source material for nonmilitary uses. These countries are also entitled to get restricted data on refining of source material, reactor development, production of special material, health and safety, industrial and other peacetime uses of atomic energy.

In the field of military cooperation individual nations or regional defense organizations may receive restricted information on the uses of atomic weapons and defenses against them. No details may be given about nuclear weapons themselves except their size, weight and shape, and how they are used and delivered to the targets.

President Eisenhower's pool proposal is treated in a separate section. The President is empowered to cooperate with a group of nations in a pool plan provided the agreement is approved by Congress.

In the matter of domestic development of atomic energy, the bill essentially ends the Government monopoly except in the ownership of special material. Private persons or companies may be licensed by the AEC to own and operate nuclear reactors or other facilities for producing power and special material. They may patent inventions, except those dealing with atomic weapons. For a period of 10 years the AEC is empowered (but not required) to classify important patents as "affected with the public interest" and to require the holders to license these patents to others.

Most of the Congressional debate centered on President Eisenhower's recent directive ordering the AEC to buy power from a private utility group. Under the directive the private companies are to build the generating plant, but the AEC and Tennessee Valley Authority are committed to buy the output and to pay all local, state and federal taxes on the project for 25 years.

Democrats said the plan would cost the Government much more than if TVA built and operated the additional facility itself. They called the presidential order a "giveaway." An attempt was made in the Senate to attach an amendment to the Atomic Energy Bill forbidding the transaction. This measure was defeated, but an amendment prohibiting the payment of taxes by the Government was passed.

Criticisms of the bill by two Democratic members of the Joint Committee, Representatives Chet Holifield and Melvin Price, provided the basis of the opposition arguments. Among the issues they raised were:

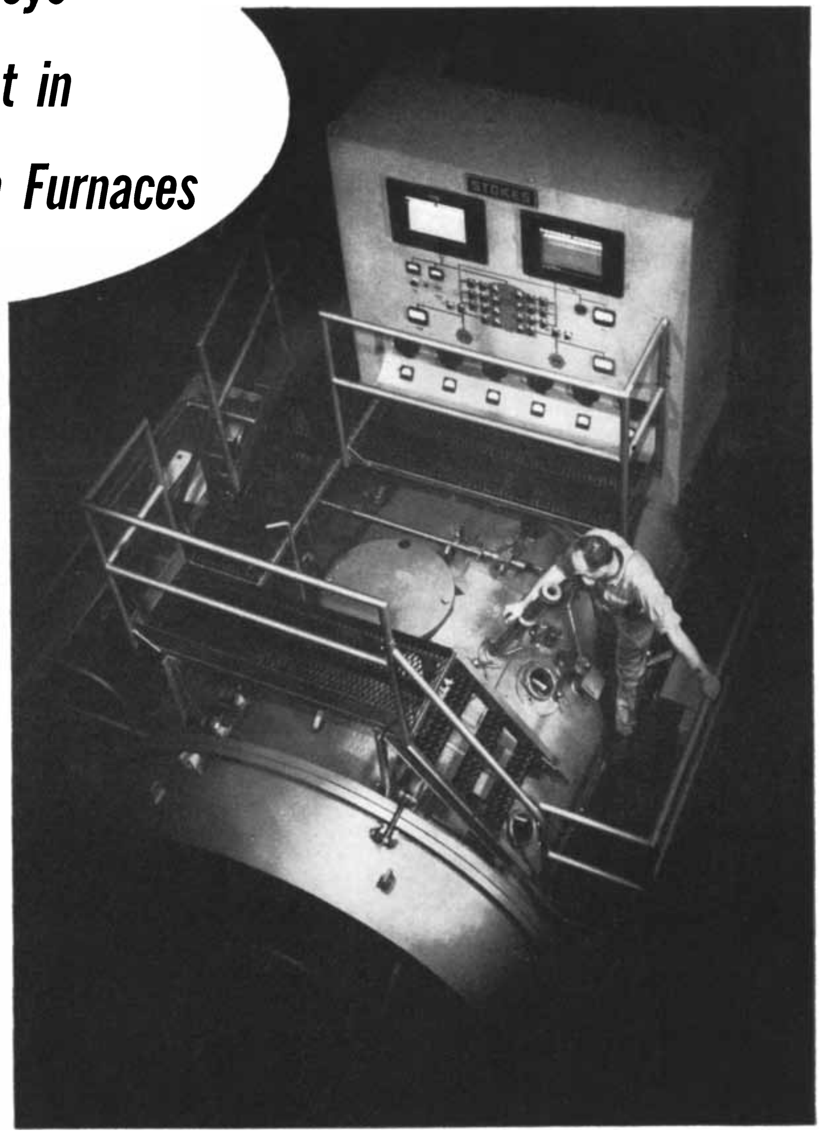
The bill, completely rewriting a technical and complex law, was presented to Congress as a single package in the closing days of the session when the legislators lacked time to consider the measure in detail.

There was no comprehensive report from the AEC on peacetime atomic power, such as the McMahon Act required before new legislation.

The transfer of atomic power to private development lacks the safeguards embodied in all other Federal power legislation, such as control over rates. The bill enables the AEC to "turn this energy resource over to private power monopoly under licenses unconditioned except for the requirements of national security and public health and safety."

Private operators will receive a "built-in subsidy," because the Government

High-temperature Alloys now Melted and Cast in Stokes High-Vacuum Furnaces



A Stokes high-vacuum melting furnace of 1000-pound capacity at Utica Drop Forge & Tool Corporation, Utica, N. Y. The furnace is to be used for the melting and casting of high-temperature alloys for jet engine rotor blades.

Vacuum furnace melting and casting is the economical method for producing many new metals, with greatly improved properties. Alloys that can stand up in rocket engine combustion chambers and advanced jet engine turbines, metals essential for the construction of nuclear reactors, still other high-purity metals with properties not previously attainable . . . these are just a few of the more than thirty new elements vacuum processing has added to the industrial spectrum.

Vacuum-melted high alloy steels have greater tensile, yield, and impact strengths than conventionally-processed metal, plus greater stress-rupture strength at elevated temperatures, less creep, less brittleness. High-purity iron, processed in vacuum, has 60 to 75% greater stress-rupture strength and 400% more elongation than conventional metal. In anti-friction bearings, vacuum-processed steel has shown an increase of 300% or more in fatigue strength, and given a whole new perspective to the subject of wear-resistance.

Moreover, vacuum processing of alloys conserves critical hardening elements, since there is minimum loss of these metals during melting. More usable metal is obtained from each melt, and virtually all of the scrap can be salvaged by vacuum melting.

STOKES is *building* vacuum furnaces to process these high-purity metals in quantities up to 2000 pounds, and *planning* 5000-pound units. STOKES vacuum furnaces reflect the practical experience accumulated in fifty years of building vacuum equipment. An interesting NEW brochure is ready for mailing on request!

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

STOKES

STOKES MAKES: High Vacuum Equipment, Vacuum Pumps and Gages / Industrial Tabletting, Powder Metal and Plastics Molding Presses / Pharmaceutical Equipment will be obliged to buy all the fissionable material they make.

Liquid Metal Fuel

Brookhaven National Laboratory has announced plans for a new type of nuclear power reactor using liquid metal as the fuel. The fissionable metal, uranium 233, will be dissolved in liquid bismuth or in a mixture of bismuth with other metals. It will breed new fuel in a thorium blanket. Its liquid fuel can be cycled continuously through the reactor core and through chemical processing chambers.

The chief advantages of the design are:

The reactor will operate at high temperature (therefore high efficiency) without building up high pressures.

Fission products may be removed cheaply and easily, partly by bubbling inert gas through the fuel to drive off gaseous products and partly by using molten salts to absorb rare earths.

Liquid metal is not damaged physically by radiation.

The fuel will be burned completely.

Experiments on the various process steps are now in progress at Brookhaven. The engineers gave a detailed description of their work in a series of articles in *Nucleonics.*

European Nuclear Laboratory

Felix Bloch, professor of physics at Stanford University, has been named director of the European Nuclear Research Center now being built by 12 nations in Geneva, Switzerland. He will head a three-man council whose other members are Eduardo Amaldi of the University of Rome and C. J. Bakker of the University of Amsterdam.

Bloch, who shared the 1952 Nobel prize in physics for his work on nuclear magnetism, was born in Switzerland. He returns to his native country this September to take up his new duties.

Friendly Machine

The National Bureau of Standards appears to have produced the most versatile, gregarious and good-natured collection of vacuum tubes ever assembled. The paragon is a high-speed digital computer called DYSEAC, meaning SEAC the second. It started out to be merely a second model of the Bureau's earlier machine, SEAC (Standards Eastern Automatic Computer) but its designers have endowed it much more richly than its ancestor. DYSEAC's

What's new in rocket engines?

Only in form are today's rocket engines "new." The idea existed as early as the 13th Century, when Chinese archers lashed arrows to tubes of gunpowder.

This modern form of an old idea has been made possible by alloy, stainless, and heat-resistant steels, and other special metals made with Vancoram ferro alloys. For these are the only metals that can withstand the inferno of a rocket engine's insides.

So it has been throughout industry. In the chemical, petrochemical and allied industries, for example, Vancoram ferro alloys of chromium, titanium and vanadium have helped make possible many modern processes where high temperatures and high pressures are key factors.

For the finest of alloy steels today—and for finer ones tomorrow—Vanadium Corporation produces ferro alloys of vanadium, chromium, manganese, titanium, silicon and boron. Other Vancoram products include master alloys for the aluminum industry and uranium for atomic energy.

Outer space becomes a new frontier, thanks to modern rockets with engine parts of special stainless, heat-resistant steels. Many of these steels are made with Vancoram Exlo* Low-Carbon Ferrochromium produced by a unique special process at VCA's Graham, W. Va. plant.
*Trade-mark

New research center at Cambridge, Ohio, is the latest step in Vanadium Corporation's long-range program of planned expansion. Activities cover all phases of metallurgical research on ferro alloys and master aluminum alloys.

Heat- and corrosion-resistant alloy steel processing equipment helps the expanding petroleum industry increase the world's supply of gasoline, fuel oil, lubricants and scores of other petroleum products.

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Producers of alloys, metals and chemicals

major distinction is its ability to communicate with its surroundings. Needing no human operator, it can work harmoniously with a large variety of other devices, taking information or instructions from them or giving commands. It can operate with machines that store, tabulate, file, display and sense information; with servomechanisms and even with other big computers if they speak the binary digit language. It gets along nicely with people, too.

DYSEAC can keep several jobs going at once and it does not mind being interrupted. In a recent trial run it was hooked up with SEAC to process the results of a series of calculations by SEAC. While waiting for the data to come in, DYSEAC did not stand around doing nothing: it busied itself with a totally different job, which it put aside each time a new figure came in from its partner.

The machine's versatility and its ability to communicate with outside devices make it a good controller for automatic machinery. It can follow the progress of a group of machine as they work on a product, compare the actual results at any stage with the ideal program stored in its memory, decide how to correct for any discrepancy and issue appropriate orders to the machines.

DYSEAC contains more than 500 vacuum tubes and more than 20,000 germanium diodes together with associated circuitry. But it is built up from just two kinds of packaged plug-in units, which are manufactured by mass production. The whole device is set up in two 40-foot, air-conditioned trailer vans and can travel wherever it is needed.

Oldest American

Although there is not the slightest doubt that human beings have lived on the American continent for at least 10,000 years, there have been no bones to prove it. Now archaeologists appear to have found their first Ice Age American. A collection of human bones, dug up last year in Texas, has been identified as dating from the Pleistocene epoch. The bones are at least as old as Folsom man, who has been known heretofore only from his flints.

The first fragments of bone were discovered by Keith Glasscock, an amateur archaeologist, on a ranch near Midland, Tex. He found them together with some Folsom points in a "blowout" —a shallow hole made by wind erosion. Suspecting he had something very important, Glasscock took his find to Fred Wendorf, an anthropologist at the Mu-

seum of New Mexico. Wendorf then made a full-scale excavation of the site.

Digging deeper into the hole, the excavators found skull fragments and pieces of leg, rib, teeth and fingers. There were also the skeletons of a number of prehistoric beasts, chiefly horses. All these samples were sent to T. Dale Stewart, physical anthropologist at the U. S. National Museum in Washington, D. C. Stewart was able to put together a fair section of skull and upper jaw, enough to tell that the owner had a long, narrow head and probably looked much like a modern American Indian. Both the human and animal bones were tested for fluorine content. The results of this comparative dating method established that the man was a Pleistocene fossil.

It appears that the man predates Folsom. Wendorf and his party believe that the Folsom flints originally were in a higher stratum than the one in which the bones were located and sank as wind removed sand from the blowout. Geologists estimate that the deposit is between 12,000 and 20,000 years old.

Old Arctic Village

The remains of a large human settlement more than 1,000 years old, identified as belonging to the Arctic Dorset culture, have been uncovered on the Melville Peninsula in northern Canada (see "Early Man in the Arctic," by J. L. Giddings, Jr.; Scientific American, June).

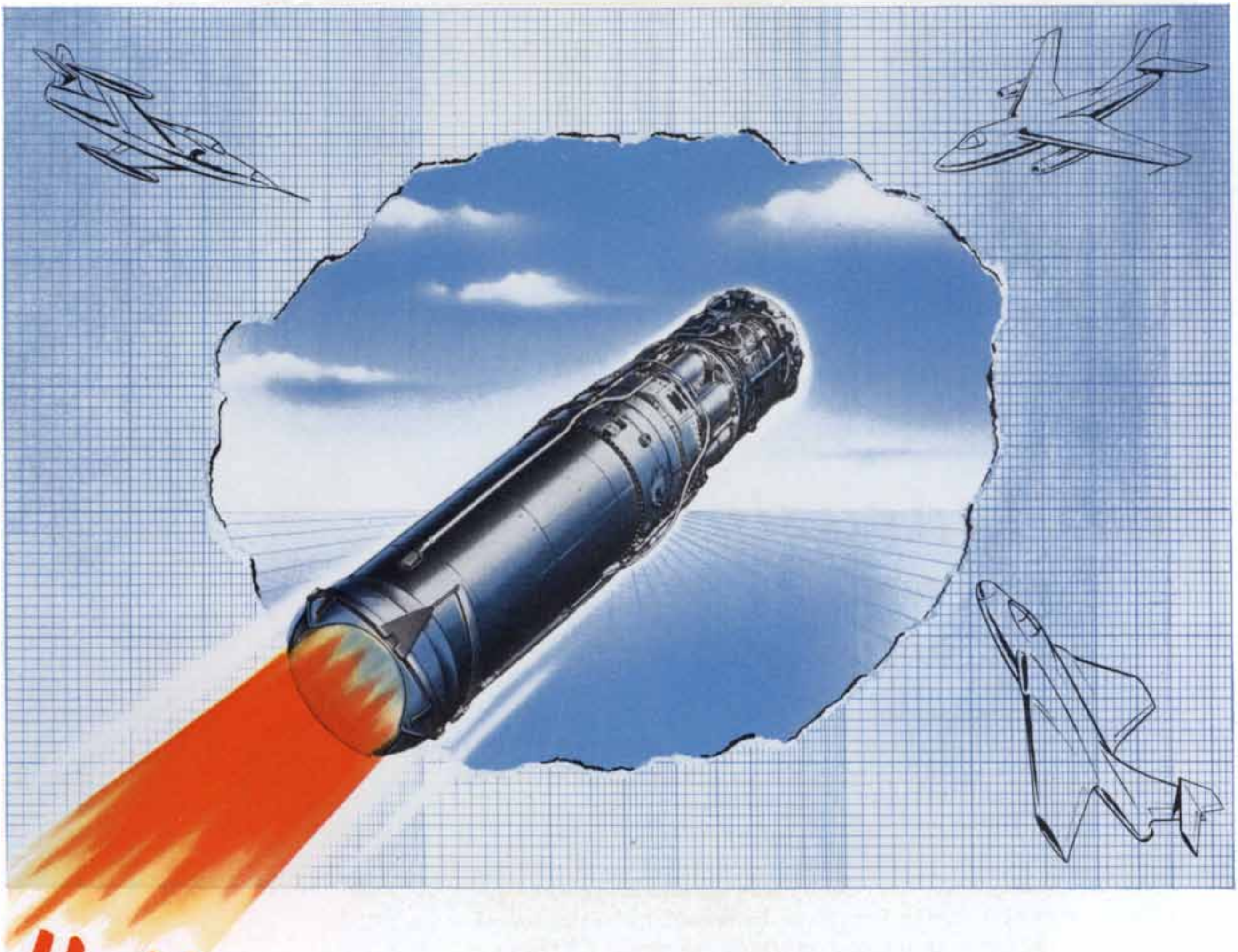
By far the largest Dorset settlement ever found, it consists of more than 100 houses. Many graves and implements have been unearthed, and the site is expected to yield much new information about these little-known people and their relation to other Arctic cultures. A joint expedition of the University Museum of the University of Pennsylvania and the National Museum of Denmark made the discovery.

New Celestial Gauge

Among the many unanswered questions about radio stars is the elementary one: Where are they? The big new radio telescopes are determining their direction more and more accurately, but there has been no way to measure their distance. Now workers at the Jodrell Bank Experimental Station in England have announced an ingenious method that will give a rough measure of distance.

The method depends on the recent discovery that interstellar hydrogen gas emits 21-centimeter radio waves. A hydrogen gas cloud absorbs radio energy

NEW HORIZONS IN ENGINEERING



Hotter "Hot end" components

Jet engine performance is measured in terms of "specifics". "Specific thrust" is pounds of thrust per pound of air per second. "Specific weight" is pounds of engine weight per pound of thrust. The goal is always more and more thrust for less and less weight.

In this quest, the ability to produce higher "specific thrusts" at lower "specific weights" depends on the ability to handle ever-increasing temperatures, and is therefore a direct measure of the success of new designs. To this end, the ingenuity of engineers and metallurgists is constantly taxed to achieve durability at higher temperatures through better design and better materials.

Jet engine "hot end" components and other complex fabricating problems are not new to I-T-E's Special Products Division. Its engineers and production men have specialized in solving the problems involved in tooling for and producing "hot end" components of hard-to-work alloys in complex designs.

Perhaps these men can help you with your problems.

Why not send for Publication SP-100, S-9 today.
It shows what has been done to help others.

RADAR ANTENNA SYSTEMS
design, development and fabrication

JET ENGINES
manufacture of major hot-end components

THERMODYNAMICS
design, development and fabrication of equipment to operate on advanced theories

GUIDED MISSILES
advanced fabricating techniques

TITANIUM
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SPINNING
combining spinning and drawing to an almost limitless variety of designs in a wide range of metals

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at the same wavelength. Thus if the radio beam from a radio star in the direction of a hydrogen cloud arrives at the earth with a weakened 21-centimeter component, that must mean the source lies beyond the cloud.

D. R. W. Williams and R. D. Davis, who report their work in *Nature,* have studied two of the best-known radio sources—the ones in Cygnus and Cassiopeia. The hydrogen map shows a pair of clouds lying along the directions to both of these radio stars. Williams and Davis have computed theoretically how much absorption there should be if a beam passes through one or both of the clouds. The radiation from the Cygnus source shows just about the maximum theoretical absorption. Hence it presumably lies beyond the farther cloud, which means that it is at least 30,000 light-years away. The result is consistent with the visual estimate, since the Cygnus source is thought to arise from two colliding nebulae outside the Milky Way. The Cassiopeia radio source shows comparatively little 21-centimeter absorption, so Williams and Davis place it somewhere between 1,600 and 8,000 light-years from the earth.

TB Progress

With the aid of the new drug isoniazid, cases of pulmonary tuberculosis that were considered inoperable a few years ago can now be cured by surgery. So report physicians of the National Jewish Hospital at Denver, famous medical center for tuberculosis and chest diseases.

Although tubercle bacilli become resistant to isoniazid, the resistant germs apparently lose their ability to invade uninfected tissue. Thus diseased lung areas may be cut out without fear of stirring up and spreading the infection. The hospital also uses new techniques which measure heart and lung capacity and tell a surgeon how much lung he can cut away.

Anatomy of Chromosomes

What is a gene? Geneticists are much less confident of the answer than they used to be. Most of them believe that there are heredity-determining units of some sort in the chromosomes, but they are not clear as to just what the units are.

Daniel Mazia, University of California zoologist, has found a way to dissect chromosomes chemically and has succeeded in showing that they are made of chemical subunits. First the chromosomes are treated with a chelating agent that binds calcium and magnesium. (Chelating agents are chemicals that surround, or "sequester," metal atoms, thus inhibiting their chemical activity.) Then the treated material is bathed in a weak ionic solution. By this means Mazia has divided chromosomes into a number of short segments, each of which is chemically similar to an intact chromosome.

He interprets this result to mean that there are units in the chromosomes, held together electrically by bridges of calcium or magnesium ions.

Good Guys and Bad Guys

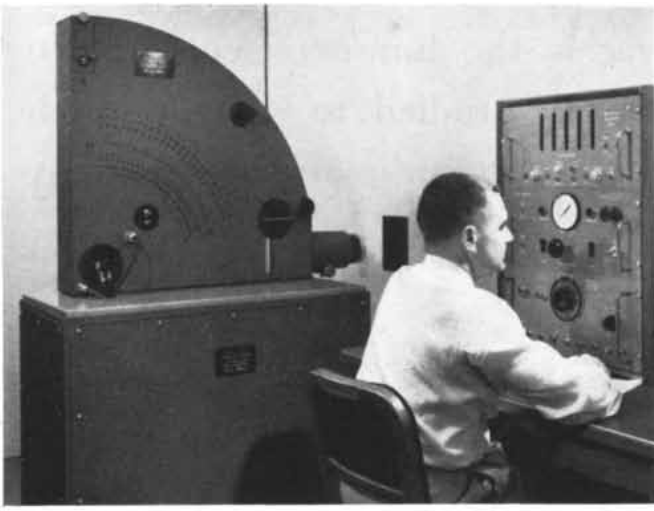
On the current U.S.S.R. scene, the heroes and villains of science appear to be trading places. Albert Einstein, who used to be a wrecker, has been promoted to a builder, while Trofim D. Lysenko is losing his medals.

Einstein has been under official Soviet attack for 15 years. His theories were considered "pernicious bourgeois mysticism," in the words of *Pravda*. Recently *Pravda* made a turnabout and sharply attacked Einstein's critics, according to dispatches in the New York *Times*. An article signed by Academician S. L. Sobolev, a prominent physicist, criticized scholars who confuse Einstein's philosophy with his scientific work. The writer accused Moscow University physicists of having "unsuccessfully attempted to deny the physical contents of Einstein's theory of relativity," and recalled that Lenin had thought highly of Einstein's work. Sobolev named names. He singled out two Moscow University faculty members, Professors Akulov and Nozdrev, as foes of Einstein's friends. While on the subject of scientists who seek to "get rid" not only of criticism but of the critics as well, Sobolev also mentioned two other prominent members of the Soviet Academy of Sciences: biologist K. M. Bykov and Lysenko himself.

An even stronger attack on Lysenko appeared in *The Journal of General Biology*, an organ of the Soviet Academy. N. V. Turbin, a geneticist, discussed in particular Lysenko's claim to have changed one plant species into another. Evidence offered for a change from pine trees to spruce, said Turbin, was "clearly falsified," and "evidence of the transformation of wheat into barley and rye into oats lacked verification." The whole theory of the formation of species through environmental change, Turbin concluded, is "unsubstantial and essentially mistaken."

FOR PHYSICAL
RESEARCH

magnifying time



This is an instrument designed to permit leisurely examination of things that happen in those midget building-blocks of the fourth dimension—microseconds. A 35-millimeter camera, its resemblance to your Leica stops there. It takes 1/100,000 of any second you pick out and gives you a sequence of 25 crisp pictures, each showing its part of whatever you may have arranged to be going on at the time.

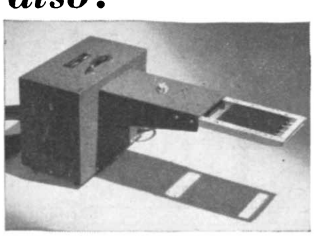
We have two models of this Beckman & Whitley Framing Camera: the 189 which runs to 1,200,000 exposures per second, the Model 222, which can double this figure, and special models for even higher speeds. Incidentally, it is done with mirrors.

Here at the right we find another time-stretching instrument. This device takes only one picture at a time, but the picture has unusual characteristics which endear it to the hearts of many research people. The Model 168 Synchronized Streak Camera wipes the image of an external event across a piece of 4 by 10-inch film at the somewhat impressive rate of 5.46 millimeters per microsecond—the complete exposure thus taking 44 millionths of a second.

Since the completed picture is a plot of space versus time, latent facts can be derived concerning speed and direction relationships.

We have literature which goes into the more technical and detailed aspects of both of these cameras and copies are yours for the asking.

also:



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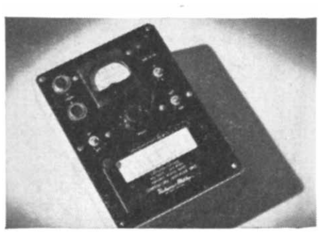

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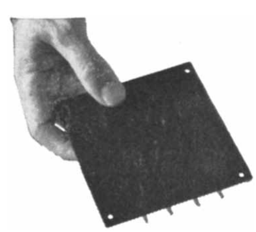

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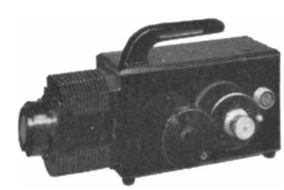

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High Temperatures: FLAME

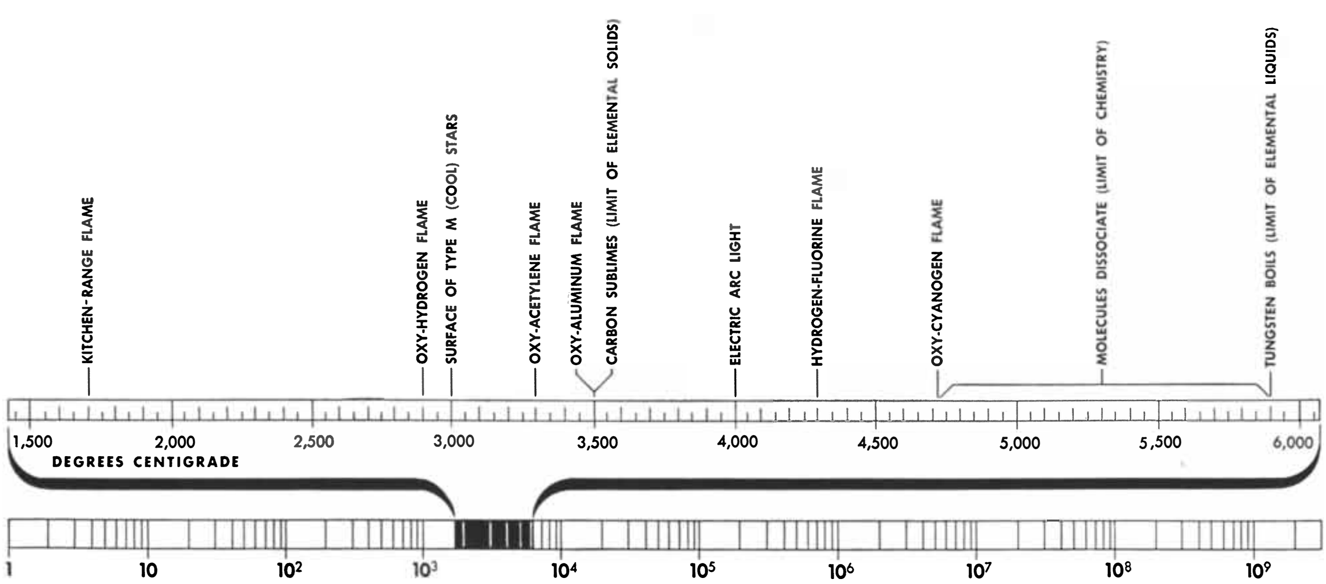
Our principal source of intense heat is the luminous combustion of gases. The phenomenon is intensively studied to increase both the temperature of flames and our knowledge of matter and energy

by Bernard Lewis

Fire has always been one of the most fascinating of nature's phenomena. It is a subject of inexhaustible mystery: the more intimately man studies it, the more it leads him on to new discoveries and to new questions. From the ancients' concept of fire as one of the four fundamental elements grew the alchemy of the Middle Ages. Later it was the investigations of combustion by Antoine Lavoisier and others that gave rise to modern chemistry. Today the study of flames is leading deep into questions of quantum mechanics and the fundamental nature of our physical world.

The province of this article is the range of temperature from a few hundred to a few thousand degrees—the familiar flames that cook our food, drive our engines, smelt our ores, do our work. To approach an understanding of fire we must first define combustion. Combustion is a heat-producing chemical process that may take place at almost any rate or temperature: it may be as slow and mild as the rusting of iron or as violent as the explosion of hydrogen with oxygen, which gives a temperature of 3,000 degrees centigrade. It does not necessarily involve oxygen, for some metals may burn in nitrogen, and certain substances such as hydrazine (N_2H_4), hydrogen peroxide (H_2O_2) and ozone (O_3) can burn in the absence of any medium except themselves; that is, at a sufficiently high temperature they decompose and give off heat without combining with another substance. Hydrazine and hydrogen peroxide are well-known rocket fuels. Ozone is particularly interesting because its burning gives only a single product: two molecules of ozone yield three molecules of oxygen plus heat.

The simplest definition of fire is that



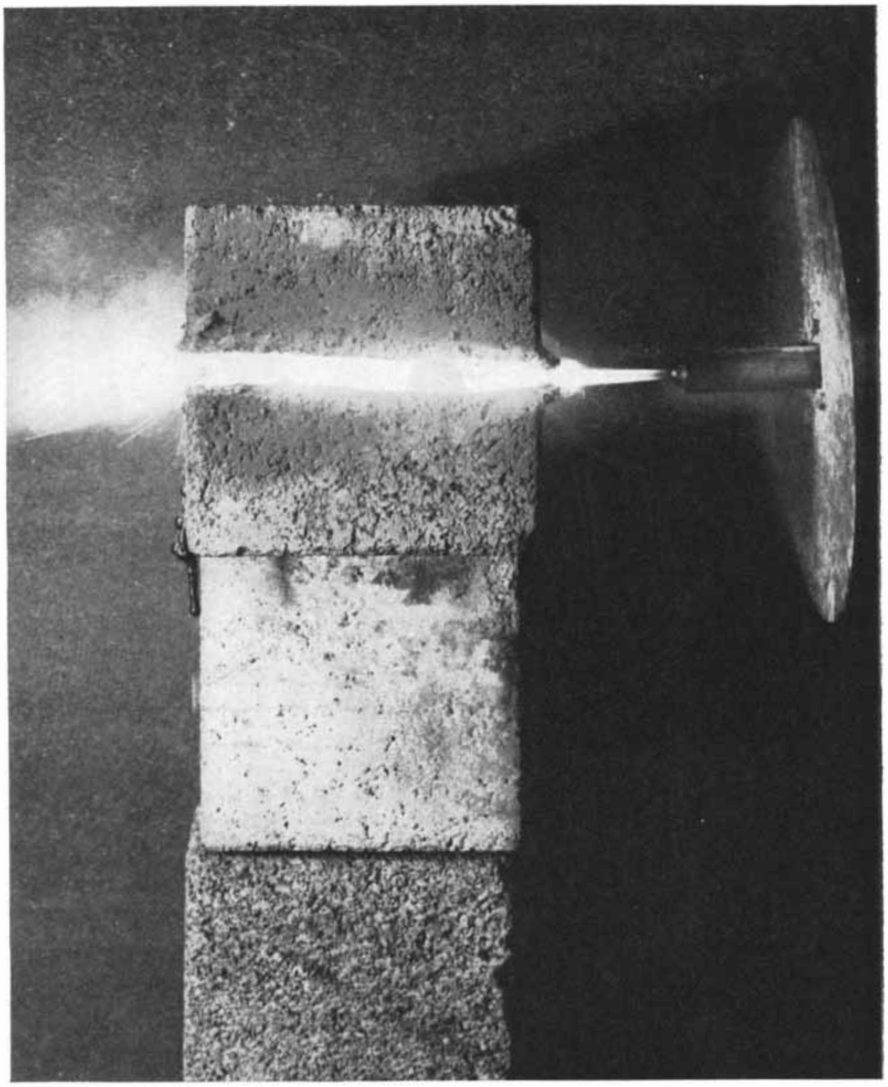
HIGH TEMPERATURES in chemical terms range up to the hottest flames, the dissociation of molecules and the evaporation of elemental liquids. Above the high temperatures are very high temperatures (*see page 132*) and ultrahigh temperatures (*see page 144*).

it is any combustion intense enough to emit light. It may be a quietly burning flame or a climactic explosion. It grows and sustains itself in the reacting medium by the heat it produces, for the heat raises the temperature and the temperature in turn raises the reaction rate until heat is produced as fast or faster than it is lost to the surroundings. But heat is not always the sole nor even the principal agent that initiates flames and explosions. Another agent is a chemical process known as branching of reaction chains.

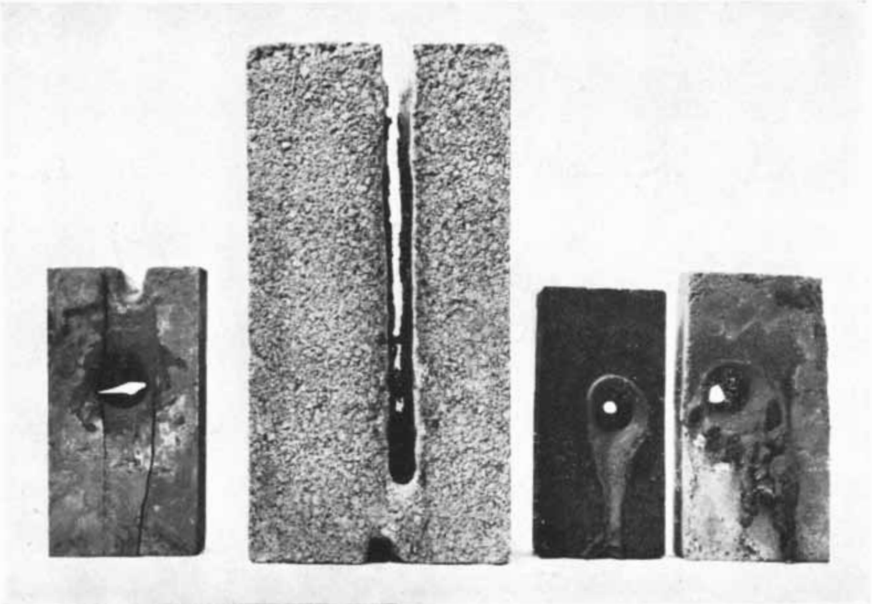
The phenomenon of reaction chains, particularly the difference between branched and unbranched chains, is illustrated in the two diagrams on the next page. The first shows the reaction of hydrogen and chlorine. These elements have such an affinity for each other that a hydrogen atom will detach a chlorine atom from the chlorine molecule and *vice versa*. Therefore an atom of hydrogen seizes one atom of chlorine and releases the other, which in turn frees an atom of hydrogen from a hydrogen molecule and so on. The chain of reactions is straight, *i.e.*, "unbranched." On the other hand, in a mixture of hydrogen and oxygen an atom of hydrogen takes an atom of oxygen from an oxygen molecule to form a free radical OH and release an oxygen atom, which in turn takes a hydrogen atom to form another OH radical and free a hydrogen atom. The two OH radicals produce two free hydrogen atoms. The net effect is that from the action of one hydrogen atom two new hydrogen atoms emerge, each capable of propagating its own reaction chain. The chain, in other words, is "branched." The branches may multiply without limit and proceed rapidly to an explosion. This type of chain reaction is comparatively rare in chemistry, but it has been made familiar by the atomic bomb, where each fission of a uranium atom releases neutrons which may start branches.

A typical combustion process is the burning of gasoline in an engine. Here the octane fuel, mixed with air, is compressed and ignited by a spark. Two molecules of octane (C_8H_{18}) react with 25 molecules of oxygen in the air to form 16 molecules of carbon dioxide and 18 molecules of water, with a heat yield of 2,632,000 calories. The hot carbon dioxide and water vapor form the working fluid that exerts pressure in the cylinder and drives the engine.

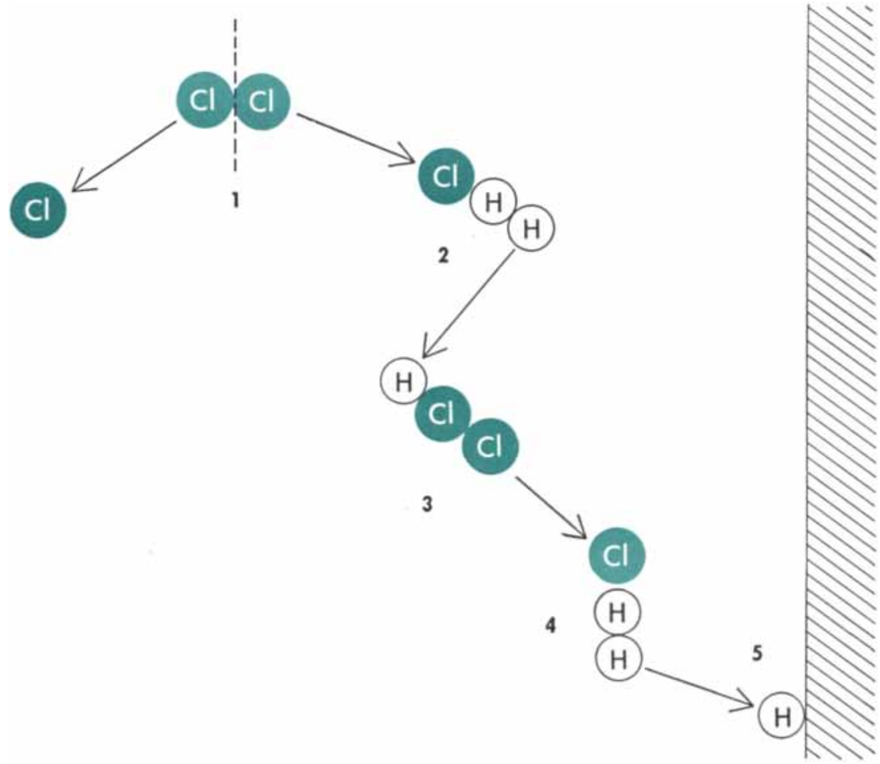
The spark starts the chemical reaction in a small zone of the fuel mixture; as this flames up, heat flows into the ad-



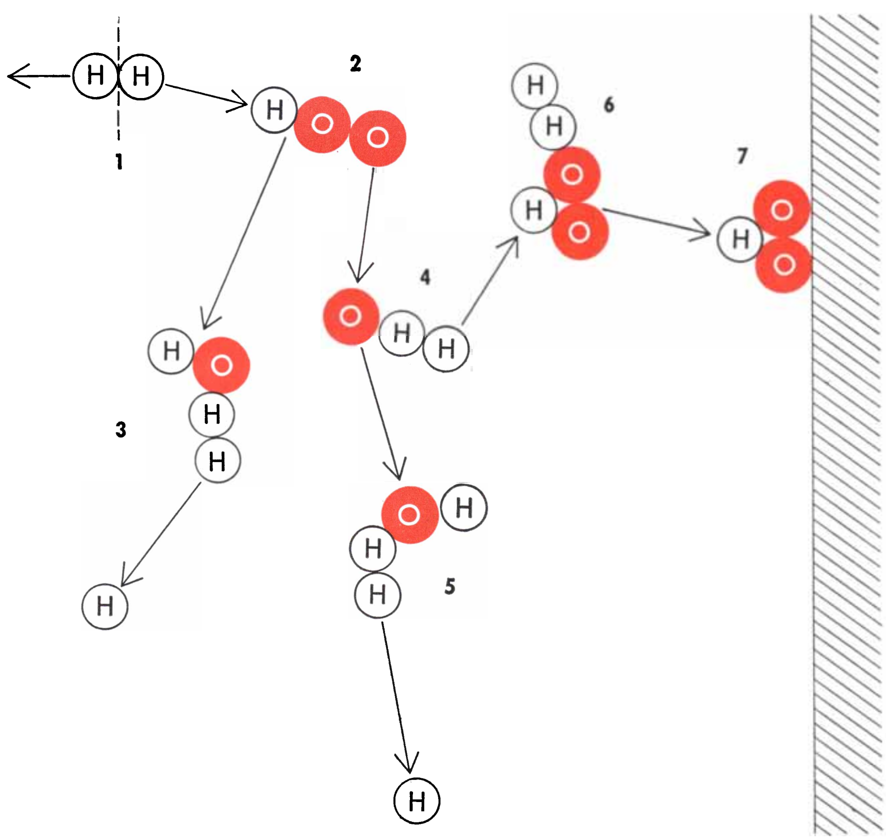
OXY-ALUMINUM TORCH burns through concrete in the High Temperature Laboratory of Temple University. Fed by powdered aluminum, this flame is 3,500 degrees centigrade.



MATERIALS BURNED by the oxy-aluminum torch are, from left to right: graphite, concrete, red brick and refractory brick. Melted material cooled on the surface of the last two.



CHAIN REACTION of chlorine and hydrogen begins when a molecule of chlorine splits. One chlorine atom then hits a hydrogen molecule, combining with one hydrogen atom and freeing the other. The reaction continues until an atom is adsorbed on the vessel wall.



BRANCHED-CHAIN REACTION of hydrogen and oxygen frees three hydrogen atoms to replace the original one. The reaction stops when a majority of the hydrogen atoms form the radical HO_2. This unreactive radical migrates to the vessel wall and is adsorbed there.

jacent layer of unburned gas, and so on. In this way a propagating zone of intense burning called a combustion wave is established. If an explosive mixture flows continuously from an orifice, a combustion wave can, under suitable conditions, propagate against the stream at a rate that matches the flow velocity of the stream. This is exemplified in the familiar stationary flame of a kitchen-range burner.

Within the combustion wave itself the temperature rises sharply from the unburned side to the burned side. The wave thickness and temperature gradient vary greatly, depending on the fuel: in a mixture of hydrogen and fluorine the temperature rises about 4,500 degrees C. in the short space of about one thousandth of an inch. Let us follow the progress of a combustion wave through a small zone of gas. The zone at first merely absorbs heat from the low-temperature front of the wave. When a hot enough part of the wave reaches it, the gas in the zone breaks into rapid chemical reaction, or flame. Now the burning gas itself generates heat, first at a rising rate, then at a declining rate as the fuel is used up. While it is generating heat, it passes forward to the advancing wave front as much heat as it absorbed before it began to liberate heat. In this way a wave continuously "borrows" and "repays" heat out of a revolving fund which travels with the wave and is referred to as the "excess enthalpy" (excess heat content) of the wave. The velocity of propagation of the wave is called the burning velocity. It ranges from a few inches per second for weak hydrocarbon-air mixtures to several hundred times this value for mixtures such as hydrogen and fluorine.

Across the combustion wave the chemical population of the reacting zone of gas changes radically: it becomes a mélange of pristine fuel molecules, final products and intermediate dissociated atoms and fragments of molecules known as free radicals [see "Free Radicals," by Paul D. Bartlett; Scientific American, December, 1953]. There exist "cool" flames which are sustained by a chain-branching process rather than by the production of heat. These waves leave in their wake a residue of intermediate combustion products such as aldehydes and peroxides. By chilling a flame through contact with a cold solid surface, or better still, by diluting the mixture so that intense burning is avoided, it is possible to recover substantial quantities of such intermediate products.

A combustion wave adjusts itself auto-

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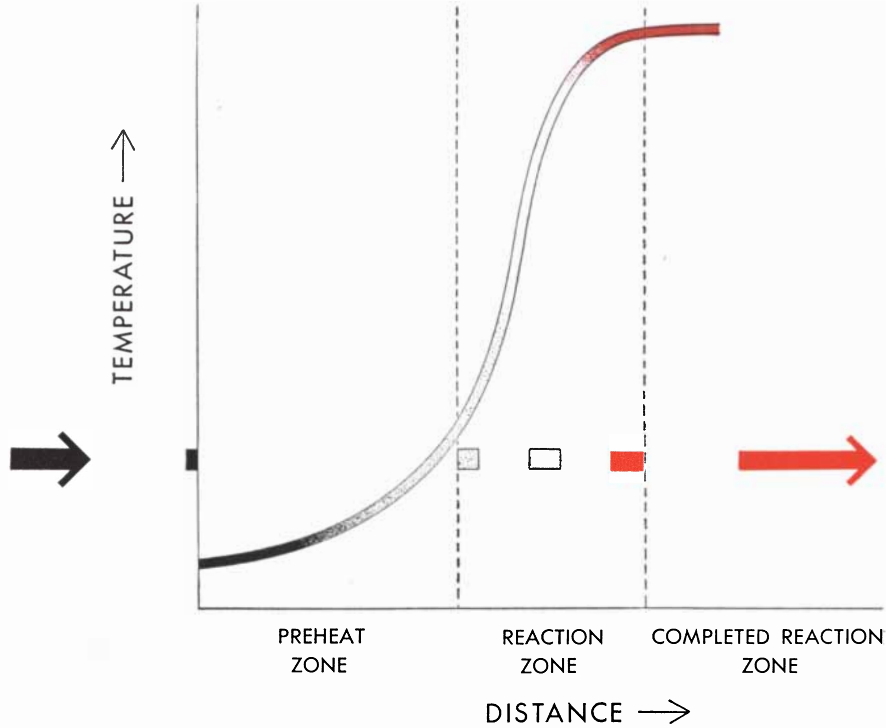

COMBUSTION WAVE is divided into three zones. In the preheat zone the temperature of the fuel and air is raised by the "excess enthalpy" of combustion. In the reaction zone the mixture is further heated by the combustion of the fuel. In the completed reaction zone the fuel is completely burned. The small rectangles suggest change in volume with burning.

matically to a steady state in which the reacting zone passes on to the next zone exactly the amount of excess enthalpy it has received. Such a wave possesses the ability to restore itself when disturbed. But if the burning mixture is progressively diluted so that the temperatures and reaction rates in the wave are reduced, the resistance of the steady state to perturbations decreases and finally vanishes. The combustion wave then disintegrates. Any fuel mixture has upper and lower limits of inflammability which are governed by the relative proportions of fuel and oxygen. Methane, for instance, will burn in air at room temperature only if the percentage of methane is between about 5 and 15 per cent. An increase in temperature or pressure will widen the range of inflammability. Information on the limits of inflammability is important to industries that produce, store, handle and transport potentially explosive materials.

Combustion waves lose heat to solid bodies with which they come in contact. A solid therefore quenches burning in a gas for some distance from it. If the diameter of a duct is made small enough, an explosive mixture cannot burn in it. The critical quenching diameter depends upon the composition of the fuel mixture, the pressure, the temperature and the shape of the duct. A mixture of hydrocarbons and air at very low pressure will not burn in a duct as much as several inches in diameter, but a mixture of oxygen with hydrogen or acetylene can propagate a flame in a fine tube with a bore of only a little more than one thousandth of an inch. Bundles of narrow ducts are often used as flame "traps" to arrest flashbacks, just as, conversely, a wide duct is employed to promote flashover in a kitchen range or a jet engine. For high-altitude flight the diameters of engine ducts and chambers are especially critical, because the flame-quenching distance increases markedly with decreasing pressure.

From an ignition source such as an electric spark a combustion wave propagates in all directions. At any instant the combustion wave thus forms a thin shell around a core of burned gas. As the shell grows, it must obtain additional heat or "excess enthalpy" to satisfy the demand created by the enlargement of its area. This heat is furnished by the core of burned gas. Whereas in later stages of the process, when the shell has grown large, the heat thus taken from the burned gas is negligible, it is relatively large in the early stages and leads to a significant decrease of temperature in the wave crest. In fact, unless the wave is given a sufficient initial boost of heat by the ignition source, the temperature drops so much that the wave

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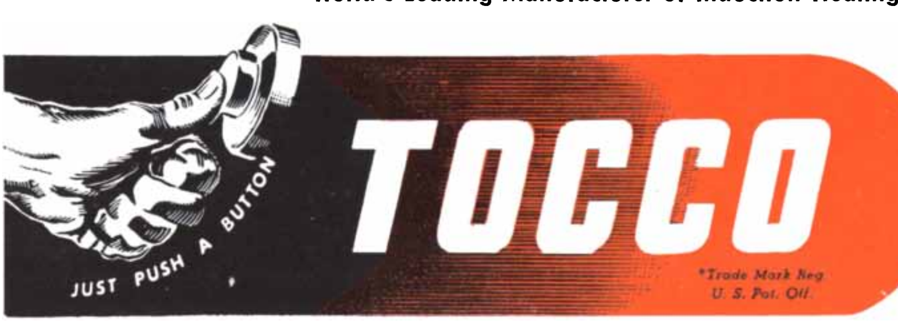

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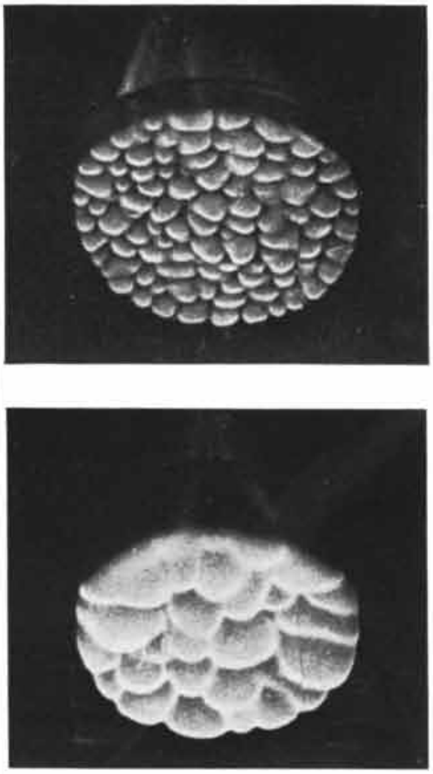
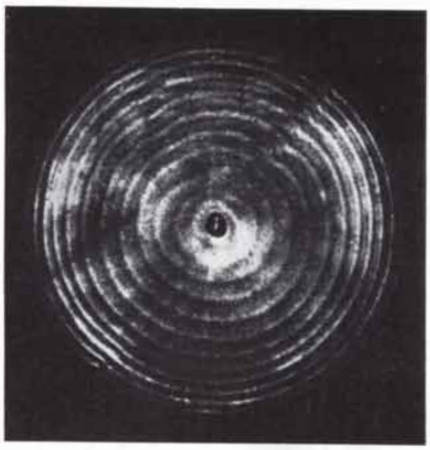


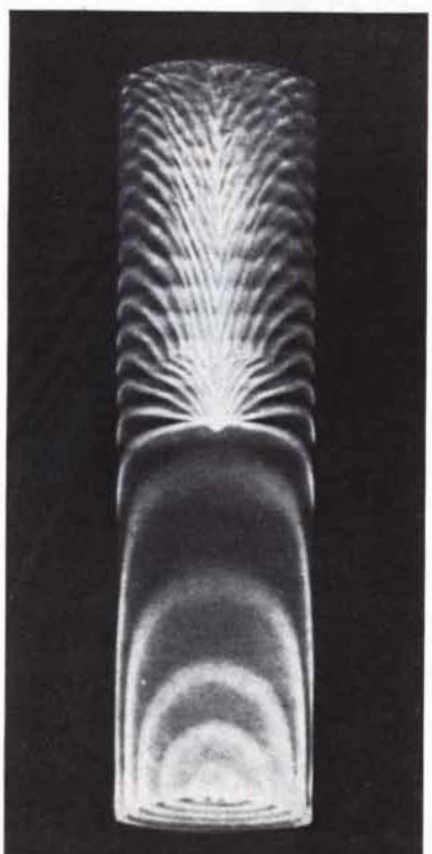
CELLULAR FLAMES in a six-inch glass tube were photographed from below by George H. Markstein of the Cornell Aeronautical Laboratory. This flame aberration is believed due to the preferential diffusion of oxygen in a mixture of butane and air.

peters out. This explains why a low-energy spark may pass through an explosive mixture without igniting it, even when the temperature in the path of the spark is of the order of several thousand degrees. The minimum spark energy required for ignition depends upon the composition of the explosive mixture, the pressure and the temperature. Certain weak mixtures may require as much as a calorie, while hydrogen and oxygen in proper ratios can be touched off by less than one millionth of a calorie—a spark far less energetic than the static electricity a human being generates by walking on a carpet on a dry day.

The spherical way in which a combustion wave develops can be demonstrated by igniting a gas mixture with a spark in the center of a glass sphere; the upper photograph on the opposite page shows such a wave at successive moments. In a cylindrical vessel the wave follows the pattern illustrated in the lower photograph.

A combustion wave, in expanding the gas within it, produces a thrust which raises the pressure in the unburned gas ahead of it. Although this force is generally small, it may produce important effects. It accentuates any turbulence in a gas stream. In a fast-burning mixture confined within a duct the thrust and burning velocity, reinforcing each other, may produce a shock front. The consequent sharp rise in pressure and temperature in turn causes a detonation wave. Such waves travel with high velocities, of the order of several miles per second. They are maintained by the energy released in the chemical reaction and attain a constant velocity which is the sum of the velocities of sound and of the flow in the burned medium. In high explosives such as TNT or nitroglycerin the pressure in the shock front





FLAME PROPAGATION from a spark was photographed at regular short intervals. At the top the flame is shown in a spherical glass vessel; at bottom, in a cylindrical one.

is of the order of 100,000 to 200,000 atmospheres.

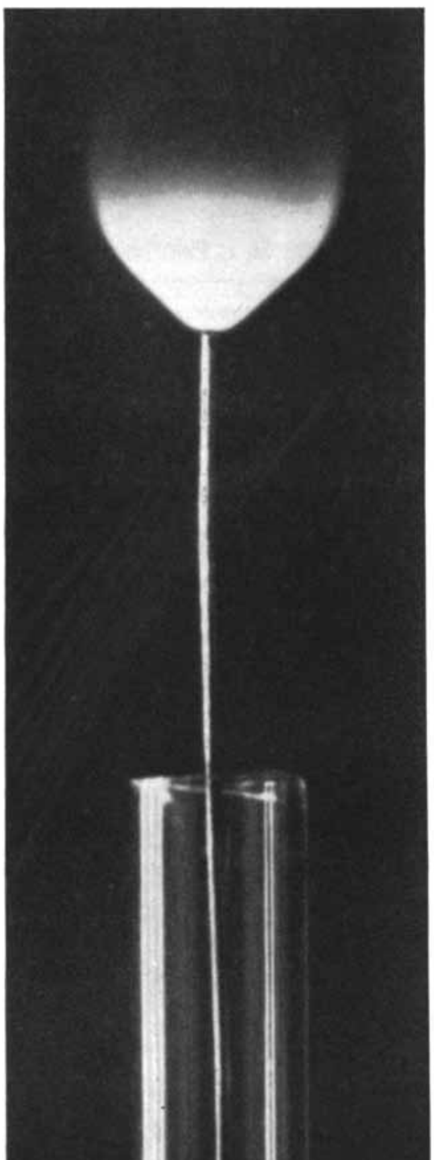
The most familiar flame in our civilization is, of course, the gas burner, known to us variously as the burner on the kitchen stove or the oil furnace, the welder's torch, the airplane's jet engine. In the kitchen burner a jet of fuel gas, after entraining air, flows at a given pressure from numerous orifices in the burner head. The flame is stabilized by means of the flow distribution and quenching effects. The combustion wave anchors itself at an equilibrium position whose distance from the burner rim depends on the rate of gas flow. When the velocity of this flow is reduced to less than the burning velocity, the flame flashes back into the tube. When it is increased so that it exceeds the burning

UPRIGHT FLAME CONE is stabilized on a ring placed in a stream of inflammable gas flowing from the glass tube at the bottom.

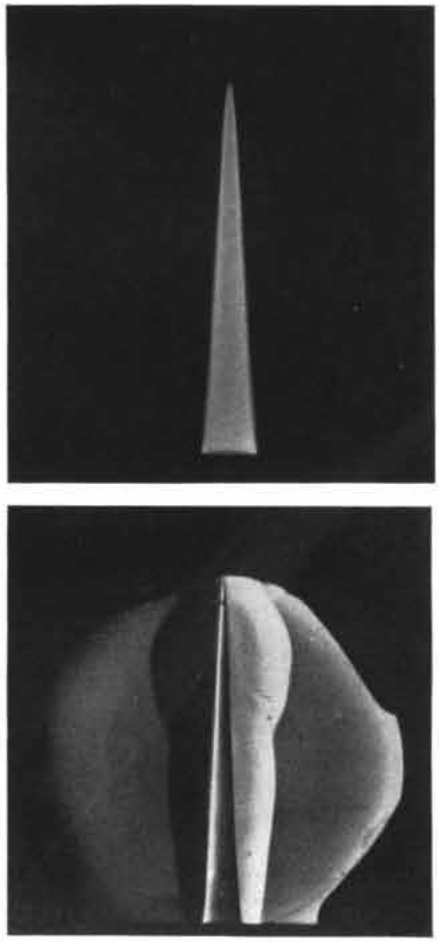
velocity everywhere in the stream, the flame blows off.

When one fuel gas is substituted for another, the critical flow velocity for stabilizing the flame changes. This situation constitutes an important problem in the gas industry, where it is frequently desired to bring in other available fuel gases to meet peak demands. The burner design and flow conditions must be arranged to provide a stable position for each fuel.

A ring or some other obstacle in the gas stream may stabilize a flame under conditions in which it might otherwise blow off [*see photograph on opposite page*]. The gas flow is retarded around the ring, and the combustion wave assumes the shape of an upright



INVERTED FLAME CONE is stabilized on a rod. Without the ring or the rod the flame would simply blow away from tube.

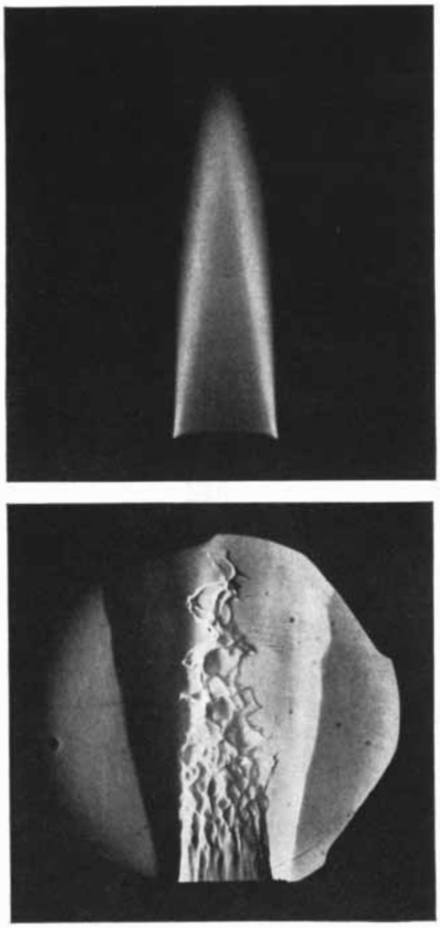


LAMINAR FLAME is photographed by its own light (*top*) and by the schlieren method. The latter shows sharp combustion wave and its rounded envelope of hot gas.

cone. A rod placed upright in the stream makes the flame take the form of an inverted cone [*photograph on preceding page*]. The obstacle method of stabilizing flames is finding application in combustors for jet engines, which demand very high flow velocities.

In the foregoing illustrations the gas flow is laminar; that is, the streamlines form a regular pattern and the combustion wave is smooth and steady. When turbulence is introduced into the stream, the combustion wave becomes wrinkled. The wrinkles and irregularities are not noticeable to the naked eye, but they show up in photographs made by the schlieren technique, which registers density differences and thus makes visible the unburned gas with its envelope of burned gas [*see the bottom photograph above*].

The flame that man has known ever since he discovered fire—the burning of wood, a candle flame—is known as diffusion flame. Scientific research on such flames has been confined essentially to studies of the factors that affect the shape and length of the flame. When wood or coal burn, their hydrocarbons



TURBULENT FLAME is similarly photographed by its own light (*top*) and by the schlieren method (*bottom*). The broad flame reflects turbulent combustion wave.

break down to incandescent carbon, which emits intense radiation. Such flames find considerable use as sources of radiant heat in industry.

Not the least interesting aspect of the study of flames is their colors. In the spectral analysis of their light radiation the physical chemist has found a tool to identify the presence of atoms and radicals in the flame and to develop a picture of the kinetics of the chemical processes that occur at high temperatures. Hydrocarbon flames not rich in fuel have a blue color, whose source is the C-H radical; hydrocarbon flames rich in fuel show a green light emission known as the Swan bands, whose source is the C-C radical. OH and other radicals give no visible light; they must be photographed in the ultraviolet or infrared.

After thousands of years we are at last learning some of the inner mysteries of fire, one of man's earliest tools, still his most abundant source of energy, and lately reaching its most advanced expression in jets, flame throwers and atomic fireballs.

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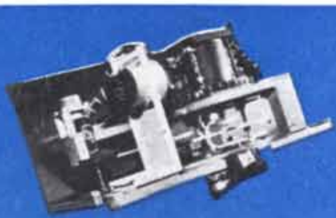

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REFRACTORY MELTS at the focal point of a solar furnace (*see opposite page*). Under ideal sky conditions a theoretical maximum temperature of 8,500 degrees Fahrenheit, or 85 per cent of the temperature of the sun's surface, may be obtained in this furnace.

High Temperatures: MATERIALS

The containment of heat in new industrial processes and jet propulsion systems strains the melting points of metals and ceramics. A combination of them called cermets shows promise

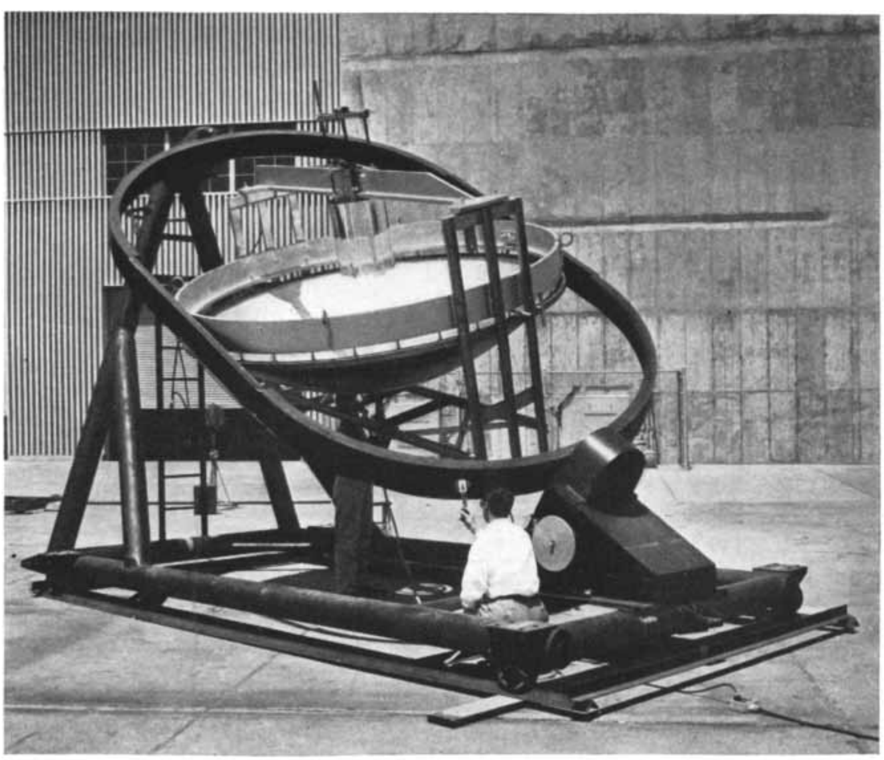
by Pol Duwez

It is no secret that the major bottleneck in man's use of energy—indeed, in his whole heat technology—has been the problem of materials. The great modern steel industry did not become possible until, at the end of the 19th century, chemists developed refractory bricks and crucibles capable of containing molten pure iron, whose melting point is 2,795 degrees Fahrenheit. In the field of power the bottleneck is especially conspicuous. With the exception of water power, every major source of energy available to man involves handling a fluid at high temperature: this is true of the steam engine, the gasoline engine, the gas turbine, the nuclear reactor. Ever since the French engineer Sadi Carnot formulated his famous principle concerning heat engines in 1824, we have known that the efficiency of the transformation of heat energy into work rises enormously as we increase the temperature difference between the hot and cold sides of the cycle. But there is a limit to how high we can go on the hot side. That limit is dictated by the heat-resistance of the solid vessels that must contain the motive fluid—gas or liquid. If we only had more resistant materials, we could design more efficient and more reliable engines than any in use today.

The failures of materials at high temperatures are matters of common observation. Steam boiler explosions, car engine valve breaks, jet airplane disintegrations—these disagreeable examples of the breakdown of materials under heat are familiar enough. As we go to higher speeds and temperatures, the possibility of catastrophic consequences increases. In the airplane jet engine, whose turbine may rotate at more than 15,000 r.p.m. and be subjected to temperatures of well over 1,200 degrees, we are so close to the danger point that the critical parts of the engine have to be inspected very frequently.

Let us consider what requirements a material must meet if it is to be used at high temperatures. We may note in passing that the meaning of "high temperature" varies: for a steam-turbine designer it may be 1,200 degrees F.; for a gas-turbine designer, 2,000 degrees or higher; for a metallurgist concerned with an open-hearth or an electric furnace, 3,600 degrees; for a rocket designer, as high as 5,500 degrees.

First of all, the material must have



SOLAR FURNACE at Convair laboratory in San Diego, Calif., has a 120-inch mirror. The temperature is controlled by advancing or retracting a cylinder around the focal point.

a high melting point. This immediately imposes a drastic limit on the possibilities. Of the 92 natural elements, not more than 20 have melting points above 3,000 degrees. Since the melting temperature is an intrinsic property of a substance, we cannot alter it by mechanical working or any other physical treatment of the element. We can, however, create a considerable number of chemical compounds, especially oxides and carbides, that have high melting points.

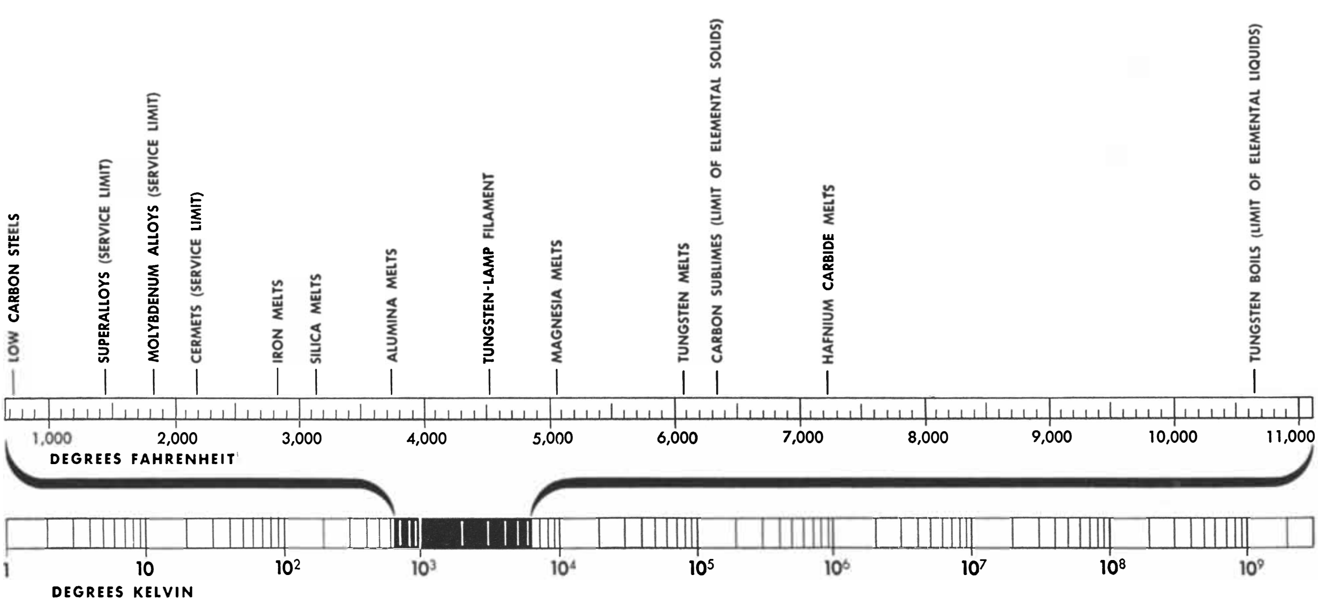
Secondly, the material must retain useful strength at high temperature. In some uses—for example, the blades of an aircraft gas turbine—the stress on the material as well as the temperature is so high that strength is the all-important factor. Thirdly, the material must be chemically inert at high temperature so that it will not react with the fluid it contains. Hot gases from a burning fuel tend to be highly corrosive, because they usually contain an excess of oxygen, which will readily form oxides with most metals at high temperature.

All materials can be divided into two general classes: metallic and nonmetallic. We shall look at the metallic materials first. For use at high temperature we must immediately rule out aluminum, magnesium, zinc and lead because of their low melting points. Iron, which has been and still is the gift of God to metallurgists on this planet, fortunately has a relatively high melting point. Around it in the periodic table is a group of metals melting in the same range: namely, nickel, manganese, chromium and cobalt. Small amounts of these elements are alloyed with iron to form steels with good physical properties at high temperature. A strong incentive to the development of such steels arose about half a century ago when the steam turbine became a serious competitor to the old piston steam engine. To make the turbine as efficient as the piston engine, both the temperature and the pressure of the steam had to be increased. In addition the metal had to be strengthened, because the blades of the turbine were subjected to much higher stresses than those previously encountered. These new engineering problems forced the metallurgist to create new alloys and to study new aspects of their behavior under stress at high temperature. For instance, under these conditions all alloys have a tendency to stretch slowly as time goes on—a phenomenon known as "creep." During the last 30 years a tremendous amount of research and testing has been done on creep, but it is not yet fully understood.

Together with creep, the problem of corrosion became a serious one in the early days of the steam turbine. This problem was alleviated by the welcome discovery of stainless steel. The first typical stainless steel consisted essentially of 73 per cent iron, 19 per cent chromium and 8 per cent nickel. The new type of alloy ushered in one of the liveliest periods in metallurgical history. There was no rest for the research metallurgist: every time he developed a better alloy, the mechanical engineer promptly raised the steam temperature and demanded a still more refractory one. In the meantime designers saw, as the working temperatures rose, that sooner or later it would be possible to use the combustion gases directly in the turbine instead of transferring the heat to an intermediate fluid such as steam.

This new challenge greatly accelerated the research for new alloys. The really outstanding improvement in gas turbine alloys came during World War II, after it was demonstrated that the jet engine was the answer to high-speed flight. In less than five years the operating temperature of the gas turbine was raised from below 1,200 to more than 1,500 degrees F. So-called "superalloys" were developed for the high-temperature jet engine (they have since found applications in many other fields). These alloys involve small additions of molybdenum, tungsten and columbium to the basic metals, such as iron, cobalt, nickel and chromium. Since the end of the war further progress in raising the gas turbine operating temperature has been relatively slow. It seems that 1,800 degrees is about the limit of the operating temperature that can be satisfactorily withstood by alloys of iron, nickel, chromium and cobalt.

The only metals of much higher melting point that are available in relatively large quantity are molybdenum, tungsten, tantalum and columbium. Molybdenum is generally recognized as having the greatest potential. It is relatively abundant in nature and may be produced at a reasonable cost. Un-



TEMPERATURE SETS LIMITS on choice of materials for containment of heat. Metals and cermets are shown at the present service limits of these materials. Cooling techniques make it possible to contain much higher temperatures within limits shown.

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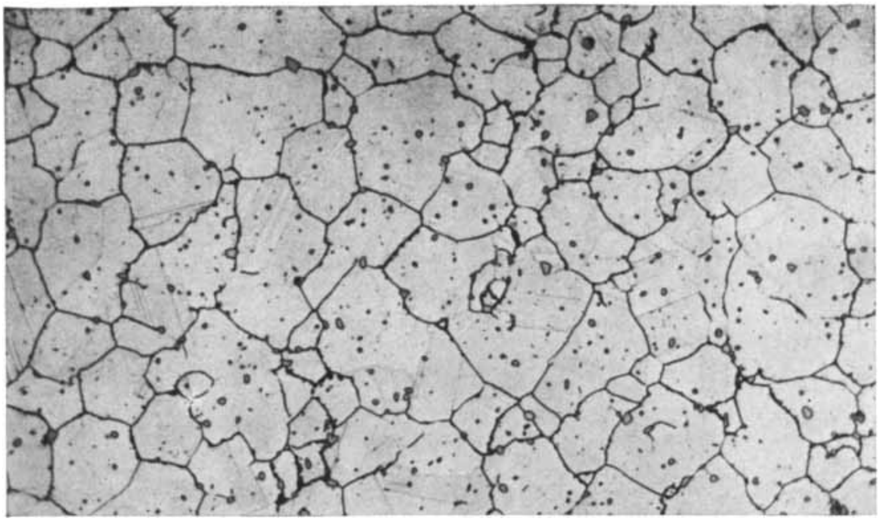
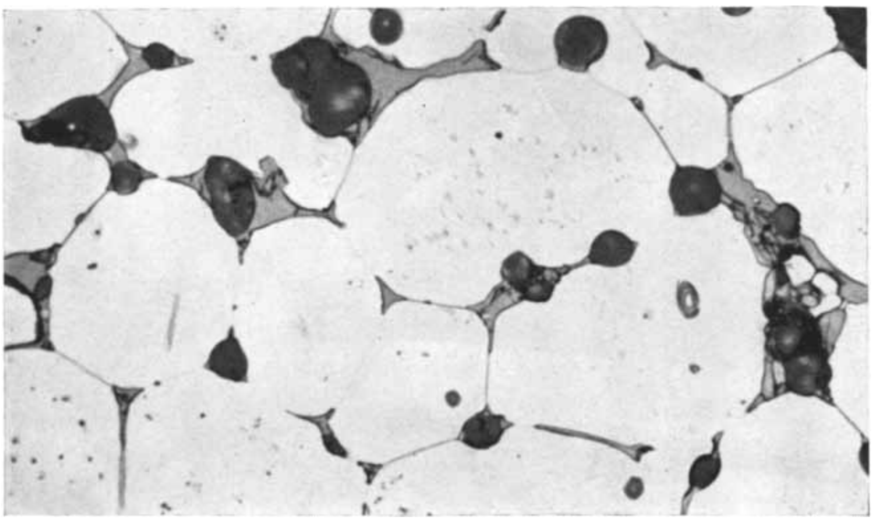
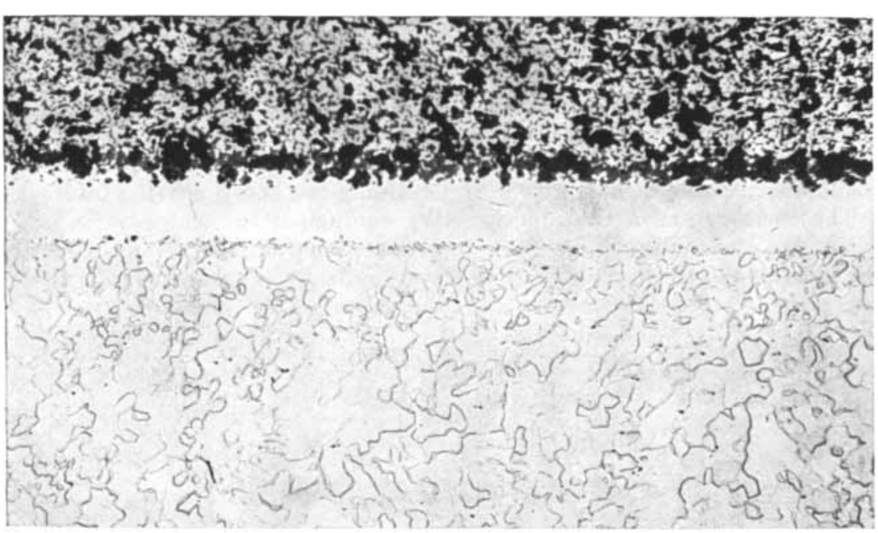


SUPERALLOY of chromium, nickel and cobalt, etched to bring out grain structure, is magnified 250 times. These photographs were made at General Electric Research Laboratories.



CERMET combines a metal (chromium) and a refractory (thoria) to meet the demand for high strength at high temperatures. The thoria is the dark material among the metal grains.



CERAMIC COATING on molybdenum is designed to protect this metal from corrosion at high temperatures. The coating, which consists of glass and chromium powder, is at the top.

fortunately, nature has been very unkind to the metallurgist in making molybdenum (and other metals of very high melting points) exceedingly sensitive to oxidation at high temperature. Since in most of our engines a fuel is burned with an excess of air, a strongly oxidizing atmosphere always prevails. As in many other chemical processes, the rate of reaction of a metal with oxygen increases very rapidly with temperature. In the case of molybdenum the oxide formed on the surface of the metal becomes volatile above a certain temperature, and from there on the rate of oxidation rises catastrophically.

One answer to the problem would be to cover the metals with a refractory coating that is inert to oxygen. Much effort is being devoted to the study of possible coatings. If the problem can be solved, molybdenum and its alloys will be used on a large scale. If not, 1,800 degrees may be the highest we can go with the metals.

Something should be said here about titanium, the "wonder" metal which a few years ago was highly publicized as an ideal solution to the problem of high temperatures. The metal can now be produced commercially in the pure, ductile form. Its relative lightness and strength make it very attractive for many engineering applications. Its resistance to corrosion at room temperature is comparable with, and in some cases better than, that of stainless steel. It turned out, however, that at high temperatures titanium is rapidly corroded by both oxygen and nitrogen, and its strength decreases very markedly. For all practical purposes it seems that titanium alloys will not be of great value above 1,000 or 1,200 degrees F. In spite of these limitations titanium is still one of the most important metallurgical advances of the century. In aeronautics it looks like an answer to the "heat barrier" of supersonic flight—a barrier which demands a substitute for aluminum. Steel seemed the only alternative until titanium came into the picture. In the temperature range from 400 to perhaps 1,200 degrees the advantages of titanium appear to be appreciable. Future improvements in our knowledge of titanium alloys and of their heat treatment will probably establish titanium as the best structural material for supersonic aircraft.

At the present time ceramics are getting as much attention as metals in high-temperature research. Ceramics of course are in the nonmetallic class—which means that they are metals in

combination with other elements (*e.g.*, oxygen, carbon, boron) that give them properties entirely different from the metallic. The main difference is that metals are ductile while ceramics are brittle. What attracts high-temperature engineers to ceramics is that these materials generally have high melting points—often above 3,000 degrees F.

The starting point in the fabrication of ceramic articles is usually a powder. The powder, in the pure form or mixed with a binder, is pressed into a die and heated to a sufficiently high temperature to create a bond between the particles—an operation known as sintering. Such a fabrication technique imposes severe restrictions on the possible sizes and shapes. A more important limitation of ceramics is their brittleness and sensitivity to sudden heating or cooling.

During the last 10 years, however, promising new types of ceramics have been developed: oxides, carbides, nitrides, borides and silicides. Some of these materials, such as titanium carbides and zirconium borides, have reached the testing stage in actual engines. Ceramic oxides entirely avoid the problem of oxidation, which is so troublesome in the metals. But they are most brittle and sensitive to thermal shock. On the other hand, ceramic carbides, nitrides and borides have relative-

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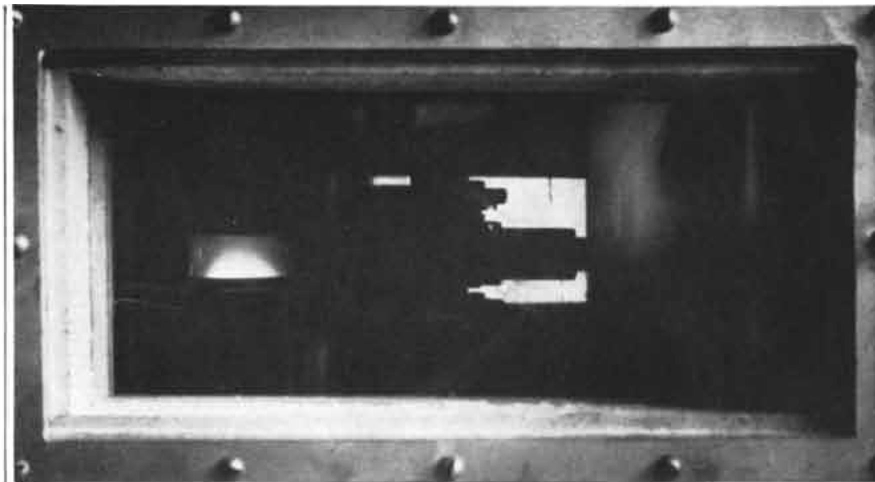

TURBINE BUCKET glows at 1,100 degrees F. in a test chamber at the General Electric Research Laboratories. Stresses encountered in a gas turbine are simulated in this chamber.

ly good mechanical properties but are vulnerable to oxidation. And so we are confronted again with the problem of finding a compromise between good mechanical properties and chemical inertness in an oxidizing atmosphere.

Such a compromise is represented by the so-called cermets—combinations of ceramics and metals. They are made of a mixture of ceramic and metal powders. After pressing and sintering, the hybrid material takes the form of a metallic network surrounding fine particles of oxides, carbides or other compounds.

A typical example is the mixture of alumina (aluminum oxide) and chromium metal. Alumina is extremely stable in oxygen at high temperature but brittle. Chromium is one of the most oxidation-resistant metals. The hope is that chromium will impart to the complex some resistance to both mechanical and thermal shock, which is lacking in pure alumina. Although some success has been attained along these lines, much remains to be done. In the field of cermets there is a need for more fundamental studies of the nature of the bond between a metal and compounds such as oxides, carbides and borides.

Whether or not nonmetallic materials or cermets will replace metals and alloys in high-temperature engines is difficult to predict. But it is quite certain that in any case the high-temperature materials of the future will be less ductile, and consequently less resistant to shock, than those we are using at present. This lack of ductility appears to be an inevitable price we must pay for higher temperatures. It will be no small problem to design satisfactory engines made of such materials.

We are not entirely at the mercy of the limitations of materials. The solid materials exposed to hot gases can be kept at moderate temperatures by cooling. In blast furnaces, for example, the copper nozzles that deliver pre-heated air into the hottest combustion zone of the furnace have long been water-cooled. In rockets the combustion chamber and nozzles are sometimes designed so that one of the liquid propellants (either the fuel or the oxidizer) is circulated in cooling passages around the chamber. In the German V-2 this cooling system made it possible to use plain carbon steel in the construction of the combustion chamber.

Recently there have been experiments with a cooling scheme that passes the cooling fluid through the wall instead of around it. In this technique, known as "porous-wall cooling" or "sweat cooling," a liquid or a gas diffuses through the porous wall, maintaining a continuously regenerated protective film on the surface exposed to high temperature. The method has been found efficient, especially in cases in which the rate of heating of the surface is very high. We must, however, develop porous metals which will have the required physical properties and will be amenable to fabrication by practical techniques.

It is obvious that at best no material with a melting point above 10,000 degrees F. could possibly be synthesized. As we approach such extremely high temperatures, cooling will become more and more important. Cooling, however, introduces complications in the design and fabrication of engines. Consequently for a long time to come the major effort will be devoted to the improvement of materials. Possibilities in this direction are far from exhausted, and the field should be a challenging one for young metallurgical engineers.

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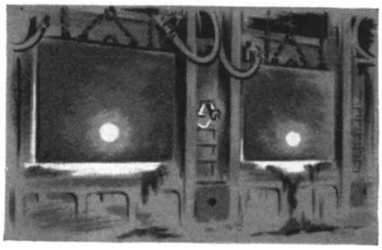
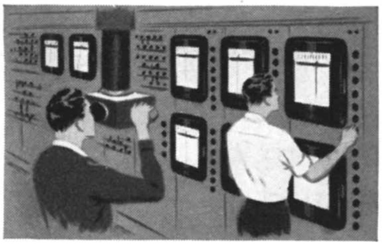


Rayotube® staring at furnace roof reports temp. to Speedomax Controller



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High Temperatures: CHEMISTRY

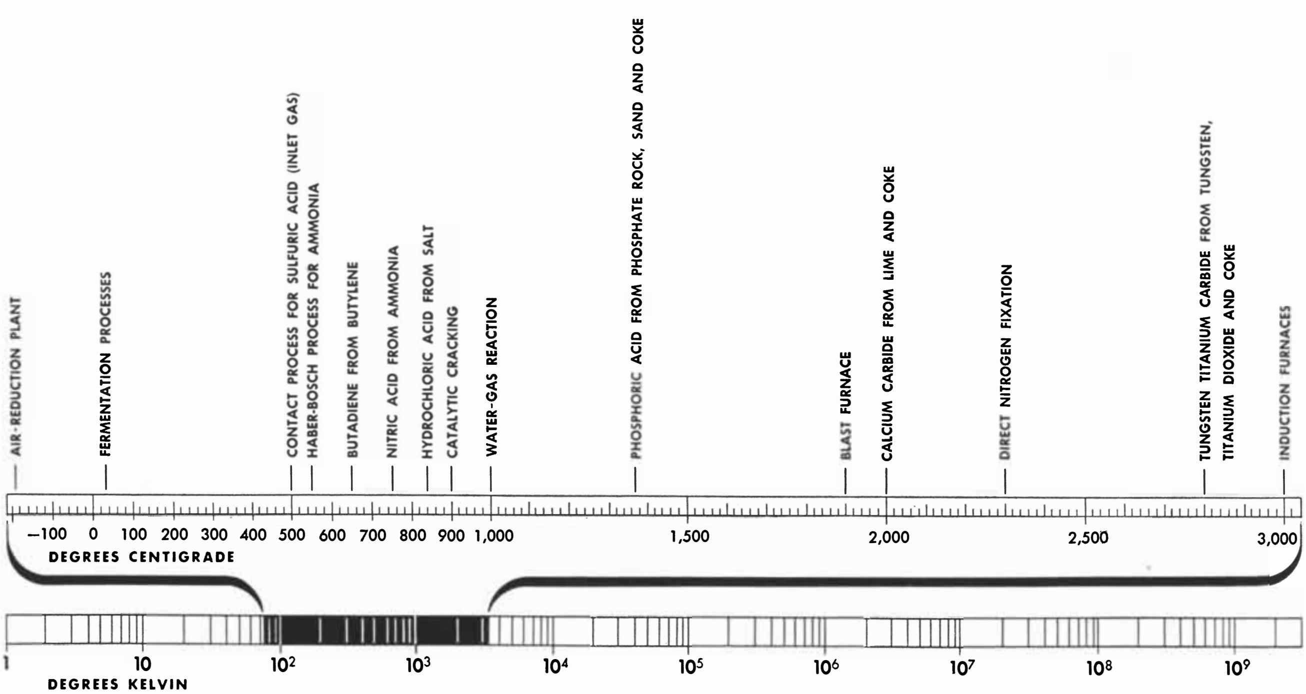
Between 1,000 and 3,000 degrees centigrade lies the present frontier of chemical technology. A chemical plant making nitric oxide from air heated to 2,100 degrees is already in operation

by Farrington Daniels

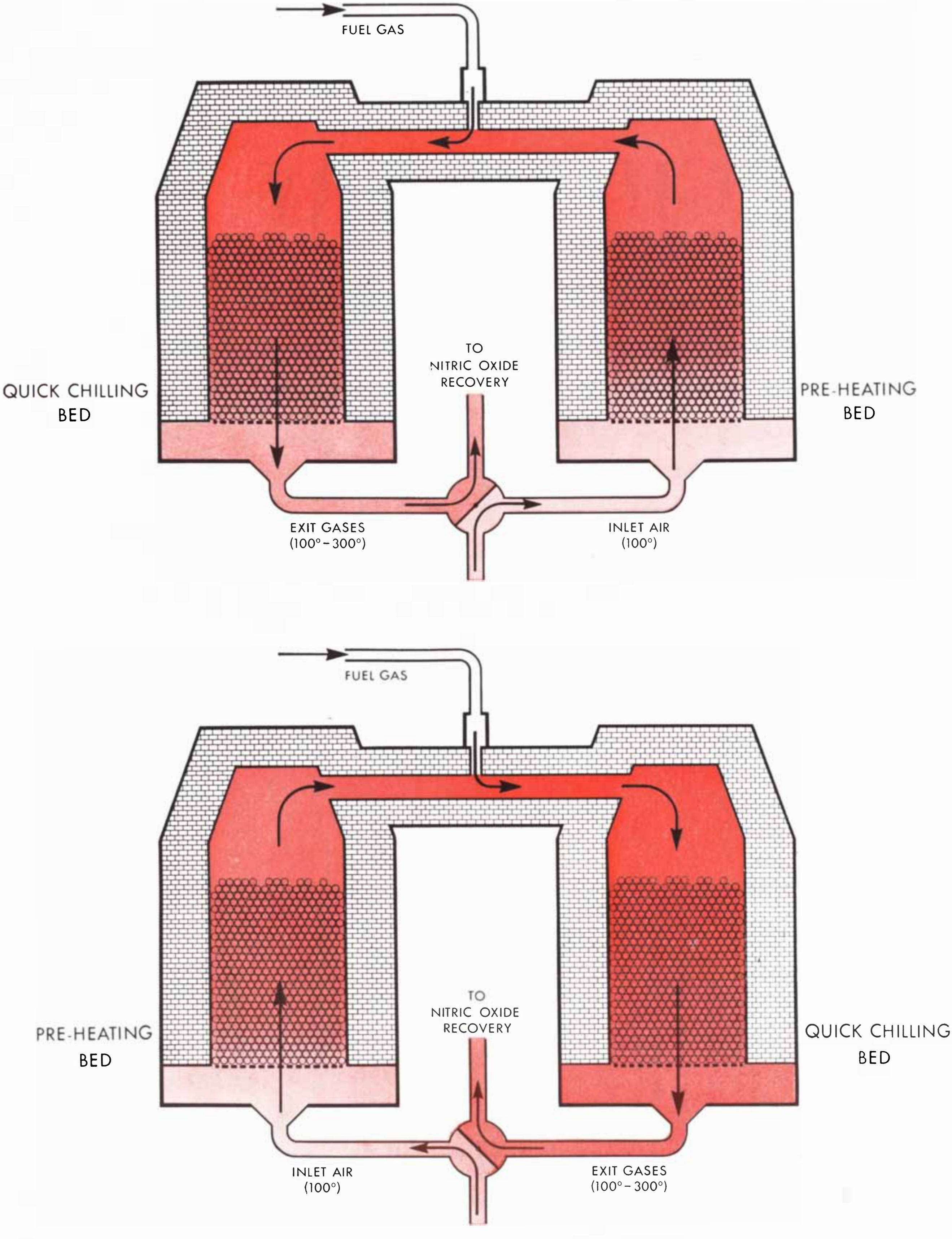
For a chemist the region of temperature from 1,000 to 3,000 degrees centigrade is a challenging frontier. As he pushes on in this territory, the familiar landmarks gradually disappear.

At 1,000 degrees centigrade he may use a standard electric furnace as his source of heat, contain his chemicals in a quartz flask and measure temperature with an ordinary thermocouple. At 1,500 degrees he may substitute silicon carbide or platinum wire for nichrome in his heater, and he needs special thermocouples for measurement. Beyond 2,000 degrees he emerges into a very different world. He may generate such temperatures in various ways—by flame, induction heater, electric arc, solar furnace, special resistance heaters—and he can resort to certain special instruments, such as an optical pyrometer for measuring temperatures and the spectrograph, X-rays or the mass spectrometer for analyzing the heated substances. But he is hard put to find refractories that will hold those substances, and the reactions among them may be unusual.

Above 2,000 degrees there is no liquid water (hence no aqueous reactions); there are few solids or organic molecules or complex molecules of any kind. The chemical landscape is composed chiefly of simple gaseous molecules of no more



CHEMICAL TECHNOLOGY utilizes temperatures from some 200 degrees below zero centigrade up to 3,000 degrees. Direct nitrogen fixation refers to the high-temperature process described in this article, which makes nitric oxide out of nitrogen and oxygen in air.



PEBBLE-BED FURNACE for the production of nitric acid from air is depicted in two conditions of operation. In the drawing at the top air heated to 100 degrees C. enters the bed of magnesia spheres at the right. The air is further heated by contact with the spheres and then raised to 2,100 degrees by combustion with fuel gas. The air is finally chilled by contact with the pebble bed at the left. When the pebble bed at the left gets too hot, the direction of flow is reversed as shown in the drawing at the bottom.

than two or three atoms. The common rules of valence break down; for example, aluminum in combining with oxygen or other atoms may have a valence of one, two or four as well as the usual three. At 2,000 degrees and above only the most stable gaseous molecules, such as nitrogen and carbon monoxide, can exist. At these temperatures carbon monoxide does not burn with oxygen. Above 4,000 or 5,000 degrees molecules and ordinary chemical reactions practically disappear. The scene is composed chiefly of atoms and ions.

Although the high-temperature chemist has simple molecules to deal with, his standards for predicting or measuring their behavior fail him. The same laws of thermodynamics and chemical kinetics apply at high temperatures as at low temperatures, but the factors in the equations are so changed in value that molecules seem to behave strangely. At ordinary temperature the tendency of a compound to enter into a chemical reaction can be estimated roughly by the heat evolved; entropy often can be disregarded. At high temperatures, on the other hand, entropy becomes more important. Besides this, the reaction rates are enormously speeded up. At 2,000 degrees reactions which go on slowly enough to measure at ordinary temperatures become practically instantaneous, and reactions which at room temperature are too slow to observe now take over the scene.

At high temperatures catalysts and surface reactions become far less important than at room temperature. At ordinary temperatures the contact of a gas molecule with a solid surface or the loose combination between the solute and solvent in a solution may provide a few thousand calories toward the activation energy and thus make a reaction go faster, as in the catalytic cracking of petroleum or the Haber synthesis of ammonia. At 2,000 degrees, however, the only reactions that go at measurable speed have such large activation energies that the few extra calories that catalysts or surface contacts may supply are insignificant. As a matter of fact, at these high temperatures the chemist no longer is primarily concerned with reaction rates but becomes mainly interested in the equilibrium conditions, that is to say, the chemical composition at equilibrium.

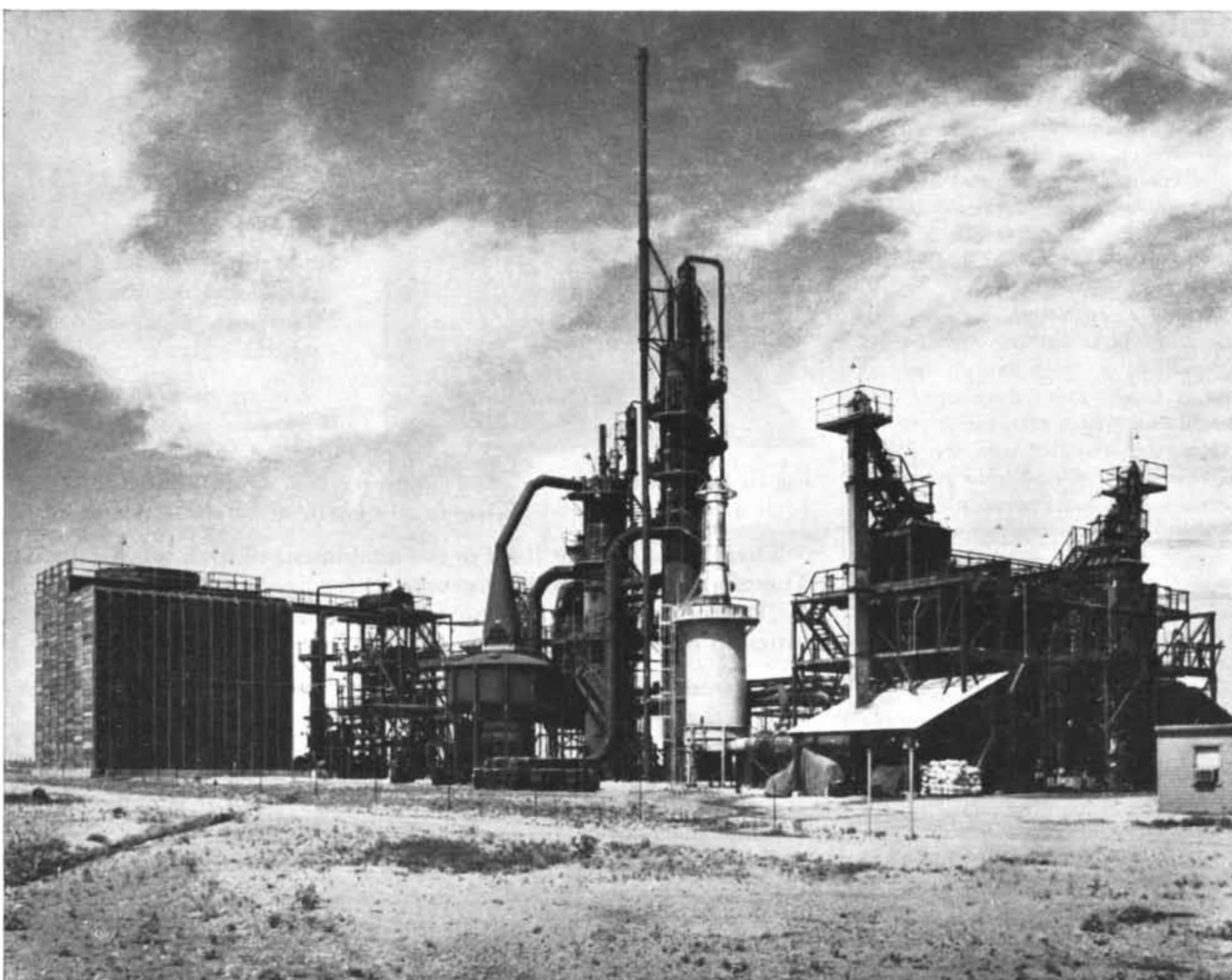
From the point of view of commercial chemistry the interest in high temperature lies in the fact that it may produce valuable chemicals which cannot easily be made at ordinary temperatures. A

good example is the fixation of nitrogen, making nitric oxide. The nitrogen of the air is the source of much of our fertilizer and nearly all our explosives, but its fixation is expensive. Most of the ammunition of the last world war was made by the Haber process, in which nitrogen from the air is combined with hydrogen to give ammonia. The process requires a catalyst and heating under very high pressure. In spite of the complicated equipment required, this process is a flourishing billion-dollar industry. Now it appears that it may be possible to manufacture nitric oxide more simply by a new process using high temperatures.

At 2,100 degrees C. nitrogen and oxygen in the air combine directly to form nitric oxide at a rapid rate, and a little more than 2 per cent of the mixture at equilibrium is nitric oxide. If the air mixture is allowed to cool slowly to room temperature, all the nitric oxide will revert to nitrogen and oxygen. But the compound can be "frozen," so to speak, by cooling it rapidly from 2,100 to below 1,500 degrees. After this fast "cooling" the nitric oxide will not break down when it arrives at room temperature. It is said to be thermodynamically unstable but kinetically stable; for all practical purposes it is stable. In fact, city air often contains appreciable amounts of nitric oxide, left as a residue from the quick cooling of the exhaust gases of automobile engines.

Some years ago F. G. Cottrell proposed the principle of fixing nitrogen by quick chilling. The idea was explored at the University of Wisconsin between 1939 and 1946 and has since been developed further by the Food Machinery and Chemical Corporation, which is now producing up to 40 tons of nitric acid per day in a high-temperature plant built for the U. S. Army.

The process is carried out in a simple furnace consisting of two chambers [*see drawings on page 110*]. The walls are lined with bricks of magnesia of high purity, which is refractory to high temperatures. Each chamber is filled with a "pebble bed" of small magnesia spheres. The pebble bed, which might well find wider use in chemistry, is essential to the process, for it allows a very rapid transfer of heat to or from a gas flowing through it. The gas, in this case air, first is blown through the pebble bed in the chamber on the right, where it is preheated by the pebbles. It then flows through a passage where it is mixed with fuel gas and passes to the pebble bed in the chamber on the left. This bed chills the hot gases, and they are reasonably cold when they leave by the exit pipe at the bottom. Gradually the exit temperature of the gases issuing from this bed rises; when it reaches 300 degrees the flow is reversed and the bed on the left now becomes the preheating bed while the one on the right acts as the chilling bed. This alternating process continues indefinitely. Eventu-



NITROGEN FIXATION PLANT operating at 2,100 degrees is located near Lawrence, Kan. It was designed and built and is operated for the Department of the Army by the Food Machinery and Chemical Corporation. It makes 40 tons of nitric acid per day.

Croesus' cavalry stampeding at the sight of Persian camels

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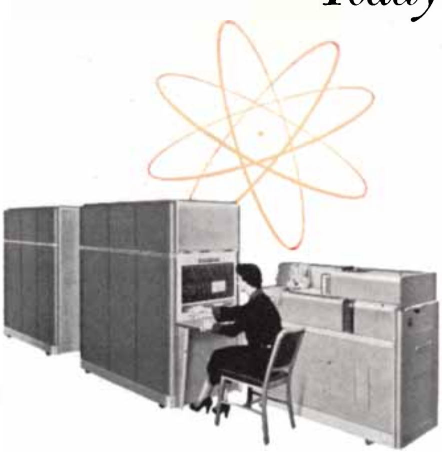

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ally the temperature of the hot gases at the top of the furnace stabilizes at 2,100 degrees C. or more, while the gases come out of the chilling bed at 300 degrees or so.

The unique feature of this furnace is the extremely rapid rate of chilling. In the early experiments there was a temperature difference of 1,800 degrees between the top and bottom of the chilling bed, and the bed was only 18 inches thick. Thus the temperature drop was 100 degrees per inch. Since the gas flowed through the 2,100-degree bed at a velocity equivalent to 360 inches per second, the calculated rate of chilling was 36,000 degrees per second!

The pebble-bed furnace accomplishes several important objectives in a very simple manner: (1) by preheating the air it achieves temperatures well above what could be attained solely by burning a fuel gas; (2) it cools the gases to thermal stability before appreciable dissociation of the nitric oxide can take place; (3) heat extracted in the chilling part of the cycle is stored and used to preheat the incoming gas when the flow is reversed, so that the cost of heating is reduced.

It has been demonstrated in the production plant that yields of 2 per cent and more of nitric oxide can be produced from air by this process. To concentrate this nitric oxide from the large volume of air in which it is diluted, the furnace gases are passed over beds of silica gel, on which the nitrogen dioxide is absorbed. The gas is then driven off by heating and reacted with water to give nitric acid.

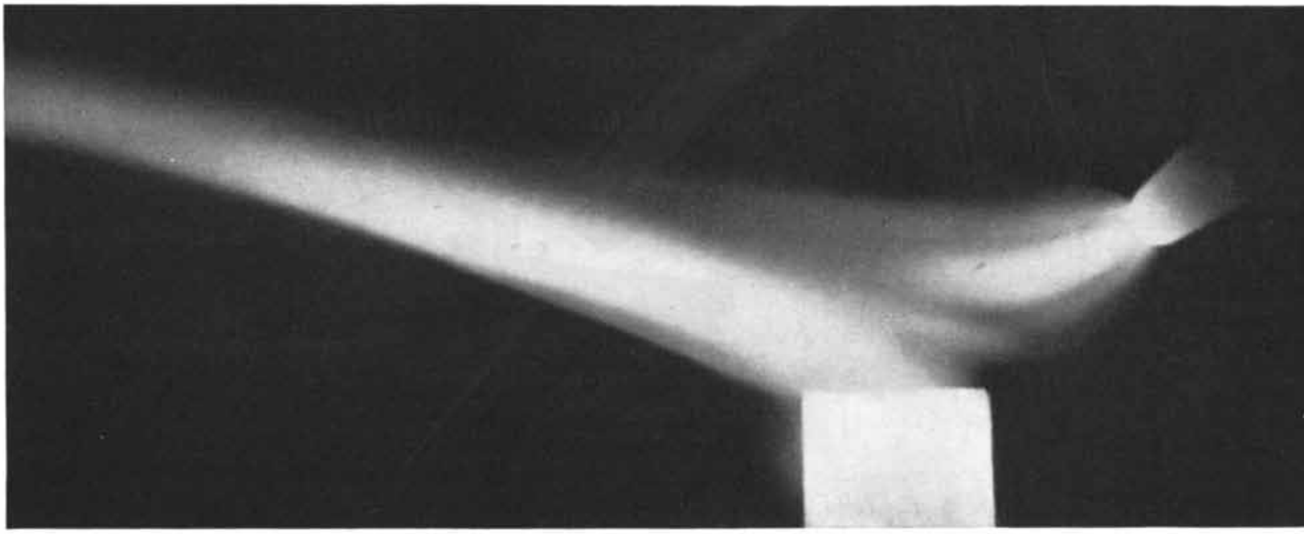
The raw materials for making nitric acid by this process are air and water; the cost of the fuel gas and air-blowing is not large, and the labor requirements are small. It is too early to know what the cost of making nitric acid will be, but it is already competitive with the Haber process in small units. Improvements and experience may well bring the price of nitric acid by the new process considerably lower.

High-temperature chemistry so far offers no other product so obvious or so cheap as nitric oxide, but there are interesting possibilities. One is ozone, also a valuable substance. It could be made by heating oxygen to a very high temperature and cooling it very rapidly. Ozone would have to be chilled with greater speed than nitric acid, way down to room temperature. Pebble-bed chilling would not be fast enough.

Another intriguing possibility is the direct synthesis of cyanogen (C_2N_2)

from nitrogen and carbon. It is also possible to get valuable products from complex gases by decomposing them thermally in a pebble bed at high temperature. For example, under the proper conditions we might get some butadiene directly from butane. Acetylene from natural gas is another possibility. And as Bernard Lewis points out in his article [*page 84*], quick chilling makes possible the recovery of valuable intermediate products in gas combustion flames. When organic compounds are heated to high temperatures, they often decompose into free radicals (*e.g.*, the methyl radical CH_3) which are extremely reactive—so active, in fact, that they have not yet been isolated. They can build up to larger molecules. At high temperatures these radicals often start chain reactions which can give rise to many products. Ways will surely be found to utilize these radicals to form desired chemicals.

Complicated organic compounds do not properly belong in a discussion of high-temperature chemistry, because in the neighborhood of 2,000 degrees they do not exist. The inorganic compounds offer more possibilities. Some reactions involving chlorine and fluorine are of possible interest, but the problem of making vessels that will not react with these chemicals becomes acute [*see Pol*



CHEMISTRY AT VERY HIGH TEMPERATURES

The flaming electric discharge depicted above is called a high-intensity arc. Its maximum temperature has never been measured precisely, but may be as high as 10,000 degrees C.; it is hot enough, at any rate, to boil the most refractory solids. This fierce heat, which up to now has not been put to practical use, may soon open new fields of technology—very-high-temperature chemistry and metallurgy.

High-intensity arcs have been known and used for many years, but only as sources of bright light. (The arc in the photograph is a light source manufactured by the National Carbon Company.) High-intensity arcs owe their intense heat to the type of current flow between their electrodes. In an ordinary low-intensity arc, current at the positive pole originates in a glowing crater, which usually covers only a part of the electrode tip. The size of the crater depends on the current strength; it grows larger if the current is increased and smaller if the current is decreased. Thus higher current does not mean a more intense arc but simply a thicker one.

When the crater covers the whole tip, however, the situation changes. A further current increase can take place only within the space that is already conducting electricity. In other words, a rise in current means an increase in its intensity and hence in the temperature of the electrodes. Eventually, if the current is increased enough, the boiling point of the electrode material (usually carbon) is reached. Now there is a dramatic shift to high-intensity conditions. The temperature jumps abruptly to twice the boiling point of carbon or higher and a brilliant white flame shoots out of the anode. (This "tail flame," as it is called, can be seen in the photograph as the white streak running upward to the left.)

The mechanism behind the sudden transition is quite complex, but can be roughly explained as follows. Ordinarily the space in an arc just outside the anode contains a mixture of electrons, which are traveling toward the anode, and positive gas ions, which are diffusing away. These positive ions partly offset the negative "space charge" due to the electrons. When the anode material starts to boil, however, the resulting vapor sweeps the positive ions away much more quickly. Thus the space outside the anode becomes more highly negative, and each new electron that arrives must do more work to get to the anode surface through the negative space charge. In other words, a greater part of the total energy in the arc current is now dissipated very close to the anode. This in turn heats the anode still hotter, causing it to vaporize faster. The cumulative process quickly builds up to an equilibrium point at which the stream of anode vapor, or tail flame, shoots out fast enough to carry away the energy released by the current.

When the high-intensity arc is used as a chemical furnace, the material to be treated is crushed, mixed with carbon and incorporated into the anode. This material then vaporizes and emerges in the tail flame, where it may be made to react with other substances. The high-speed flame carries the reacting gases quickly away from the hot zone, so that they cool and condense rapidly. As Farrington Daniels explains in his article, *Duwez' article on refractories on page 98].*

Reactions between solids and gases may be important at these high temperatures. Sometimes the molecular units of the solid go into the gas phase without chemical dissociation; sometimes they even become more complex. For example, when sodium chloride is heated sufficiently, the gas in equilibrium with the liquid contains Na_2Cl_2 as well as

quick chilling is often essential in high-temperature work to prevent reversal of desired reactions.

A process which has already been tried out on a pilot-plant scale is the refining of beryllium ore. Here the tail flame is mixed with chlorine and the metal atoms from the vaporized ore react to form metallic chlorides. In addition to beryllium, the ore usually contains aluminum, iron and silicon, which can be recovered as by-products. Each gaseous metal chloride condenses at a different temperature. As the cooling tail flame is piped through a number of chambers at successively lower temperatures, a single metal salt is collected in each. The pure metals are then extracted by electrolysis.

The technological possibilities of the high-intensity arc were first recognized in 1938 by Charles Sheer, a nuclear physicist whose hobby was spectroscopy. It was while experimenting in his basement with an arc as a spectroscopic light source that he hit on the idea of using it as a chemical furnace. The big problem was to find a way of getting the reacting materials into the very narrow high temperature zone near the anode. Sheer decided it had to be done by putting the material into the anode itself. He and a former classmate, chemist Samuel Korman, found that a good electrode could be made by mixing a low grade of soft coal with the crushed chemicals and then baking the mixture. The coal forms a continuous lattice of conducting carbon running through the whole electrode.

Sheer, Korman and other associates have now formed the Light Metals Refining Corporation to exploit the high-intensity arc. One of the first projects will be a beryllium extraction plant. At present pure beryllium costs about $100 a pound. Sheer estimates he can make it for $25. He also believes that many other metals and certain nonmetallic materials can be economically refined by very-high-temperature chemistry.

simple NaCl. There are also unusual combinations not known at room temperatures, such as Na_3Cl and $NaCl_2$. Again, when graphite is heated the gas phase shows molecules of C_2, C_3 and C_5 as well as C atoms. Some of the refractory oxides dissociate into the metal and gaseous oxygen, while others vaporize to give an oxide in the vapor phase as well.

If magnesium oxide could be heated sufficiently high in a reducing atmosphere to give magnesium, and if this could be recovered without reverting to the oxide, a way might be opened for obtaining magnesium metal from magnesia.

All sorts of unexpected reactions occur when steam or very hot gases pass over solids. Hydroxides in gaseous form frequently become important in the picture. The high-temperature chemist finds many opportunities to use his knowledge in solving corrosion problems in ordinary combustion engines, turbines, jet engines and rockets. The desire for increased efficiency and better fuels has stimulated many new studies of high-temperature reactions.

Nature has provided us with high-temperature laboratories in the form of volcanoes. The gases that come out are water vapor, carbon dioxide, methane, hydrogen sulfide, hydrochloric acid, hydrofluoric acid, ammonia and boron compounds. The origin of some of these compounds is not fully understood, but in general they follow the predictions of high-temperature chemistry. The geochemical origins of some of our rocks also involve high-temperature chemical reactions in the liquid phase followed by extremely slow cooling.

Much new information on high-temperature chemistry will be reported at a symposium on this subject to be held in New York by the American Chemical Society this month (September). It will be under the direction of Leo Brewer of the University of California. The latest values of the heats of dissociation of several diatomic gaseous molecules will be given, including the energy required to break apart S_2, SO, F_2 and N_2 and related molecules. These data are important in making predictions of chemical equilibria and rates of reaction. There will be reports on progress in the understanding of the heat required to pull apart the atoms in graphite and in many gas-solid systems at high temperatures, including materials such as iron halides, titanium chlorides and the oxides and nitrides of zirconium, titanium, magnesium, uranium and many other elements.

High Temperatures: PROPULSION

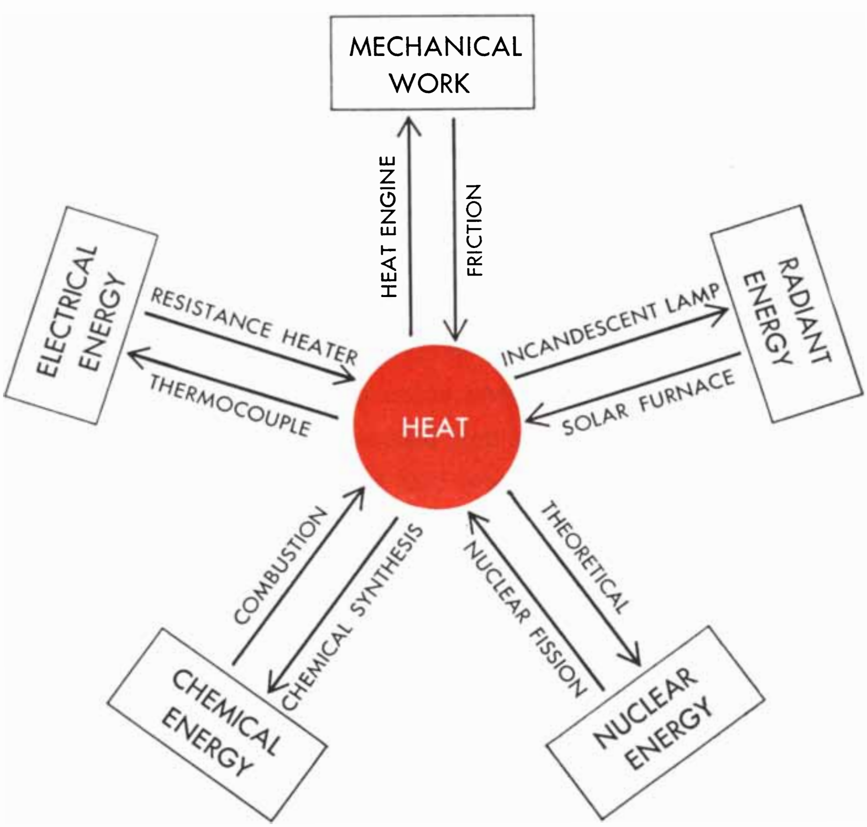
Efficiency increases with temperature in the engines that convert heat into other forms of energy. Jet engines are now approaching the limiting temperatures of flames and materials to contain them

by Martin Summerfield

Heat is a low-grade form of energy, according to physicists with the entropy principle in mind. The practical man, who does not ordinarily deal with entropy, will nonetheless agree with this point of view, because it is reflected in the relatively low price paid for heat and in its relatively limited range of uses compared with other forms of energy.

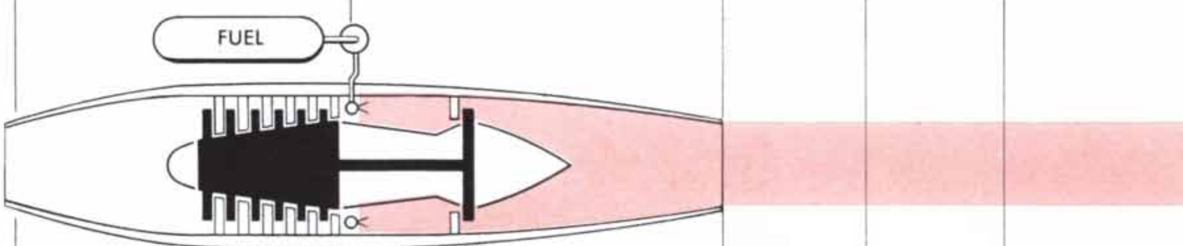
For example, except where water power makes electricity unusually cheap, it costs less to heat one's home with a coal or oil furnace than with electricity. One important reason for the higher price of electric energy is that when heat is converted to electricity, about two thirds of the heat from the fuel is wasted—carried away in the cooling water. On the other hand, electric energy can be transformed into heat without any waste whatsoever. This is true also of mechanical energy, probably the most important form of energy in our industrial civilization. Furthermore, mechanical energy is versatile: it can be applied with only minor losses to drive machinery, to generate electric power, to propel vehicles. There is no thermodynamic limitation on the efficiency of the utilization of mechanical energy.

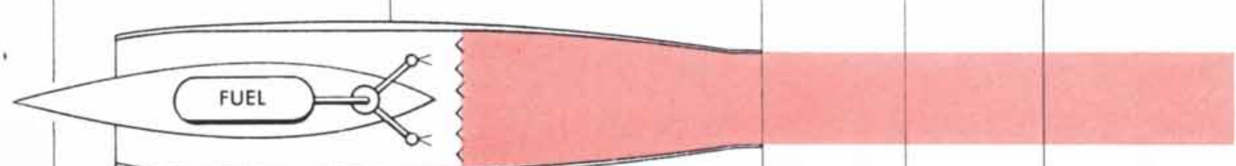
What makes heat a low-grade form of energy is the Second Law of Thermodynamics or the entropy principle, which imposes an inevitable limit on the efficiency with which heat can be converted to other forms of energy. Every heat engine makes use of a hot working fluid—steam, heated air or combustion gases—in converting heat to mechanical work. The converted energy is abstracted from the hot working fluid, but the limiting factor is that at the lowest temperature of the cycle there is heat remaining in the fluid which is not converted to work but is dissipated: either discarded with the ejected working fluid or carried away by the condenser cooling water.



CONVERTIBILITY OF HEAT into other forms of energy is demonstrated in this chart. As the arrows show, the transformation of energy in each case goes in either direction.

The loss of heat may be minimized by designing an engine that minimizes the exhaust or condenser temperature. In an automobile engine this means making the expansion stroke, or compression ratio, as large as possible. However, even at compression ratios of more than seven





INTAKE VELOCITY	TYPE OF ENGINE	COMBUSTOR TEMPERATURE	JET TEMPERATURE	JET VELOCITY	PROPELLANT OR FUEL CONSUMPTION
	ROCKET	3,000	2,000	7,500	15
800	TURBOJET	900 600	400	2,000	1
2,000	RAMJET	2,000	1,200	4,000	3

AEROTHERMODYNAMICS of three jet engines are compared in this chart. The numbers in the columns labeled intake velocity and jet velocity refer to feet per second. Those in the columns labeled combustor temperature and jet temperature refer to degrees centigrade. Those in the column labeled propellant or fuel consumption refer to pounds per hour per pounds thrust. The two figures given for the combustor temperature of the turbojet refer to the temperature in front of the turbine rotor (*left*) and behind it (*right*).

LAMINAR FLOW produces a flame with a tall, thin zone of primary combustion. This zone is the bright area in the center of the flame. The dark area within the bright one is the unburned fuel mixture; the blue area outside it, the zone of secondary combustion.

TURBULENT FLOW produces a flame with a short, thick zone of primary combustion. This permits more compact combustion chambers because the fuel burns in a shorter distance. Photographs are by S. Hight and R. W. Mascolo of Princeton University.

to one the exhaust gas still comes out red hot (about 800 degrees centigrade) and carries away nearly half the heat of combustion. The attempt to improve efficiency by going to still higher compression ratios runs into the difficulties of engine knock. A Diesel engine gets around the knock barrier by substituting direct injection of fuel for carburetion, and so compression ratios of 15 and more become possible, with a reduction of about 30 per cent in fuel consumption. But then mechanical difficulties, arising from the high pressures, start to crop up; the engine becomes heavy and bulky. In any case, the best thermodynamic efficiency we can attain remains below 50 per cent. It matters not what kind of engine we devise. In a jet engine we lose heat in the hot gases of the jet; in a steam turbine, in the condenser cooling water. The operation of the Second Law cannot be escaped.

Since it was first formulated by Sadi Carnot in 1824, the Second Law has been reinterpreted and generalized in various ways. The simplest statement of it is the one enunciated 100 years ago by the physicist Rudolf Clausius: It is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature. At first glance this seems obvious, almost trivial, and far removed from the preceding discussion of the unavoidable dissipation of heat in a heat engine. But is it so far removed? Suppose that an engine could be devised that would transform heat into work at 100 per cent efficiency, that is, without rejecting any of the input heat to the surroundings. If we could do that, we could couple this engine to a dynamo to transform the energy into high-temperature heat in an incandescent lamp. The net result would be the transfer of heat at a relatively low temperature input to a higher level without loss. The Second Law asserts that this is impossible. Why? In any type of heat engine, a certain fraction of heat *must* be conducted to the surroundings (Clausius' external agency) at a lower temperature. This amount depends on the lowest temperature in the process.

In the remainder of this article we shall focus our attention on a modern class of heat engine—the jet engine.

Jet propulsion is a direct process for the transformation of heat energy into propulsive work; it eliminates the intermediate steps such as a piston or shaft hooked up to an aircraft propeller or to a locomotive wheel. Three of the most

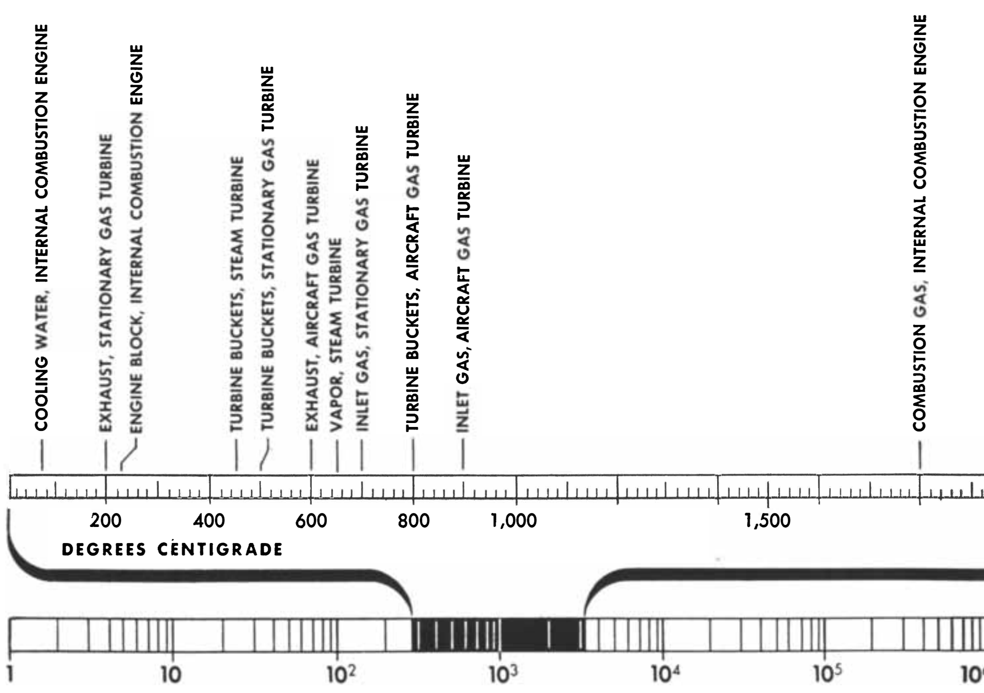
important present types of jet-propulsion engines are illustrated on page 121.

The simplest in principle is the rocket. A high-temperature gas is generated at high pressure in the combustion chamber and is then allowed to flow through the exhaust nozzle to create a high-velocity jet. The rocket is distinguished from other jet engines by the fact that it carries its own oxidizer and does not take in air. Air is a relatively poor oxidizer, since 79 per cent of its volume is made up of inert nitrogen and other gases that serve only to dilute the burning mixture, slow down the reaction and depress the flame temperature. There are available today a number of energetic oxidizers. Two of the most widely used in rocket engines are liquid oxygen and concentrated nitric acid. More ambitious engineers are developing rockets that employ liquid fluorine, and some really brave souls are thinking of liquid ozone. The rocket industry can boast with justification that it has broadened enormously the scope of combustion engineering. The old-time engineer instinctively thought of a carbonaceous fuel burning with air when he thought of combustion. Today engineering textbooks in which combustion is treated in so limited a fashion are rapidly becoming obsolete.

Two energy-conversion processes are at work in the rocket engine: (1) in the combustion chamber chemical energy is converted into heat; (2) in the exhaust nozzle heat is converted into the kinetic energy of the jet. Conversion of chemical energy to heat is not limited by the Second Law of Thermodynamics, and so the combustor may attain an efficiency of over 95 per cent. But rarely can more than 50 per cent of the heat be converted to jet kinetic energy. The unconverted heat is thrown away with the hot jet—at a temperature of about 2,000 degrees C.! This wasted portion may be reduced by increasing the pressure in the combustor, but the engine designer has trouble enough already without borrowing more by raising the pressure unduly. Most practical rocket engines of the liquid propellant type operate with pressures of about 300 pounds per square inch.

The rocket delivers a jet of higher velocity (up to 11,000 feet per second with hydrogen and oxygen) than any other jet-propulsion engine. But its fuel economy is far poorer than that of the turbojet or the supersonic ramjet. The reason is that it must carry its own oxidizer, which is counted as part of the fuel. The turbojet delivers the lowest jet velocity (usually about 2,000 feet per second), but more than 98 per cent of the flow in the jet is air, which it gets free from the atmosphere. The fuel consumption of present-day turbojets is only about one pound per hour for each pound of thrust, whereas an aircraft rocket engine consumes about 15 pounds per hour per pound of thrust.

It is clear that the turbojet easily wins

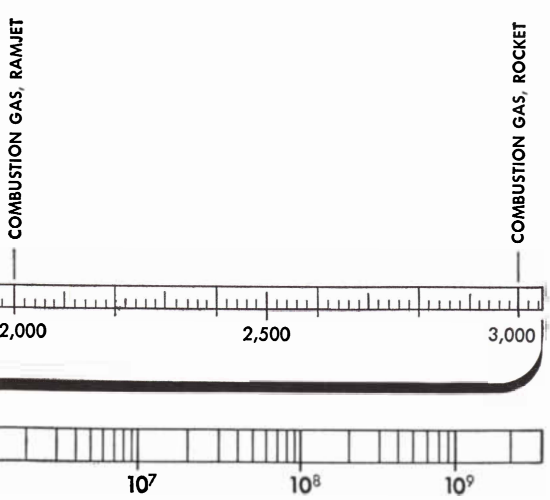


ENGINE TEMPERATURES suggest performance characteristics of various heat engines. In gas turbine, for example, it is temperature drop between inlet and exhaust that measures over the rocket when it comes to aircraft range, but it is a poor second in the speed contest. A turbojet pays for the free use of atmospheric air by having to take in the air at high speed; it develops thrust only as a consequence of the still higher speed with which this air is expelled in the jet. It has no favorable differential at all when its speed exceeds 2,000 feet per second. The turbojet with its present temperature limitations can never be used above Mach 2 and probably not above 1.5.

In the turbojet engine the incoming blast of air is first brought to a near standstill in the entrance duct [*see illustration*]. The momentum of the air is converted to pressure and its kinetic energy to heat. Then a compressor raises the pressure of the air still more, and its temperature, too. Next the air is heated in the combustor. The heated air then rushes through the turbine rotor, expanding and cooling as it flows. Its heat creates a high-speed stream which gives up its kinetic energy to drive the turbine rotor. Finally the hot gas exhausts through the nozzle in the tail pipe, converting heat into jet kinetic energy. A complex process indeed, but it works well.

The ramjet is much simpler mechanically than the turbojet, but far more difficult to develop from a practical standpoint. It has not yet emerged from the field-test stage.

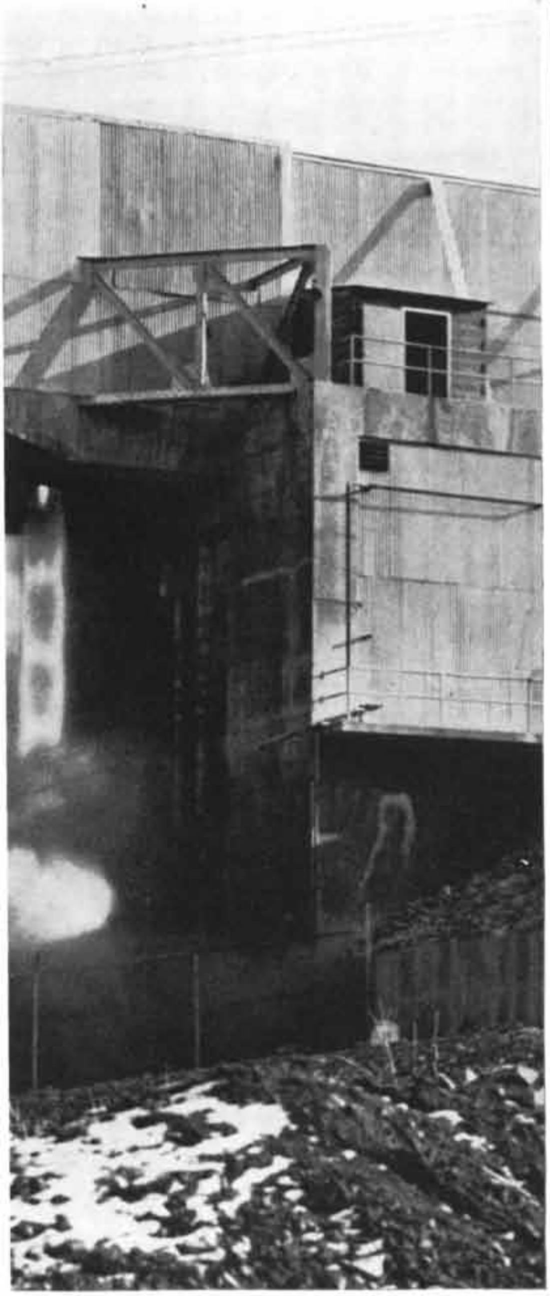
The ramjet depends on this idea: if



heat available to do work. This in turn is limited by temperature of turbine buckets.

LARGE ROCKET MOTOR built by Reaction Motors, Inc., is fired on a test stand

the flight speed is high enough, a compressor becomes unnecessary, because the entering air blast itself develops the desired pressure simply by ramming to a near standstill inside the diffusor. Take out the compressor, as well as the turbine that drives it, and all that remains is a duct with no moving parts. The three principal components of the ramjet are the inlet diffusor, the combustor and the exhaust nozzle. Without a turbine there is no danger of overheating turbine blades, and so the combustion temperature can be made as high as the fuel will allow—about 2,000 degrees C. for standard petroleum fuel. A hotter



at the Naval Air Rocket Test Station near Dover, N. J. The jet is at right center.

gas can raise the jet velocity 2,000 feet per second above that of the turbojet, and the speed limitation of Mach 2 can be swept away. It is easily possible for the ramjet to fly at Mach 3 or more.

Many other forms of jet engines are possible. For instance:

The turboprop is a gas turbine connected to a propeller. Part of the thrust is provided by the propeller; part is provided by the jet issuing from the gas-turbine tail pipe.

The pulsejet is a ramjet which, through the agency of flapper valves, takes in air in a series of gulps instead of in a steady flow. The gulps are synchronized with explosions of the fuel in the combustion chamber. The pulsejet was used on the German V-1 flying bomb and may have a practical application as a tip drive for helicopter rotors.

The turbojet-ramjet combination is a turbojet which raises the exhaust velocity by means of an afterburner that heats the air to 1,500 degrees C. or more. Afterburner equipment is installed today in many types of military jet aircraft. It is particularly important for supersonic flight.

The ramjet-rocket combination is a rocket surrounded by a ramjet-type duct. The heat in the jet, ordinarily wasted in a simple rocket, is utilized to augment thrust.

All these jet engines and others not mentioned have two processes in common: (1) the conversion of heat energy into jet kinetic energy by expansion in a suitably shaped exhaust nozzle; (2) the heating of gas to a high temperature in the combustion chamber by chemical reaction in a high-speed gas stream. In recent years these fields of study have been named "aerothermodynamics" and "aerochemistry," respectively.

In a jet-engine exhaust nozzle the hot gas enters at a velocity of only a few hundred feet per second and emerges at a velocity of several thousand feet per second. The methods of aerodynamics should suffice to tell how much pressure is needed in the chamber ahead of the nozzle to expel the gas at the desired high speed. But simple aerodynamics is not enough. The kinetic energy acquired by the gas results from the conversion of some of its heat energy, and this conversion is governed by the laws of thermodynamics. Consequently, to compute the velocity change and the associated pressure and temperature changes for the flow of a hot gas through a nozzle, it is necessary to deal simultaneously with the laws of thermodynamics and aerodynamics. In this way the science of aerothermodynamics has evolved.

The flow of gas through a nozzle is not the only aerothermodynamic problem. Flow through the ramjet diffusor, the flow through a supersonic wind tunnel, the flow in a high-speed gas-jet pump or ejector, indeed, almost any problem in high-speed flow requires the application of the principles of aerothermodynamics.

Jet-engine combustion chambers differ from most industrial combustion devices in the fact that it is of the greatest importance to burn the fuel in as compact a chamber as possible. The reason is obvious: in an aircraft we must mini-

HYDROGEN PLUS FLUORINE	4,500
CYANOGEN PLUS OXYGEN	4,700
HYDROGEN PLUS OXYGEN	3,200
GASOLINE PLUS OXYGEN	3,100
GASOLINE PLUS NITRIC ACID	2,750
NITROMETHANE	2,200
ETHYLENE OXIDE	1,100
.90 HYDROGEN PEROXIDE	750

ACETYLENE	2,250
HYDROGEN	2,100
CARBON MONOXIDE	2,100
METHANE	1,900
ALUMINUM (POWDERED)	3,500
BERYLLIUM (POWDERED)	4,500

FLAME TEMPERATURES of rocket propellants are given in degrees C. at pressure of 300 pounds per square inch (*top*). Other flames are shown at 15 p.s.i. (*bottom*).

mize the size and weight of the chamber. This means that we have the problem of holding an intense flame in a high-velocity stream and completing the combustion reaction in a very short time. Here again is an interplay of two processes: the flow through the combustion chamber is an aerodynamic process, but the temperature and density of the gas stream as it flows through the chamber are controlled by chemical kinetics. To answer the simple question, What is the gas velocity halfway between the inlet and the exit?, it is necessary to deal simultaneously with the laws of aerodynamics and of chemical kinetics. This gives rise to the field of aerochemistry.

Improvement in jet-propulsion engines will depend primarily on using higher temperatures and higher pressures. In the turbojet the highest feasible temperature at present is 900 degrees C., because even the best available turbine metals become dangerously weak at this bright-red temperature. The severity of the problem can be illustrated in this way: A typical chromium-molybdenum steel widely used in aircraft today loses 97 per cent of its strength at 800 degrees in a high-output turbojet. For turbine blades in high-temperature service it has been necessary to abandon steels and ferrous alloys completely.

Metallurgical research of the past

decade has brought forth a group of superalloys, for example, forging alloy S-816, which contains mainly cobalt, chromium and nickel. This alloy is used for the turbine blades of the modern J-47 jet engine. Other superalloys promise to extend allowable metal temperatures to 1,000 degrees C. in the next decade, but progress toward temperatures higher than that will require new approaches. The cermets offer the possibility of a big jump in temperature; blade temperatures of 1,500 degrees may become feasible when the technical problems of producing these materials with acceptable physical properties are solved [*see Pol Duwez' article on page 98*]. Another possibility is to cool the turbine blades, either with a circulating liquid or by air piped from the compressor. A liquid-cooled turbine wheel of stainless steel has been successfully operated in the research laboratory with gas temperatures above 1,200 degrees C.

If the materials barrier is removed, it will be relatively simple to generate higher temperatures. Present aviation gas turbines inject less than one third of the fuel that could be burned by the available air flow, in order to keep the temperature below 900 degrees. By increasing the fuel flow to the maximum, gas temperatures of 2,000 degrees are achievable.

Another problem is the need for efficient high-pressure compressors, for it is a well-known principle of gas turbines of the simple open-cycle type that the higher the temperature, the higher the optimum pressure ratio. Modern turbojets operate with pressure ratios up to 10 to 1. Difficult aerodynamic problems connected with the high-speed axial-flow compressor will have to be solved to permit increase in the pressure ratio.

In the ramjet there is the critical problem of preventing blowout of the flame by the 200-mile-per-hour air blast entering the combustion chamber, and of burning the fuel completely in a chamber where the reacting mixture tarries only a few thousandths of a second. Intricate flame-holders have been devised which do the job reasonably well under ordinary conditions, but blowout at high altitude is still a problem, particularly with fuel-lean mixtures.

Recent research has brought out the important role of turbulence in achieving effectively high flame speeds. Whereas the flame speed of a fuel such as methane in air is only about one foot per second under quiet conditions, with intense turbulence the flame brush can be made to advance at an effective speed of as much as 10 feet per second. This is extremely important for the development of compact combustors. The simple experiment illustrated in the photographs on page 122 brings out clearly the effect of turbulence on flame speed.

New fuels on the horizon, especially powdered aluminum and powdered beryllium, offer the possibility of higher flight speed through higher temperatures [*see table on page 129*].

Combustion in the rocket represents the present ultimate of controlled heat release by chemical reaction in a power plant. Its flame is several thousand times as intense, in terms of heat output per unit volume, as that in the most advanced oil-fired furnace. In current experiments engineers are working with temperatures of more than 3,000 degrees and pressures of 5,000 pounds per square inch. Still higher temperatures are possible; for example, fluorine and hydrogen yield a flame of 4,500 degrees. However, fluorine as an oxidizer offers only a modest gain over oxygen in fuel economy. This may seem surprising, but the answer is that the energy release per unit mass of the mixture as a whole is substantially the same. The problem of handling the extremely corrosive and toxic liquid fluorine in large quantities will undoubtedly deter its large-scale use in ordinary aviation, but the high density of the flame should make it important for special uses, such as space flight.

It appears that 11,000 feet per second is about the upper limit of speed we can attain by any chemical reaction. Liquid ozone increases the energy release by about 20 per cent, but unfortunately the extra energy is largely dissipated in dissociation of the relatively unstable water and hydrogen molecules present in the products of combustion. The velocity ceiling might be raised 2,000 feet per second if we could push the combustion pressure from the usual working level of 300 pounds per square inch to 1,000 pounds, but the pumping and cooling problems would be tremendous.

More advanced jet-propulsion performance will undoubtedly come about through the use of nuclear energy in place of chemical energy, but this development has only just begun. In the near future advances in jet propulsion will come about through the development of more efficient combustion systems and the improvement of the means of converting heat into kinetic energy.

Very High Temperatures

Here solids and liquids no longer exist, molecules are disrupted and gases are ionized. The strange dynamics of these electrically conducting gases are a new concern of physicists and astronomers

by Arthur Kantrowitz

Beyond the frontier of high temperature where the practical chemists and engineers work lies a realm of very high temperature which exists on earth only in the laboratory. It is the region from 4,000 degrees centigrade to 25,000 degrees or more. No earthly matter could long contain or survive such heat, but it is a comparatively simple feat to generate it momentarily for studies of its effects. At present these studies are of no great interest to anyone except astronomers and aeronautical (or astronautical) engineers. They will become increasingly important, however, both in basic investigation and in practical affairs.

At the temperatures we are considering there are no solids or liquids—all matter is gaseous, frequently in violent motion. In other words, we are dealing with the dynamics of high-energy gases. In recent years a remarkably convenient device for such work has been developed. It is the shock tube, which can generate extremely violent shock waves. Whenever a gas is compressed suddenly, it gains some heat. When the pressure is applied with extreme speed in a shock wave, such as is generated in an explosion or by an airplane flying faster than the speed of sound, a far higher proportion of the mechanical energy—in fact, most of it—is converted into heat. At Mach 4 (four times the speed of sound) the nose of a supersonic airplane would be heated to nearly 1,000 degrees centigrade if it were not cooled. At Mach 10 a shock wave will heat air to about 3,000 degrees; at Mach 20, to 6,000 degrees. Temperatures of this order have been achieved and investigated for some time by means of the electric arc. This article is concerned with recent studies in the shock tube.

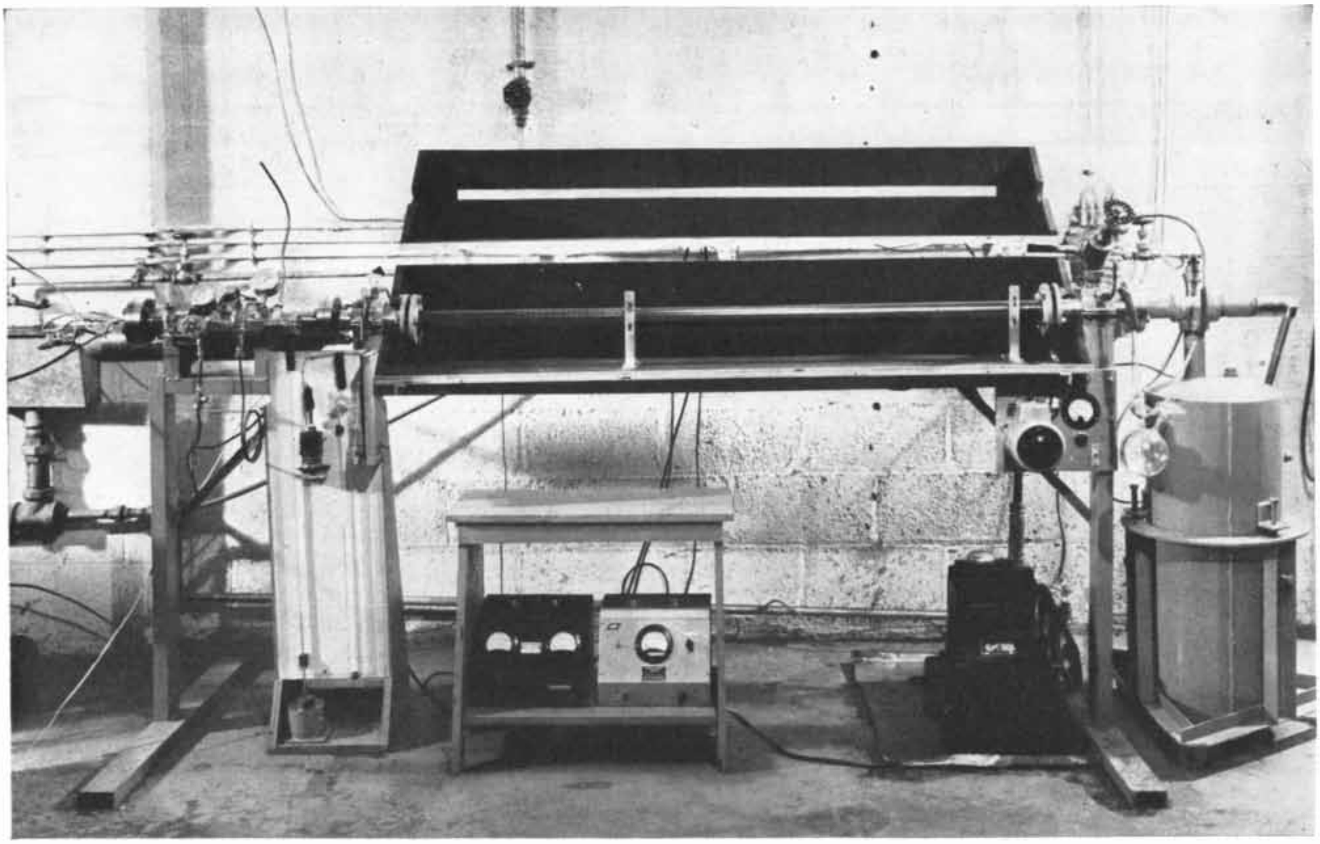
The shock tube is a simple device for producing rapid pressure jumps [see "Shock Waves," by Otto Laporte; Scientific American, November, 1949]. It is a gas-filled tube divided into two sections by a diaphragm. The pressure is pumped up in one compartment until it suddenly ruptures the diaphragm and propagates a shock wave in the other. With hydrogen as the driver gas, and the addition of a little oxygen to explode it, shock waves with speeds up to Mach 20 can be produced. Another type of shock tube, in which low-pressure gas is suddenly heated by an electric spark, has achieved shock waves as fast as Mach 34.

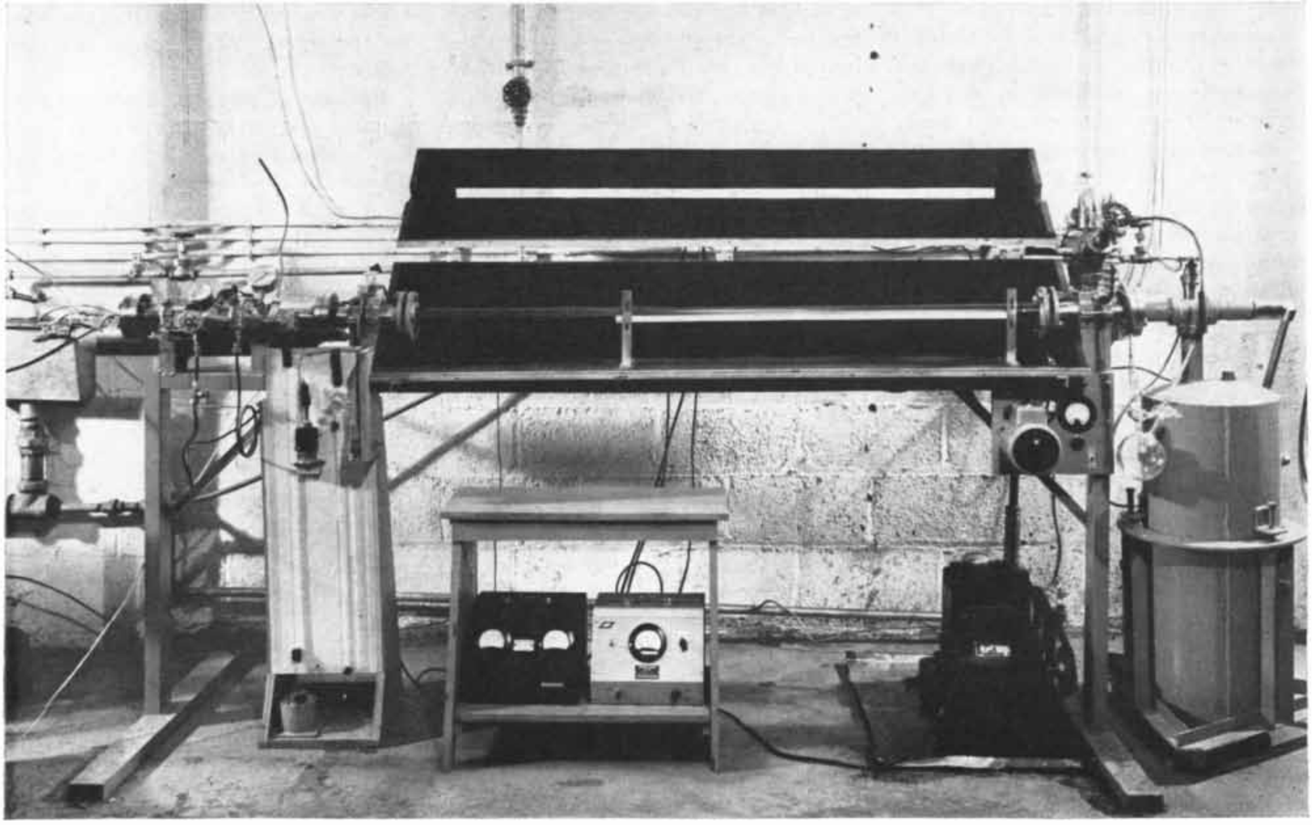
High-energy gas dynamics has been studied with the shock tube by groups working with Laporte at the University of Michigan, Edwin L. Resler at the University of Maryland, Richard G. Fowler at the University of Oklahoma and the author at Cornell University. These investigations have developed new information about (1) the chemical aspect and (2) the electrical and magnetic behavior of gases at very high temperatures.

At 20,000 degrees or more the molecules of a gas are completely dissociated into atoms, which usually are stripped of one or more electrons, *i.e.*, ionized. The principal object of the research on the "chemistry" of these high-energy gases is to determine how rapidly the predicted changes in the composition of the gas will take place in practice.

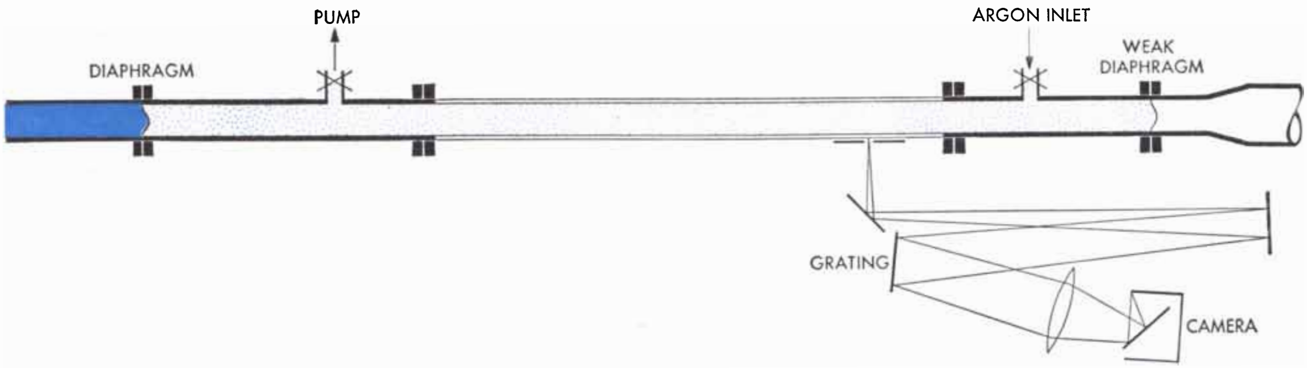
One substance that has been rather carefully studied is the rare gas argon. At 20,000 degrees C. half of the atoms of this gas will have lost an electron. Harry Petschek and Shao-chi Lin at Cornell have used the shock tube to elucidate some details which may suggest how this process goes. When argon gas is heated by a shock wave in a glass tube, there is usually no immediate visible effect. But after an "incubation time" of from one millionth to 100 millionths of a second, depending on the temperature, the gas suddenly glows brilliantly. It seems clear that the luminosity is due to a large collection of electrons which have "bred" by some such process as the following. There must be a few free electrons in the gas to begin with; just how they are released is unknown (perhaps by ultraviolet light). When the shock wave comes, these electrons are accelerated by collisions with the hot argon atoms. The electrons are so much less massive than the atoms, however, that they gain only a little energy from each collision. At a temperature of 23,000 degrees it takes about two million such collisions for an electron to acquire enough speed to knock another electron out of an atom when it hits one. But at this temperature (and under a pressure of five atmospheres in the shock tube) an electron will undergo that many collisions in about a millionth of a second. So at the end of a millionth of a second the number of electrons in the tube will have doubled; a millionth of a second later they will have quadrupled. At 23,000 degrees the incubation time before the glow appears is four millionths of a second, which means that the electrons have had time to multiply nearly twentyfold, and the light they produce has increased 400-fold.

When a gas is heated by an electric arc, the electric field, rather than collisions with high-speed atoms, accelerates the electrons to the energy that enables





SHOCK TUBE at Cornell University is used to produce very high temperatures by means of shock waves. At the left end of the tube is a short section which is filled with hydrogen. In the center of the tube is a long section, part of which is glass, containing rarefied argon. Between the two sections is a heavy copper diaphragm. When the hydrogen is exploded with a spark plug, the diaphragm breaks and a shock wave rushes through the argon from left to right. When the shock has sufficient strength, the gas becomes luminous. In the photograph at the top the shock tube is shown before firing. In the photograph at the bottom it is shown after firing. The luminous gas is seen as a horizontal white line through a narrow opening in the wrapping of the glass section.



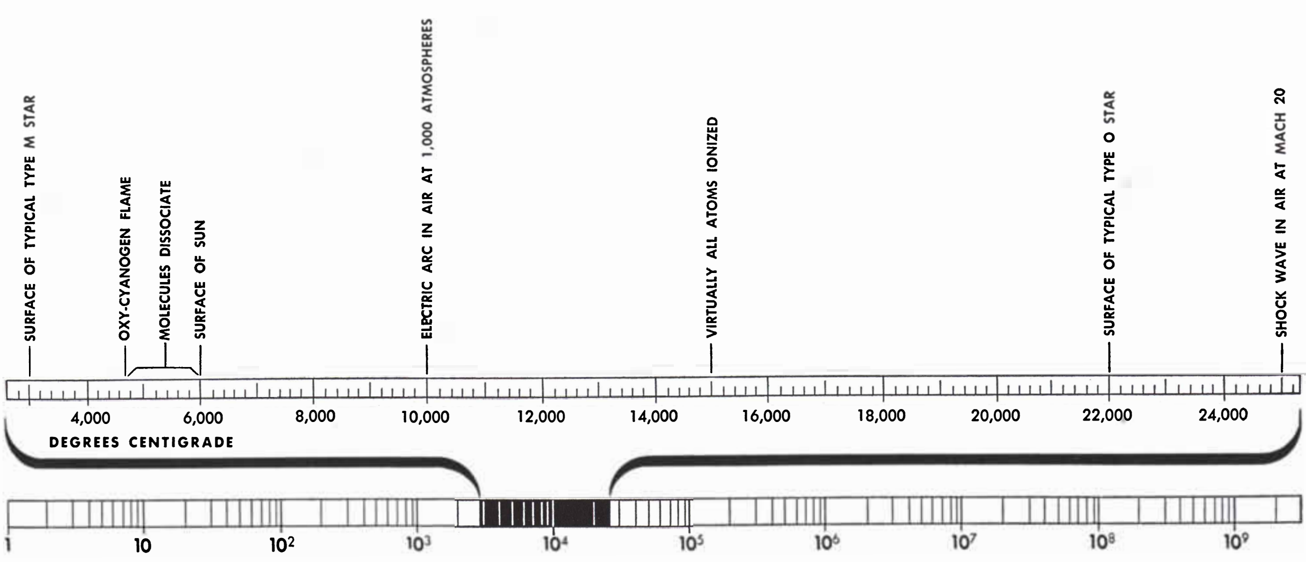
SHOCK TUBE COMPONENTS are schematically outlined. The high-pressure section for the hydrogen is at the far left. The low-pressure section for the argon is in the center. At the far right is a second diaphragm which is broken by the shock wave. This keeps the wave from being reflected back down the tube. Photographs of phenomena in tube are made with arrangement at lower right.

them to dislodge electrons from atoms and multiply. It was known that in an electric arc the electrons quickly reach a "thermal equilibrium," in which the number of electrons produced is matched by the number recaptured by ions. Thermal equilibrium also is reached in a shock tube, it was found. This was proved by a study of the spectrum of the luminous flash at the end of the incubation period. The number of electrons in the gas could be measured by a shift toward the red and a broadening of the lines in the argon spectrum. This measurement disclosed that the electron density in the tube, as in an electric arc, leveled off momentarily at an equilibrium value. There also appeared a strong continuous radiation throughout the visible spectrum which is characteristic of highly ionized gases.

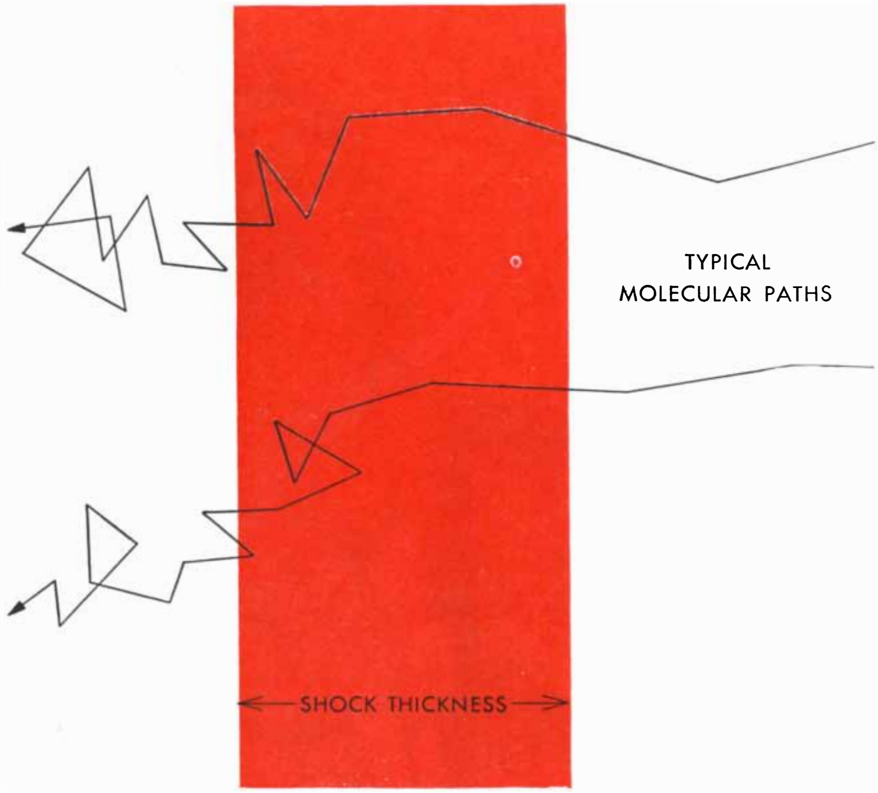
All this has some bearing on the problem of supersonic flight. If we are to design airplanes to fly at a speed such as Mach 10 without burning up, we must thoroughly understand the transfer of heat in air at high temperatures. This in turn means that we must understand what happens to air molecules at high temperatures, for that will determine the amount of heat transferred to the skin of the plane. The study of the thermal behavior of air of course will be far more complicated than that of argon, for we shall have to deal not simply with the stripping of an electron from the atom but with the dissociation of oxygen and nitrogen molecules, with the formation of nitric oxide from the free atoms [*see Farrington Daniels' article on page 109*] and with the ionization of a number of different molecules. Such studies are just beginning.

Now let us consider the electromagnetic aspect of the behavior of gases at very high temperatures. The outstanding fact is that at these temperatures a gas becomes a very good conductor of electricity, because the heat produces a large number of free electrons. Certain theoretical considerations indicated that the conductivity of any gas should rise with the rise in temperature to a limiting value which is independent of the chemical nature of the gas. This was confirmed by measurements with the shock tube. For example, argon at 15,000 degrees becomes so conductive that a current of 100 amperes per square centimeter will flow across one centimeter of the gas when the potential difference is only one volt.

Because of its high conductivity, a filament of very hot gas behaves like a wire in an electric or magnetic field. This is spectacularly evident in an astronomical mass of hot gas such as the sun. For instance, during explosions on the surface of the sun it has been observed that prominences (tongues of hot gas) erupt-



VERY HIGH TEMPERATURE range is roughly from 4,000 degrees centigrade to 25,000. The surface of a cool Type M star is 3,000 degrees; that of a hot Type O star, 22,000 degrees. The temperature of a shock wave in air at Mach 20 would be 25,000 degrees.



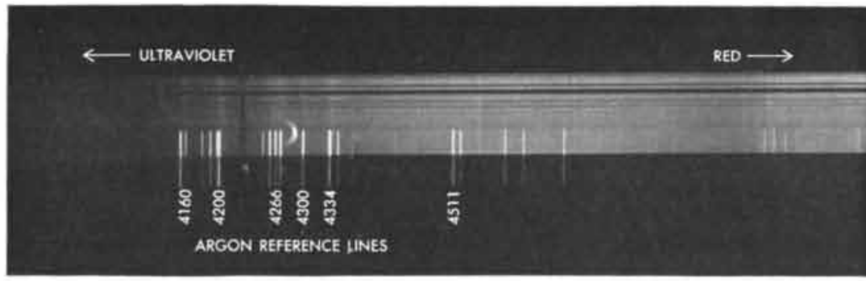
PATHS OF MOLECULES in the vicinity of a shock wave moving across this picture from left to right reflect the differences in temperature ahead of the wave, within it and behind it.

ing from the sun's surface followed magnetic lines of force instead of simply following the pressure field, as an exploding gas on the earth would do. Stimulated by such observations, Hannes Alfvén of the Swedish Royal Institute of Technology, G. K. Batchelor of Cambridge University, Enrico Fermi and S. Chandrasekhar of the University of Chicago and others have begun the new study of magneto-hydrodynamics—how gases (and liquids) move under the influence of electromagnetic and pressure forces.

It is plain that an electric current will be generated in a highly conducting gas moving across the lines of force of a magnetic field, just as it is in the armature of an electric generator. On the other hand, an electric current in such a fluid will produce a magnetic field. Thus conducting fluids in nature may spontaneously generate magnetic fields. The magnetic field of the earth is probably created in this way by motions of its hot, fluid core. And natural magnetic fields on a much larger scale have recently been invoked to explain many phenomena in cosmology. For instance, Alfvén and others have suggested that magnetic and electric fields in space may accelerate the cosmic rays ["Electricity in Space," by Hannes Alfvén; SCIENTIFIC AMERICAN, May, 1952]. Chandrasekhar and Fermi have proposed that a weak magnetic field in our region of the Milky Way supplies most of the force that prevents our spiral arm of the galaxy from collapsing under gravity.

One of the most striking demonstrations of the play of high-energy gas dynamics in space is the recently discovered phenomenon of celestial radio waves. That these waves probably emanate from violent gas motions is indicated by several items of evidence. When the surface of the sun is quiet, it emits very little radio noise; but when it erupts, the disturbed area emits about a million times more radio energy. Some of the so-called radio stars—pin-pointed sources of radio energy—are located in regions of violent gas motion. One of them is the swirling cloud called the Crab nebula, which is the gaseous remains of a star that exploded 900 years ago. Another is a region where two galaxies are colliding; collisions between the gas clouds associated with galaxies should produce strong shock waves. The possible connection between shock waves and the mysterious celestial emission of radio energy is a promising subject for research.

Astronomers have been puzzled for some time by certain lines of luminosity that are found in the heavens. Some of these lines are believed to show regions



SPECTRUM of argon heated by a shock wave is slightly shifted toward the red. The bright vertical lines at the bottom of this horizontal band are emitted by an ordinary electric discharge in argon. The wavelengths of the lines are given in angstroms. The faint and broadened lines at the top of the horizontal band are emitted by argon heated in the shock tube.

where gas ejected from the exploding supernova has collided with clouds of gas in interstellar space. The Dutch astronomer J. H. Oort recently suggested that the lines of light may represent shock waves; he points out that their thickness (some 60 billion miles) is about the size of the region one would expect a shock front to cover in the thin interstellar gas. When Oort made his suggestion, no luminous shock front had ever been observed in a terrestrial explosion. But such a luminous line does appear in a shock tube where argon is accelerated to Mach 10. In further support of Oort's theory, the picture clearly shows that the most luminous region in the gas is the shock front itself, rather than behind the front, where we should expect the gas molecules to be hottest. The luminous shock front in the shock tube is still in some respects very puzzling, particularly the fact that a brief luminosity sometimes occurs immediate-

DRUM-CAMERA PHOTOGRAPH shows changes in the luminosity of argon after a shock wave has passed. The image of the luminosity is diagonal because the film in the camera was moved vertically. The thin line at the bottom represents the shock front; the thicker line above it, the luminescent gas. The dark zone between them shows the incubation period.

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HIGH TEMPERATURE SUPER ALLOY STEELS

ALTEMP A-286 . . . an austenitic iron-nickel-chromium alloy made heat-treatable by the addition of titanium. Designed to maintain high strength and corrosion-resistance in the 1300-1500 F range, and for temperatures up to 1800 F under lower stress.

A-286 was developed in the A-L Research Laboratory in Watervliet, N.Y., in the 1949-51 period. Among the high-strength, heat-resisting alloys, it has exceptionally low strategic alloy content, improved hot-working and machining qualities, and good center ductility in large sections. Currently used in jet engines and superchargers for such applications as turbine wheels and blades, frames, casings, after-burner parts, bolting, etc.

This alloy is readily produced in large quantities without the need of special steel-making equipment. It is available in the form of billets, bars, forgings, sheet, strip, tubing and hot-extruded shapes. Certified laboratory data on the properties of ALTEMP grades are yours on request. Address Dept. SC-9.

ALTEMP S-816 . . . a chromium-nickel-cobalt base alloy, strengthened by additions of molybdenum and tungsten, and with a columbium-carbon ratio of ten to one to insure its structural stability. Designed for high strength and corrosion-resistance service in the 1200-1500 F range, and at higher temperatures under lower stress conditions. Developed in the A-L Research Laboratory at Watervliet, N.Y. in the years of 1940-43, and engine-tested and proved for periods of over 30,000 hours.

S-816 is used currently for turbine blades in two of the production jet engines, also in a number of experimental aircraft and commercial gas turbines. Except for seamless drawn tubing, it is available in practically all forms and shapes in which stainless steels are processed, including hot extrusions.

ALTEMP S-590 was designed for service in the range of 1100-1400 F temperatures where high strength and corrosion resistance are required, and where cost is also a factor. Unlike S-816, which is practically a non-ferrous alloy, S-590 has a chromium-nickel-cobalt-iron base. However, it employes the same molybdenum and tungsten additives, and the same columbium-carbon ratio.

S-590 was developed at the Watervliet Laboratory and field-proved during the same years as S-816. It is available in the same shapes and forms, and is currently being used for turbine blades and wheels in experimental commercial gas turbines.

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Among the many other Super Alloys made by Allegheny Ludlum are V-36, M-252, 19-9 DL, 19-9 DX and Waspaloy.

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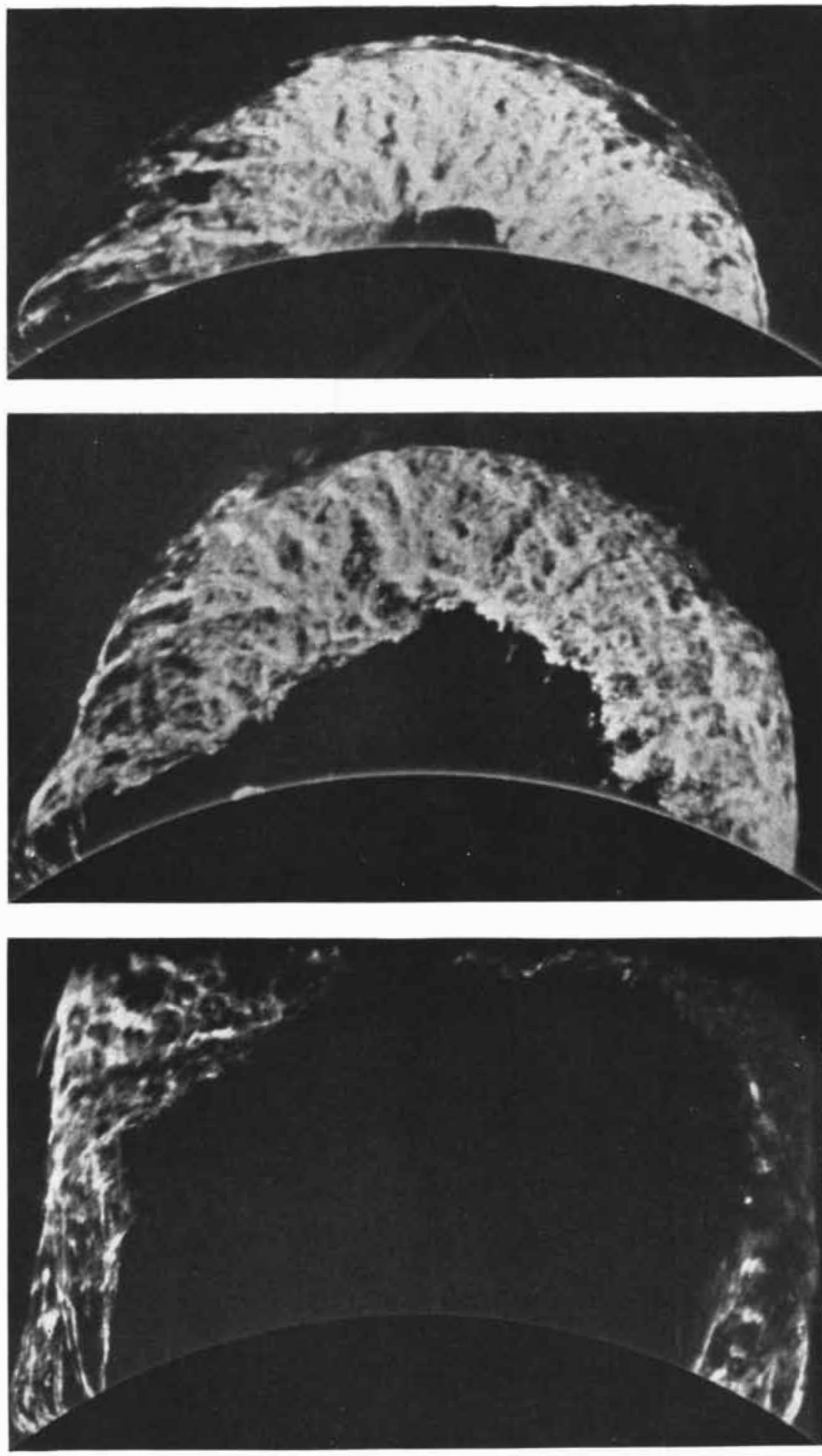


SOLAR PROMINENCE on June 4, 1946, resembles a terrestrial explosion led by a thin semicircular shock front. Parts of it suggest gases flowing along magnetic lines of force.

ly, before the incubation period [*see the thin lower line in the photograph on page 138*]. A considerable body of evidence indicates that a shock wave may push a thin, concentrated layer of ions through the gas in which it propagates, somewhat in the manner of breakers propelling driftwood on a beach. The electrons accompanying these ions would be heated by friction with the gas, thus producing the luminous region just ahead of the shock.

The investigation of the dynamics of very hot gases not only is beginning to unravel many mysteries of our astro-

Advances in Applied Radiation

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

Chemical Analysis by Neutron Activation

Samples made temporarily radioactive under neutron bombardment can be analyzed to detect minute quantities of impurities or trace components. In many cases, concentrations in the "parts-per-million" range can be measured.

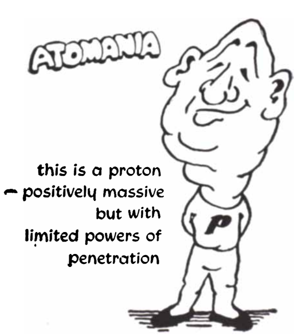
This technique has heretofore been restricted to laboratories having access to the intense neutron fluxes obtainable in nuclear-reacting piles. But today, with the availability of Van de Graaff particle accelerators, intense neutron fluxes can be produced in industrial laboratories as well as in academic research establishments. With HIGH VOLTAGE's two-million-volt Model AK-N Van de Graaff, for example, thermal-neutron fluxes of 5×10^8 n/sec-cm^2 are routinely obtainable. Activation analysis can be performed on over 60 elements with detection sensitivities better than 100 parts per million, using this neutron source.

Already, industrial laboratories are actively engaged in exploring the possibilities of this new analytical method. Results are unambiguous and are usually obtained with little sample preparation and in a relatively short time. Full information concerning activation analysis is now available from HIGH VOLTAGE, including an exhaustive table of all isotopes susceptible to neutron bombardment. Write for "Activation Analysis with Van de Graaff Neutron Sources."

High-vacuum Plumbing

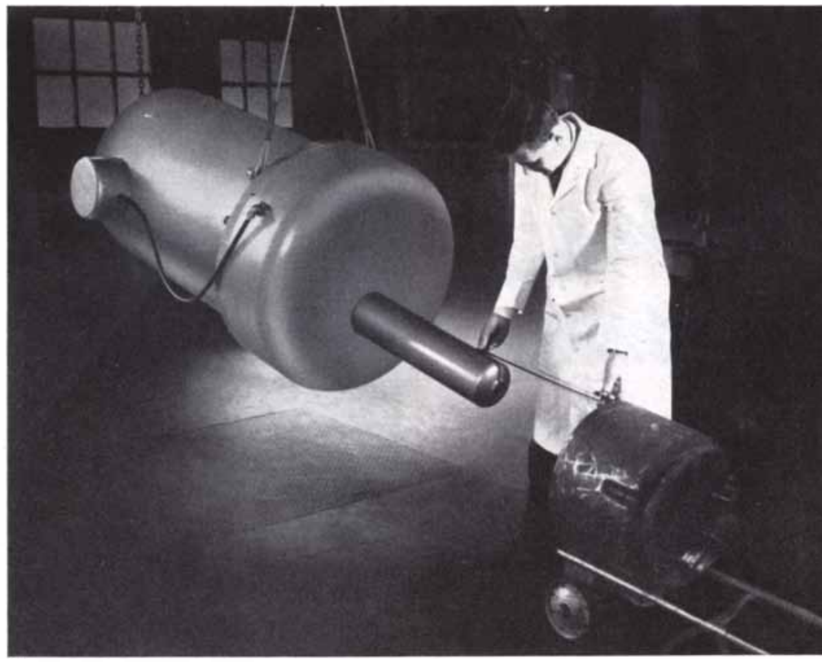
For some time, HIGH VOLTAGE has been concerned with the development of reliable, standardized high-vacuum components. The resulting design combines ruggedness with simplicity and flexibility and appears to have applications in many types of industrial and laboratory installations.

dependex high-vacuum plumbing is described in an eight-page bulletin available on request to HIGH VOLTAGE.



A New Low-cost Supervoltage X-ray Source

The need for a lower cost x-ray source for the precision inspection of steel thicknesses from 2 to 5 inches has long been felt. For many applications, radioactive sources use too much time and often leave something to be desired in definition or sharpness — and conventional x-ray machines lack sufficient penetrating power for the more difficult jobs. On the other hand, equipment for the production of highly penetrating x-rays at energies of one million volts or more has involved a capital expenditure which could be justified only for very heavy and specialized industrial operations.



At the recent meeting of the American Society for Testing Materials, HIGH VOLTAGE announced a new one-million-volt x-ray generator designed to fill the gap. Capable of penetrating steel thicknesses up to 5 inches in reasonable exposure times, this new unit, our Model JR Van de Graaff, is priced at $25,000 — less than half the cost of other available supervoltage equipment. One unique feature of the Van de Graaff for radiography is its small focal spot — the source of x-rays is less than 1 mm in diameter — making possible the production of radiographs with exceptionally clear detail.

The entire unit weighs less than 2,500 pounds and is about the size of a household refrigerator. It is therefore easily transported by crane or lift-truck. We believe that the availability of this x-ray source will be of major importance to the non-destructive testing techniques of heavy industry.

Columbia University

The 30-ton pressure vessel for Columbia University's 6-million-volt Van de Graaff accelerator has now been delivered to HIGH VOLTAGE. When completed in early 1955, this accelerator will be used for obtaining precise nuclear data by the university's Physics Department, under the direction of Prof. W. W. Havens. HIGH VOLTAGE is building this Van de Graaff, the third of its kind, under contract to the U.S. Atomic Energy Commission.

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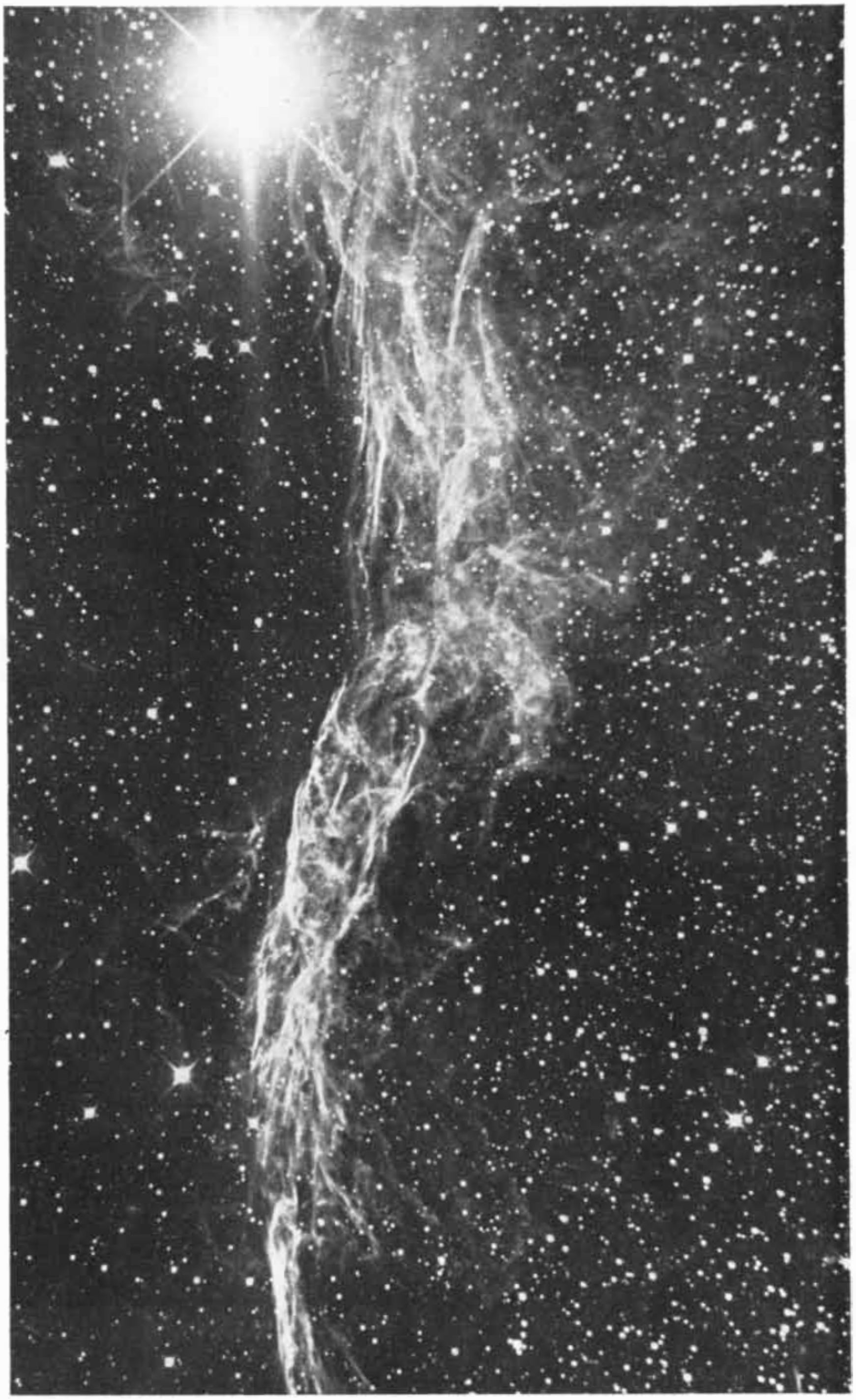
nomical cosmos but also offers some exciting possibilities in the technology of flight. Our present airplanes—rocket or jet-propelled—are ultimately limited in speed by the gas velocity that can be attained by chemical reactions. For practical space flight we shall need much higher velocities. One possible way to attain it is to accelerate gas with magnetic forces instead of merely with chemical combustion. There is no known theoretical limit to the propulsive impulse obtainable from a given mass of gas expelled in this way. The electrical energy for acceleration could be supplied by a nuclear reactor. This propulsion device would be essentially an electric motor with a gas replacing the usual solid armature.

It may even be possible to find ways to use magneto-hydrodynamic forces for control and lift, as well as for propulsion, of the ships in which man eventually will take off into space.



VEIL NEBULA in Cygnus appears to represent a collision between interstellar gas and gas expelled by the explosion of a supernova. The fine filaments in the nebula are some 100,000 million miles thick, suggesting shock waves moving through the rarefied interstellar gas.

What General Electric people are saying . . .

F. K. McCUNE

Mr. McCune is General Manager, Atomic Products Division

". . . We at General Electric believe that electric companies will be owning and operating a number of atomic power plants within the next ten years.

Second, we believe some of these will be full-scale and, what is most important, they will generate electricity at competitive costs, possibly within five, certainly within ten, years.

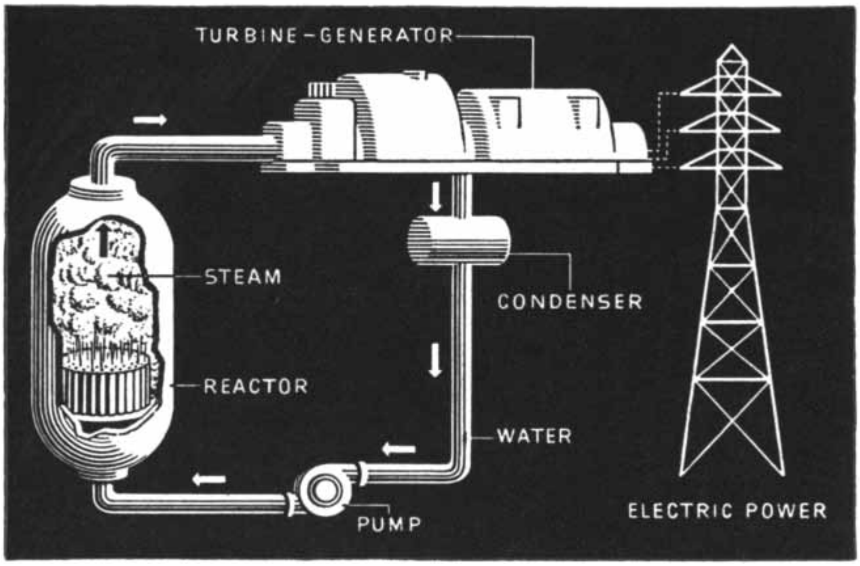
Third, we believe that this will be accomplished without Government subsidy for production plant construction or operation, and that Government-supplied fuel will be priced at cost-of-production levels.

Fourth, we believe that two nuclear reactors best suited for earliest and most effective competition with conventional fuel plants in this country are (a) the light water-moderated and cooled boiling reactor, and (b) the graphite-moderated water cooled reactor. These we think hold greatest promise in the years just ahead.

In saying these production plants will operate without Government subsidy, I do not wish to detract from the immeasurable significance of knowledge developed through A.E.C. contracts. Of course, the Government's large expenditures for research and development of plutonium production reactors, mobile power reactors, and other power reactors forms the base from which private industry can proceed. But, the important thing here is that we believe production size atomic power plants can be made economic. They will stand on their own feet. They may sell products to the Government. They will certainly buy nuclear fuel from the Government. But, trading with the Government need not be a subsidy."

Atomic Industrial Forum Panel
Washington, D. C.

Copies of Mr. McCune's complete talk may be obtained by writing to Dept. Q-2-119, General Electric Company, Schenectady 5, N. Y.



BOILING WATER REACTOR, ***of type developed by the A.E.C.'s Argonne National Laboratory diagrammed above; promises electric power at 6.7 mills/kwhr (as compared with 4.5 to 8 mills/kwhr in conventional plants).***

K. R. GEISER

Mr. Geiser is Supervisor of Engineering—Computer Unit, General Engineering Laboratory.

". . . There are three broad areas of manufacturing—manual, mechanization, and automation. In the manual area, physical effort is used to perform an operation by the use of hands or hand tools. In the mechanization area, manually operated power-driven machines, with varying degrees of controls, are used to perform one or more operations. Progressing into the automation area, we find automatic machines which are integrated with transfer devices to perform a series of continuous automatic operations. Here you see how industry can continually upgrade the manual operation into the mechanization area by replacing the hand tool with the machine; and then by adding transfer equipment we progress to the automation area. Please note that manpower will always be required. However, there will undoubtedly be fewer men as operations are automated and the emphasis will shift from the manual skills to the mental skills for both the productive and the maintenance worker.

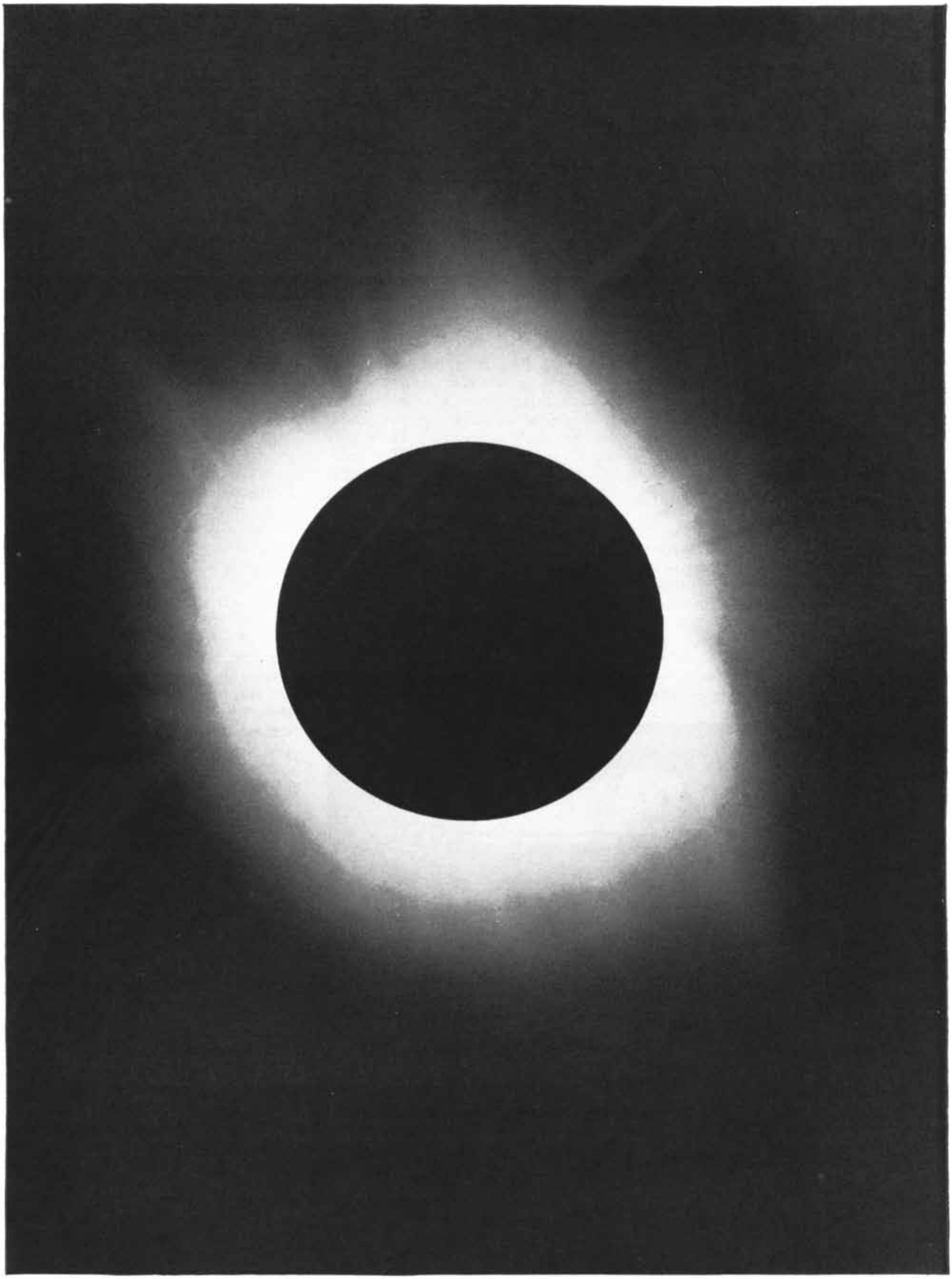
Man has always devoted much of his effort to finding ways and means to accomplish or circumvent the arduous and laborious tasks, especially those not requiring his full ability as a human being. There still exist in industry today many tedious, time-consuming, laborious or simple discrimination jobs which often lack mental stimulus for the people who must perform them. It does not require the full complexity of the human mind and body to carry tote boxes from one machine to the next nor to load parts in a lathe, nor to tighten bolts and solder wires in building, for instance, automobiles or radios.

As surely as man lives and thinks and strives for a better way of life, these things will be replaced.

G.E. Engineering Specialist

Progress Is Our Most Important Product

GENERAL ELECTRIC



CORONA of the sun was photographed during the solar eclipse of September 21, 1922. Although the surface of the sun is 6,000 degrees Kelvin, the corona is a million degrees. Its faint glow demonstrates that a high kinetic temperature produces little radiation.

Ultrahigh Temperatures

They occur in nuclear explosions and in the interiors of stars. In the latter they promote thermonuclear reactions and perhaps convert hydrogen into all other elements on the periodic table

by Fred Hoyle

The aim of this article is to consider the highest temperatures suspected to occur in the universe—the temperatures in the interiors of stars. The discussion will, we hope, throw light on the formation of the universe as we know it and on its future evolution.

Before starting on these topics it is desirable to say a little about what is meant by the word temperature. In any closed system of gas which neither receives energy from, nor loses energy to, the outside world, the particles distribute their motions among themselves through collisions in a random way so that eventually an average state of affairs is set up. The distribution of the velocities of the particles in this average situation is known as the Maxwell distribution. Similarly there is a distribution of radiation frequencies, known as the Planck distribution, which arises from the various emissions and absorptions of radiation by the particles as a result of their collisions.

Now a thermodynamic system is one in which the average conditions (the Maxwell and Planck distributions) are to be regarded as having become established, and the thermodynamic temperature is defined as the quantity which determines both the average speed of the particles and the intensity of the radiation field.

The material inside stars may be said to have a thermodynamic temperature. When we say that its thermodynamic temperature is very high, we mean that both the average speed of motion of its particles and the intensity of radiation are very great.

When a system satisfies the Maxwell distribution but not the Planck distribution, we speak of the material as possessing a "kinetic" temperature. A kinetic temperature does not imply any strong ability to emit radiation. These statements explain how it is that the visible surface (photosphere) of the sun, at a thermodynamic temperature of less than 6,000 degrees Kelvin, is able to emit a far greater intensity of radiation than the corona does, though the latter has a kinetic temperature of about one million degrees K. While the particles in the corona move at a far higher speed than those in the photosphere, they are so much more thinly dispersed that radiating collisions are relatively infrequent.

Let me come now to the main question before us. Why does the thermodynamic temperature rise above 10 million degrees in the central regions of the sun? The answering of this question raises issues that lie at the root of much of present-day astrophysics.

An approach to the origin of the ultrahigh temperature inside the sun is perhaps best made by comparing the case of the sun with that of the planets. At the center of the earth, material is under a pressure of more than 20 million pounds per square inch. (If you wish to get some faint notion of what such a figure means, think of the effort required to pump an automobile tire to a pressure of a mere 25 pounds per square inch.) Yet colossal as the pressure in the center of the earth is, it is not sufficient to cause ordinary solids and liquids to collapse. Near the center of the sun, on the other hand, the pressure is more than one trillion pounds per square inch. No ordinary solid or liquid could withstand pressures of this order. If the sun were composed of materials such as the earth and planets are made of, there would be a wholesale collapse; indeed, its collapse would be so swift it would be visible to the naked eye.

But the sun's collapse would have a limit. As it shrank, the conversion of gravitational energy to heat would heat up the internal material more and more, and would build up the internal pressure. When the sun had shrunk to about half its present size, the internal pressure would become sufficient to support the weight of the overlying layers. The collapse would then stop.

We see immediately why astronomers have deduced that the temperature inside a star must be extremely high: if it were not already high, the stars would collapse swiftly and push up the temperature to the ultrahigh range. In every star a pressure balance is self-maintained at just the right level.

Because the internal temperature of a star is so high, energy must flow from the inside to the cooler surface. (Of course the surface must be much cooler than the interior; if the surface of the sun were as hot as its deep interior, the sun would be a million million times as bright as it is—and would vaporize the earth in a minute or two.) The necessity for an outward flow of energy explains why a star must be self-luminous. The surface radiates energy away into space at the same rate as energy flows out from the interior. Its luminosity is determined by the rate of outflow of energy. That in turn depends upon the internal high temperature required to maintain the pressure balance.

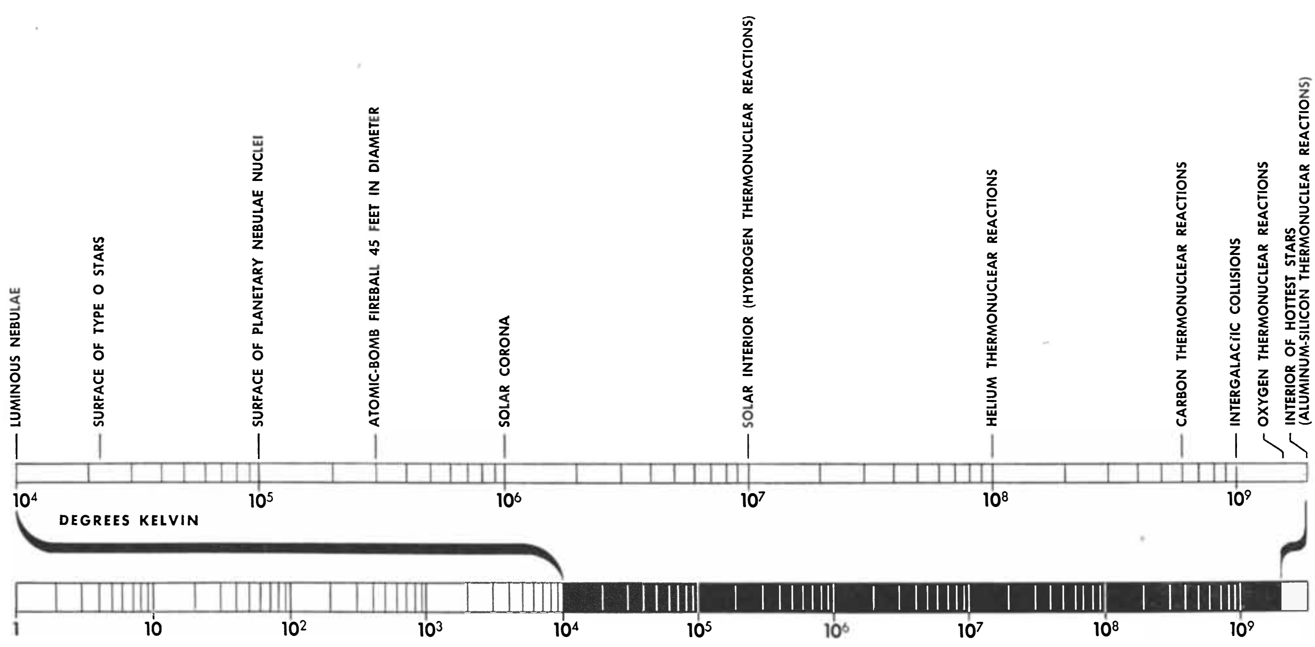
It will be noticed that so far nothing has been said about generation of energy within the star. The implication is that the star would go on radiating energy even if it were not continually producing energy by thermonuclear reactions. This is correct. The sun would emit radiation even if it were made of old brick ends. Indeed, calculation shows that if it were made of rubble, the sun would emit energy at about 1,000 times the rate it is doing now! The reason for this rather remarkable conclusion is that a sun composed of rock rather than largely of hydrogen would require a substantially higher internal temperature (some 40 million degrees K.) to maintain the pressure balance.

In case you are wondering what the thermonuclear generation of heat inside the sun accomplishes, the answer is that it enables the sun to maintain its present size. If no energy were being generated inside the sun, its steady loss of energy by radiation from the surface into space could be made good only by drawing on its supply of gravitational energy: *i.e.*, the energy released by contraction. The sun would slowly shrink—though it would take some millions of years to perceive an appreciable change in its size from the earth. As matters are, the thermonuclear production of energy acts as an automatic size regulator. If the sun were to shrink slightly, the consequent rise in its internal temperature would increase the rate of energy production. Now it is a property of the thermonuclear reactions that a temperature rise increases the production of energy much more rapidly than it does the outflow of energy. Consequently energy would accumulate inside the sun, would raise the internal pressure and would force the sun to expand until it regained its normal size. On the other hand, if the sun were larger than its present size, its energy production would be less because its internal temperature would be lower. The resulting net loss of internal energy would have to be made good by shrinkage back to the present size.

The thermonuclear reactions that generate energy in the stars have, of course, become widely known: they are called the carbon cycle and the proton-proton chain [*see pages 150 and 152*]. It is now generally agreed that the latter reactions in which protons combine to form helium with the emission of large amounts of energy, are mainly responsible for the energy production in the sun, while the carbon cycle is more important in very bright stars ["The Energy of Stars," by Robert E. Marshak; SCIENTIFIC AMERICAN, January, 1950]. The fact that stars possess an internal source of energy has the interesting consequence that they are able to maintain themselves for very long periods of time. The sun has probably existed much as it is now for four billion years or more.

The energy radiated by the stars produces quite a number of astronomical oddities. Some stars—the highly luminous blue giants—emit a great deal of their radiation in the ultraviolet. An appreciable proportion of this ultraviolet radiation is absorbed by the gas clouds that exist in space. The gas accordingly becomes considerably heated, higher pressures then develop, and under their influence the gas is caused to move around. In short, the interstellar gas is constantly being stirred up by the highly luminous blue stars. According to a view held by many astronomers, this stirring up causes the gas clouds to act as a dynamo, building up a magnetic field of considerable intensity. There is observational evidence that magnetic fields do indeed exist in interstellar space, and it is now believed that they play an important part in accelerating the cosmic rays—the extremely energetic particles that enter the earth's atmosphere from outside. Thus the energy of the cosmic rays probably stems basically from the thermonuclear reactions in the stars. Curiously, the energetic particles produced artificially by physicists really derive their energy from the same source, for the energy that is used to operate our cyclotrons, betatrons, synchrotrons, bevatrons and cosmotrons also is derived in the last analysis from sunlight!

Both of the energy-generating sets of reactions in the stars have the same net effect: they convert hydrogen into helium. One might think that so long as the sun has a supply of hydrogen, there will be no substantial change in its luminosity or size. This notion is incorrect, however, for two reasons. First, when we were discussing what would happen if the sun were made of old brick ends we saw that with an internal material of greater atomic weight than



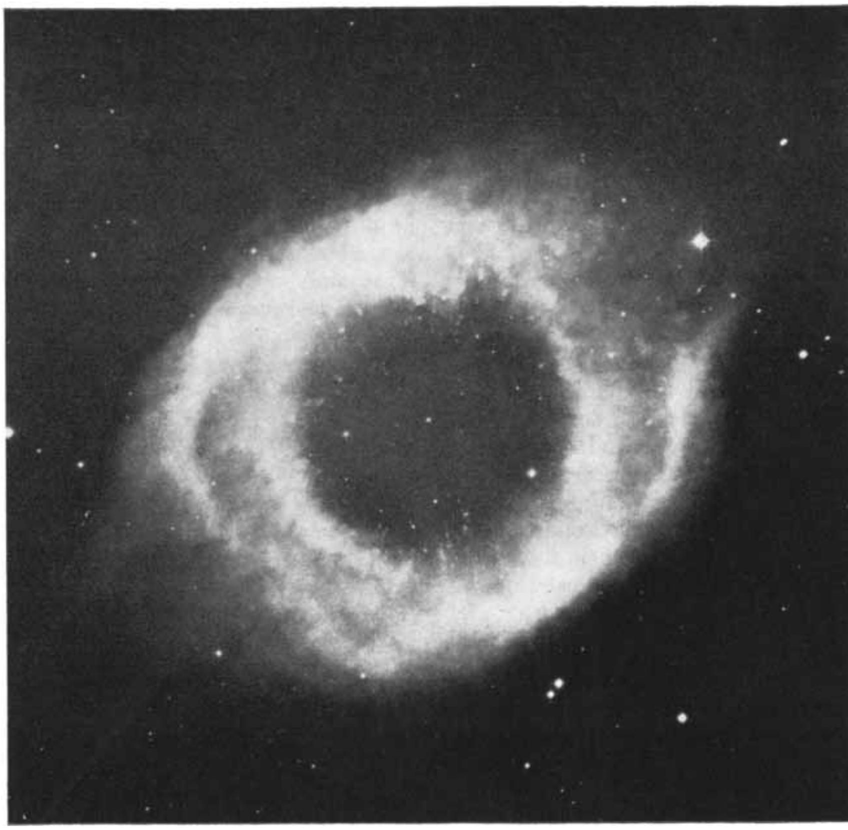
ULTRAHIGH TEMPERATURES are characterized by their ability to maintain thermonuclear reactions. They range up to 2,000 million degrees K., the temperatures in the interiors of the hottest stars. They are reflected in nebulae of only 10,000 degrees.

hydrogen, a higher temperature would be necessary to maintain the pressure balance. As the hydrogen of the sun is converted into the heavier element helium, the sun's internal temperature must rise and it becomes more luminous.

But this is not all. The rate of the thermonuclear reactions depends on the temperature. Hence the hydrogen at the hot center of the sun is converted to helium much faster than the hydrogen in the cooler outskirts. As a result the composition of the sun must become uneven, since it seems unlikely that there is any important mixing of material between the interior and the outer parts. It can be shown by intricate calculations that the effects of this unevenness will be peculiar. To begin with, the whole sun will probably shrink a little. In the next stage the central regions will continue to shrink, but the outer parts will start to swell. All this will be accompanied by a steadily increasing brightness. Ultimately the sun will become extremely luminous and extremely bloated —more than 1,000 times more luminous and about 100 times bigger in radius than at present. Then will follow a period of decline in which the luminosity decreases to about 100 times and the radius to about 20 times the present values. After this the luminosity will stabilize but the radius will continue to shrink until the sun is only about a 20th of its present size. In the final phase the sun will stop shrinking and its luminosity will then decline. It will become the type of star known as a white dwarf.

One might feel inclined to treat these calculated results as something of a fantasy, if it were not that recent observations, made notably by H. C. Arp and A. R. Sandage, give us a pretty clear indication that the course of evolution just described does in fact occur. The situation is summarized in the chart on the next page, showing a number of stars belonging to the globular cluster Messier 3 which are plotted on the chart according to their luminosity and surface temperature (as indicated by color). The position of a star in this luminosity-temperature diagram also determines its size.

Now all of the stars recorded in this diagram seem to have been closely similar to begin with: they are probably all stars with masses about 1.2 times that of the sun. Their differences in luminosity and surface temperature are to be explained on the basis that some of the stars are more advanced in their evolution than the others, the slightly more



PLANETARY NEBULA in Aquarius was photographed with the 200-inch telescope on Palomar Mountain. Its luminosity is due to ultraviolet radiation from a hot star (*center*).

LUMINOUS NEBULA in Sagittarius also was photographed with the 200-inch telescope. Called the Trifid Nebula, it is made to shine by ultraviolet radiation from a star inside it.

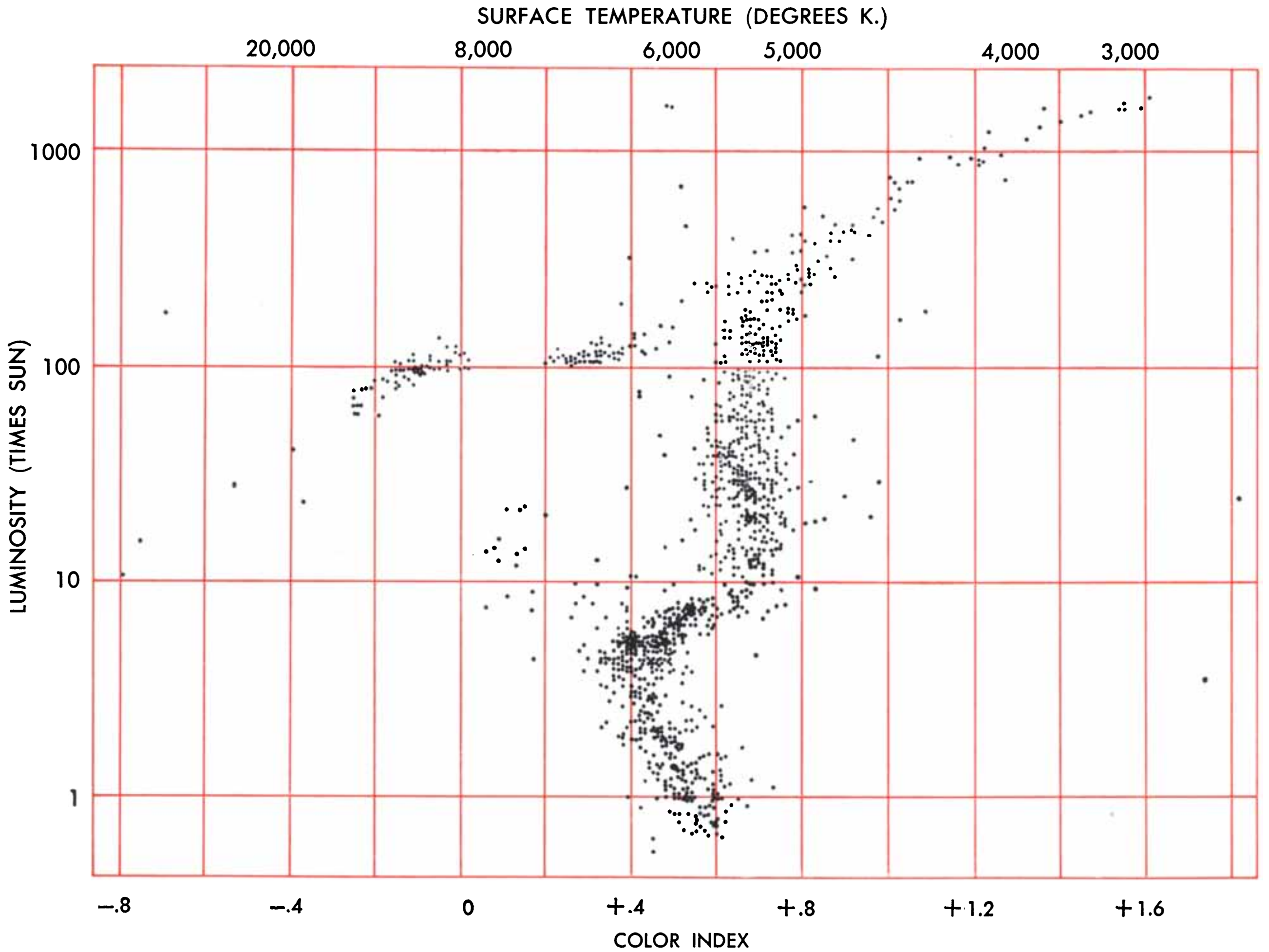
massive stars being the farther advanced. The stars fall on a clear-cut sequence simply because this is the sequence along which they are all evolving (actually there is some variation in the sequence according to the mass of a star, but such variations are comparatively small).

A star starts close to the bottom of the sequence and evolves upward along it. When it reaches the fork near the top of the diagram, it takes the route to the right, known as the "giant" branch. It evolves up to the topmost part of the sequence at the extreme upper right, then reverses and moves down again. At the forking point it turns into the "horizontal" branch. The movement along this branch corresponds to the shrinkage that follows the bloated conditions occurring on the giant branch. As the star shrinks, its surface temperature rises. At higher temperatures a greater proportion of a star's radiation is in the form of ultraviolet light. This means that the star becomes more and more difficult to observe, because ultraviolet light is mostly absorbed by the terrestrial atmosphere and does not come through to our telescopes. The shrinking star therefore fades from our sight, not because it is emitting any less energy but because too much of its energy is unobservable from our point of view. At the distance of Messier 3 we cannot see it at all in the last stages of its evolution as a white dwarf. (The setting up of an observatory on an artificial satellite would avoid this and many similar difficulties.)

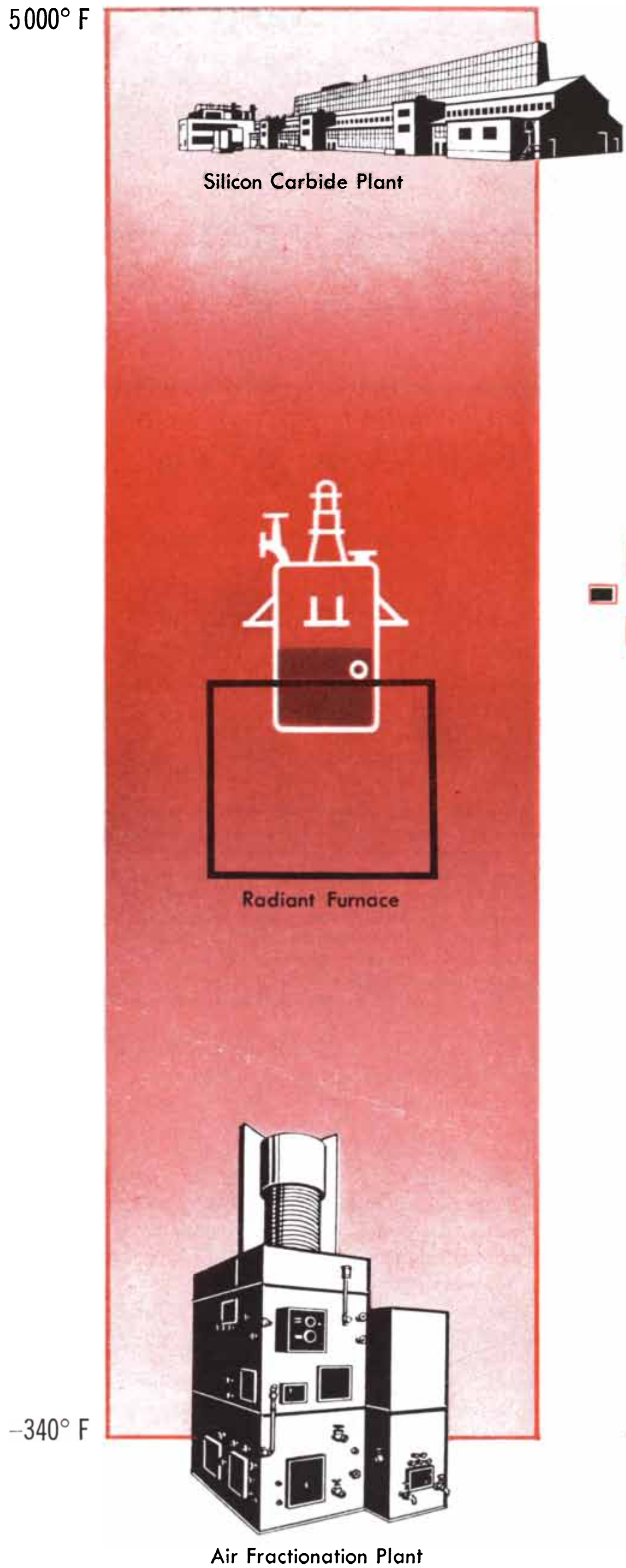
It is necessary to emphasize that all these evolutionary changes take a very long time—some five billion years from the beginning to the last lap of the journey on the horizontal branch. Most of that time is passed in the early stages—the lower parts of the sequence. Once a star gets over these early stages, it evolves with increasing rapidity. The sun is still in the early stages. Being a somewhat less massive star than those shown in the diagram, its evolution through the early stages will take longer. But the sun's turn will come.

The temperature at the center of a star near the bottom of the sequence is between 12 and 15 million degrees K. As the star progresses along the evolutionary track, the temperature in the deep interior rises. This it does for two reasons: (1) the replacement of hydrogen by helium forces the temperature higher in order that the pressure balance be maintained; (2) the central regions of the star shrink. By the time a star reaches the top of the giant branch, the temperature has risen to about 100 million degrees. (The temperature of a hydrogen bomb at the moment of explosion is closely comparable with this; it must be remembered, however, that whereas in the hydrogen bomb this high temperature is attained only in a volume of a few cubic yards, in a star it pervades a volume of some 100,000 billion billion cubic yards.)

At a temperature of 100 million degrees, thermonuclear reactions other than those which form helium become important. By the time the giant branch is reached, some 50 per cent of the star's original hydrogen has been entirely con-



COLOR-LUMINOSITY DIAGRAM of the stars in the globular cluster Messier 3 was plotted by H. C. Arp and A. R. Sandage of the Mount Wilson and Palomar Observatories. Each dot represents a star. The distribution of stars suggests the path of their evolution.



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$$_{6}C^{12} + {}_{1}H^{1} \longrightarrow {}_{7}N^{13} + h\nu$$

$$_{7}N^{13} \longrightarrow {}_{6}C^{13} + {}_{1}e^{0}$$

$$_{6}C^{13} + {}_{1}H^{1} \longrightarrow {}_{7}N^{14} + h\nu$$

$$_{7}N^{14} + {}_{1}H^{1} \longrightarrow {}_{8}O^{15} + h\nu$$

$$_{8}O^{15} \longrightarrow {}_{7}N^{15} + {}_{1}e^{0}$$

$$_{7}N^{15} + {}_{1}H^{1} \longrightarrow {}_{6}C^{12} + {}_{2}He^{4}$$

CARBON CYCLE is an important source of energy in very hot stars. In the first nuclear reaction shown here a nucleus of carbon 12 ($_{6}C^{12}$) fuses with a proton or hydrogen nucleus ($_{1}H^{1}$) to yield a nucleus of nitrogen 13 ($_{7}N^{13}$) and a gamma ray ($h\nu$). In the second reaction the nitrogen 13 nucleus decays into one of carbon 13 ($_{6}C^{13}$) and an electron ($_{1}e^{0}$). In the third reaction the carbon 13 nucleus fuses with one of hydrogen to yield a nucleus of nitrogen 14 ($_{7}N^{14}$) and a gamma ray. In the fourth reaction the nitrogen 14 nucleus fuses with one of hydrogen to yield a nucleus of oxygen 15 ($_{8}O^{15}$) and a gamma ray. In the fifth reaction the oxygen 15 nucleus decays into one of nitrogen 15 and an electron. In the sixth reaction the nitrogen 15 nucleus fuses with one of hydrogen to yield a nucleus of carbon 12 and one of helium 4 ($_{2}He^{4}$). The net result is to transform hydrogen into helium and energy.

verted into helium; indeed the inner parts of the star no longer contain any hydrogen. Consequently any further nuclear reactions in the central regions must use helium as fuel. The important reactions are those that convert helium into carbon, oxygen and neon. Three helium 4 nuclei fuse to form carbon 12; the addition of another helium nucleus to carbon makes oxygen 16; and oxygen plus still another helium makes neon 20. All these reactions yield energy in the form of gamma rays.

Thus on the giant branch the stars generate energy in two ways: in their outer regions they fuse hydrogen nuclei into helium; in the central zone they fuse helium into larger nuclei. The former reactions are often spoken of as "hydrogen-burning," and the latter as "helium-burning" (surely a chemist's nightmare).

Now just as the hydrogen-burning led to the exhaustion of hydrogen in the inner regions of the stars, so after a time the helium-burning leads to an exhaustion of helium. Further nuclear reactions at the center must wait for a further rise in the central temperature—which occurs as the central regions shrink. A rise to a temperature of 600 million degrees initiates nuclear reactions which convert carbon into sodium, magnesium and neon; a rise to about 800 million degrees converts neon to magnesium and oxygen; a rise to about 1,500 million degrees changes oxygen and magnesium to aluminum, silicon, sulfur, phosphorus, chlorine, argon, potassium and calcium. A further rise to about 2,000 million degrees causes all these elements to become converted into what is known as the iron group—titanium, chromium, manganese, iron (the most abundant member), cobalt, nickel, copper and zinc. All this is probably going on in the stars that populate the horizontal branch.

In short, a star begins with a very simple chemical composition—almost all

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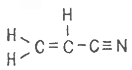
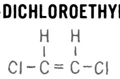
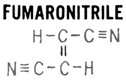


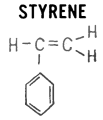
1, 2-DICHLOROETHYLENE



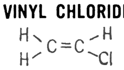
FUMARONITRILE



STYRENE



VINYL CHLORIDE



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hydrogen, with helium the only important impurity—and becomes more and more varied in make-up as its evolution proceeds. Since the temperature varies through a star, a very complex chemical structure can be built up. Consider the case where the central temperature has risen to 2,000 million degrees. At the center the material will consist entirely of elements of the iron group. Some distance out, where the temperature is 1,500 million degrees, there will be a zone made of elements from aluminum to calcium. Still farther out the main elements will be oxygen, magnesium and sodium. Neon and carbon will next be found, then helium, and finally, as an outer skin, hydrogen.

Can a star actually attain a thermodynamic temperature as high as 2,000 million degrees? It turns out to depend on the mass of the star. Such temperatures must develop in stars with masses greater than about 1.3 times that of the sun, but not in stars with smaller masses. When the sun completes its evolution, as it will during the next five billion years or so, its maximum central temperature during the final shrinkage will be only about 1,000 million degrees.

It is tempting to suggest that all the chemical elements we know have been synthesized from hydrogen by thermonuclear processes inside stars. Quite apart from the esthetic appeal of such a postulate, the suggestion derives some immediate support from the observation that hydrogen is overwhelmingly the most abundant element in the universe.

Before this theory of the origin of the elements can be considered seriously, we must answer some important questions. One is this: The clouds of gas and dust in interstellar space contain the heavier elements. How did these elements get there? Fortunately this is easy

$${}_1H^1 + {}_1H^1 \longrightarrow {}_1H^2 + {}_1e^0$$

$${}_1H^2 + {}_1H^1 \longrightarrow {}_2He^3 + h\nu$$

$${}_2He^3 + {}_2He^3 \longrightarrow {}_2He^4 + {}_1H^1 + {}_1H^1$$

PROTON-PROTON CHAIN is the principal source of energy in the sun and stars of similar temperature. In the first reaction one hydrogen nucleus fuses with another to yield a nucleus of deuterium (${}_1H^2$) and an electron. In the second reaction the deuterium nucleus fuses with one of hydrogen to yield a nucleus of helium 3 (${}_2He^3$) and a gamma ray. In the third reaction two nuclei of helium 3 fuse to yield one nucleus of helium 4 and two of hydrogen. As in the carbon cycle, the net effect is to convert hydrogen into helium and energy.

$${}_2He^4 + {}_2He^4 + {}_2He^4 \longrightarrow {}_6C^{12} + h\nu$$

$${}_6C^{12} + {}_2He^4 \longrightarrow {}_8O^{16} + h\nu$$

$${}_8O^{16} + {}_2He^4 \longrightarrow {}_{10}Ne^{20} + h\nu$$

HELIUM REACTION occurs in stars that have used up half of their hydrogen. In the first reaction here three nuclei of helium 4 fuse to yield one nucleus of carbon 12 and a gamma ray. In the second reaction the carbon 12 nucleus fuses with another of helium 4 to yield a nucleus of oxygen 16 (${}_8O^{16}$) and a gamma ray. In the third reaction the oxygen 16 nucleus fuses with a nucleus of helium 4 to yield neon 20 (${}_{10}Ne^{20}$) and a gamma ray.

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to answer. The material could have been broadcast into interstellar space by the exploding stars known as supernovae. It is suspected that at least one kind of supernovae are stars that have evolved past the horizontal branch, when most of the elements would have been built. Indeed, there are theoretical reasons for believing that the explosion may be related to the element-building processes themselves.

Two interesting tests of this theory seem to confirm it. It can be calculated that the supernova explosions which have occurred during the five billion years' lifetime of our galaxy have ejected a total mass of material which amounts to about 1 per cent of the matter in interstellar space. And just about this percentage of the interstellar matter is made up of the elements heavier than helium, according to observation. The agreement is highly satisfactory. Secondly, on our theory we should expect the stars born early in the history of our galaxy to contain much lower concentrations of heavy elements than the stars formed from the interstellar matter more recently. This expectation agrees with observation. It appears that very old stars have only about 10 per cent as high a concentration of heavier elements as recently formed stars have. The difference is presumably due to the accumulation of heavy elements in space as the result of the gigantic explosions of supernovae.

Why should hydrogen be the primeval element from which all the others are built? If that riddle is not difficult enough, here is a harder one: How did hydrogen itself come into being? We cannot beg the question by supposing that it has always existed. Hydrogen is steadily being converted into other elements by processes that seem irreversible. In spite of this, hydrogen is still the most abundant element in the universe. We must, therefore, suppose that it has a finite age, for if it had existed for an infinite time, it should all have been used up by now.

What physical process could lead to the origin of a hydrogen atom is still difficult to imagine. But I think one cannot help wondering whether the recent discoveries of the intricate structure of matter, with its plethora of evanescent particles, may not have something to do with this problem. Otherwise it is difficult to see where the fine details of physics impinge on the universe in the large. That there should be no connection at all between what one might call the subnucleonic world and the larger universe seems scarcely credible.

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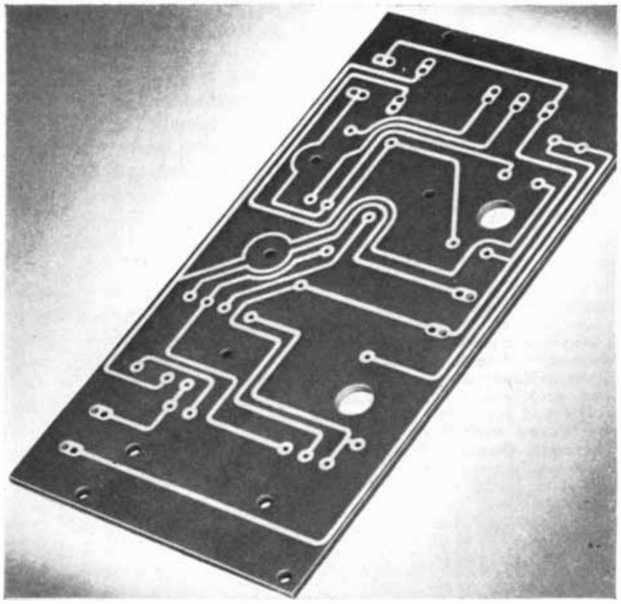

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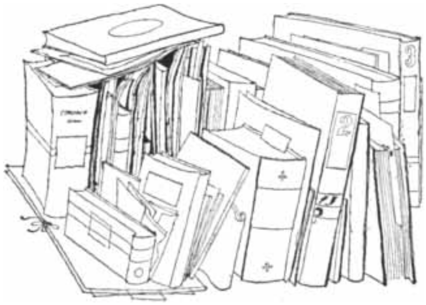


BOOKS

A compendium of knowledge about the source of virtually all the heat on the earth: the sun

by Jesse L. Greenstein

THE SUN, edited by Gerard P. Kuiper. The University of Chicago Press ($12.50).

The sun, as the nearest star, is not only the source of much of our knowledge of astrophysics but also the source of our energy, our weather and much of what we know about heat, geomagnetism, cosmic rays, the atmosphere and numerous other subjects. For these reasons this book will interest scientists and engineers in many fields. Professor Kuiper has assembled chapters by 23 authorities on the various aspects of solar physics. Not all of them are readily understandable by nonspecialists, but an excellent balance has been struck between advanced information and fundamental background for nonastronomers. The book seems to me quite a bargain—handsomely printed, beautifully illustrated and made available at a comparatively modest cost through a subsidy from the U. S. Air Force. This volume is the first in a monumental four-volume handbook which will cover the entire solar system.

We can think of the sun as a vast laboratory in which matter is subjected to extremely high temperatures and densities. At the center it is a nearly perfect gas. The temperature there is estimated to be somewhat above 13 million degrees Kelvin, and the density is about 94 grams per cubic centimeter. At the visible surface of the sun the temperature is 5,800 degrees and the pressure only about a tenth that of the atmosphere on the earth's surface. Beyond the sun's surface is an extremely thin envelope in which the temperature, curiously, rises to a million degrees. As a great, whirling ball of gas, the sun has a highly complex dynamics—far more complicated than that of the earth's atmosphere. Its three main zones—the interior, the surface atmosphere and the outer envelope—are so different from one another that they require entirely different approaches.

Bengt Strömgren, in an excellent introduction to the theory of stellar interiors, derives a new model to describe conditions in the interior of the sun. A layman may wonder how it is possible to talk with confidence about the properties of matter at such extreme conditions of temperature, pressure and unobservability; the answer is that matter is reduced to a relatively simple gas of electrons, protons and alpha particles. Strömgren deals with the two main physical questions: the sources of the sun's energy and the way in which heat is transferred from the center outward. He finds that the main energy source is the proton-proton chain of reactions that builds helium [*see Fred Hoyle's article on page 144*]. This controlled and efficient hydrogen bomb produces about eight ergs of energy per gram per second in the inner 25 per cent of the sun's mass, and has done so for at least three billion years.

Because of the high temperature the transfer of heat outward is predominantly by radiation. In the outer half of the sun's radius, however, convection becomes important and may have large effects on the atmosphere and corona. In addition, the outer layers of the sun rotate not uniformly, as a solid body does, but with decreasing angular velocity toward the poles. Thus the gases have a fairly complex velocity field. Furthermore, their flow is strongly affected by the sun's magnetic fields. Horace and Harold Babcock estimate from studies of the Zeeman effect in spectral lines that the sun has a general magnetic field of one or two gauss. T. G. Cowling considers the complex problems of solar electrodynamics, among them the peculiar fact that the huge magnetic fields of the sunspots (up to 4,000 gauss) appear and disappear within a few days. Cowling says: "Solar electrodynamics is a fascinating subject and one which is very imperfectly understood; but it is also one in which the probability of being led astray by seductive theories is very high." Nevertheless I recommend his treatment to the mathematically inclined for its wit and lucidity, and because of the new vistas opened on solar and galactic problems.

The sun's atmosphere is paper-thin compared to its body diameter of 866,000 miles. M. Minnaert offers a detailed model of the atmosphere, which he deduces to be about 300 miles thick. According to his interpretation of spectrographic studies, between the top and the bottom of this 300 miles the density of the gas increases a hundredfold, the temperature rises from 4,500 to 6,200 degrees and the pressure rises from one thousandth to nearly one atmosphere. Minnaert's model provides a basis for determining the abundances of the elements in the sun's atmosphere.

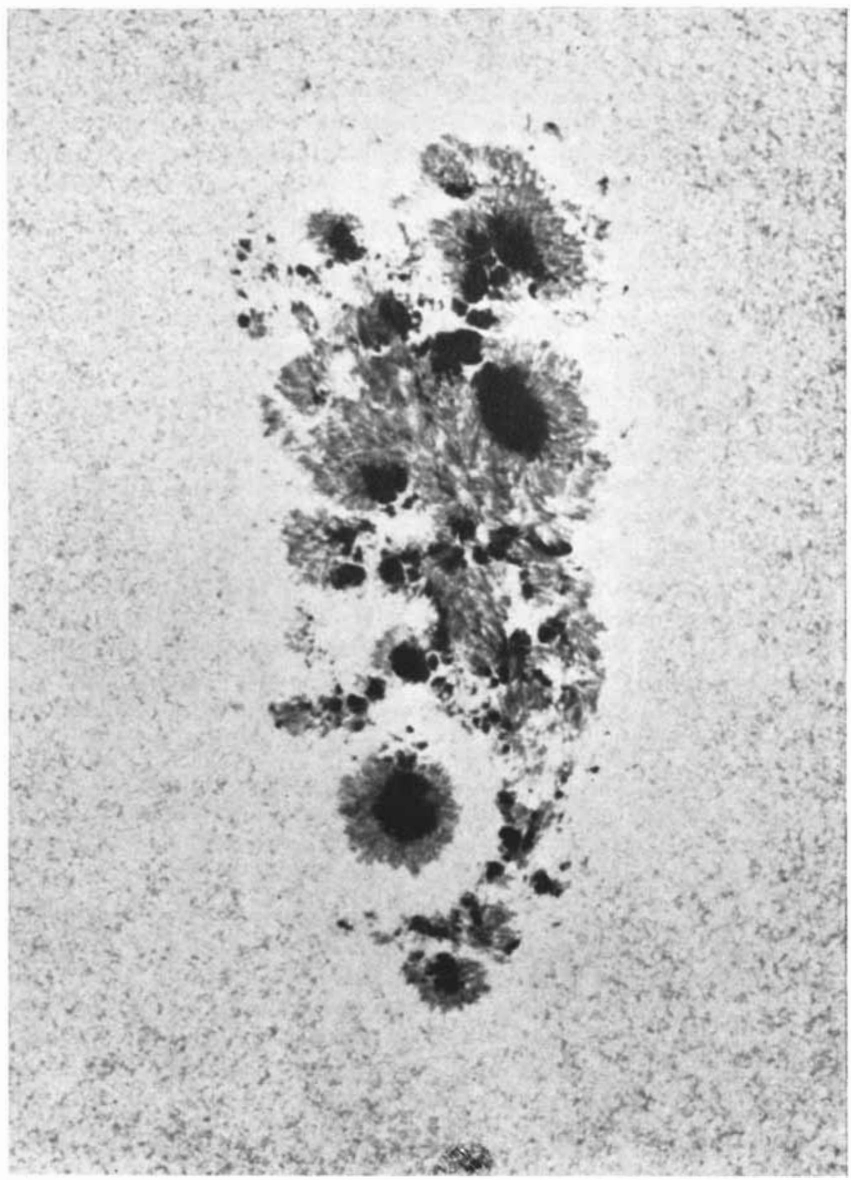
The most observed but in some respects least understood features of the sun are the disturbances we can see in and above the photospheric layers. At the lowest level are clouds of solar gas 300 miles or more in size, like giant cumulus clouds, which rise at a speed of more than a mile per second and dissipate in a few minutes. This continuous shifting pattern may be connected with deeper unstable layers. In a beautifully illustrated chapter K. O. Kiepenheuer describes the bewildering variety of phenomena at the higher levels—flares, faculae, prominences, coronal streamers and so on. These aspects of the sun's activity affect the earth's atmospheric and ionospheric phenomena in so many important ways that a good deal of government and military support has been given to investigations of them. Magnetic fields and other forces produce some weird effects on the prominences: they float against gravity for weeks; they keep a 5,000-degree temperature though in the million-degree corona; they rain down into centers of activity; they erupt into space.

The million-degree temperature of the corona has been confirmed by radio observations. Radio astronomy has provided perhaps the most exciting recent information on the sun. At radio frequencies the "quiet" chromosphere and corona emit thermal noise, and there are louder signals from sunspots, flares and active regions. These outbursts sometimes increase in intensity by a factor of 10 million in a few minutes; correlated motion studies show that the region generating the radio noise is moving outward through the corona with a speed of 600 miles per second.

I hope these few samples of the contents of this book have whetted the reader's appetite for more. The book will influence the course of further solar research. It should also be enlightening to many readers who are not specialists.

Short Reviews

Tomorrow Is Already Here, by Robert Jungk. Simon and Schuster ($3.50). As a U. S. correspondent for Swiss newspapers Robert Jungk, a former anti-Nazi underground fighter, became alarmed by our moonbound electronic technology—by its effect on our liberties and democratic traditions. There is a strong trend in America, he says, toward a "totalitarian, technicalized mass existence." He unfolds the "tomorrow" which is "already here" in a series of horrifying tableaus based on his travels through our "technological jungle." They portray the uranium-plant towns of the Northwest, where everything is brand new and spotlessly clean but the workers have to scrub themselves more often than Lady Macbeth to wipe out radioactive stains; the School of Aviation and Space Medicine at Randolph Field, where an instructor makes the grim assertion that "man is a faulty construction" for the flying tasks which lie ahead of him; the White Sands Proving Ground, where scientists propel fruit flies and monkeys into the stratosphere and speak a barbarous rocket jargon; the town of Ellenton, S. C., where, before it was razed by the AEC for its Savannah



Sunspot appears as a great vortex in the granulated photosphere of the sun

plant, a crude board sign was inscribed:

It is hard to
Understand why
Our town
Must be destroyed
To make a bomb
To destroy
Someone else's town
That he loves just the same
As we do ours. . . .

Surveying our technology in its various forms, from Madison Avenue word-mongering to automatic brains, Jungk concludes: "America is striving to win power over the sum total of things, complete and absolute mastery of nature in all its aspects." Frightened by the prospect, he has returned to Europe.

HISTORY OF STRENGTH OF MATERIALS, by Stephen P. Timoshenko. McGraw-Hill Book Company ($10.00). Based on lectures given for 25 years to engineering students, this survey by a foremost authority traces the development of the experimental and theoretical knowledge of strength of materials from Leonardo da Vinci, Galileo and Hooke through the advances of the 20th century. It also gives an account of the history of the theory of elasticity and theory of structures. The book is written in an uncluttered style, with clean, simple technical explanations and a wealth of interesting biographical material. There are good illustrations. It will appeal to a much wider group of students than the mechanical engineers to whom it is primarily addressed.

THE VOYAGE OF THE HÉRÉTIQUE, by Alain Bombard. Simon and Schuster ($3.50). The *Hérétique* was a horseshoe-shaped, inflatable rubber sausage, 15 feet long and 6 feet wide, with a 3-square-yard dinghy sail and a rudder. Bombard is a young Parisian physician who had a passion to demonstrate that, of the 200,000 persons lost annually by disasters at sea, many could be saved. Human endurance, he holds, goes well beyond the limits normally assigned by physiological science, and the sea is "rich in the necessities of life"—potable water as well as food. Together, the man and the vessel established this heretical thesis by making an almost incredible voyage—a crossing of the Atlantic on his raft. From Tangier, North Africa, to Barbados it took him 65 days. Bombard lived entirely off the sea. He showed that while you cannot get a fine dinner by dipping your hat in the Atlantic, you can survive. He ate raw fish and plankton and drank sea water in small quantities, as well as water pressed from fish. His craft was followed by a retinue of dolphins, some of which became "familiar acquaintances" to whom he talked at times. He occupied himself with navigational duties, daily medical examinations of himself, studying musical scores and reading Molière, Cervantes, Aeschylus and Rabelais. As he had anticipated, the most agonizing part of his ordeal was the fight against loneliness and fear. The physical privations (he lost 55 pounds) were secondary compared to the periodic feelings of despair, the terrors of silence. The value of Bombard's experiment to future castaways is open to question; few of them will have Bombard's training or knowledge, even fewer his lion heart. But this is a tremendously exciting story.

DESIGN FOR DECISION, by Irwin D. J. Bross. The Macmillan Company ($4.25). One of the interesting mathematical developments of recent years is the extension of statistical procedures to the making of decisions—a field pioneered by the late Abraham Wald. In the simplest case, if one is faced with two alternative courses of action, A and B, each of which admits of a set of possible consequences (A_1, A_2, A_3 . . .), (B_1, B_2, B_3 . . .), one can draw upon mathematical techniques to evaluate the probabilities of each result and of each sequence of results. This is called thinking in terms of probability event chains. The next step is to establish a value system by means of which one can assign measures of desirability to different outcomes. Each scale of measures will correspond to a basic criterion of value. For example, one might decide that minimizing the maximum risk is the overriding consideration, or, on the other hand, that a course maximizing the expected gains is preferable even if its risks are much greater. The method known as statistical decision, of which this book gives a popular account, involves the "integration" of the prediction and value systems, thus producing a decision-making "machine." Feed the machine the necessary facts, turn the crank, and recipes for prudent courses of action will emerge. There has been a good deal of ballyhoo about the promise of this procedure, which is obviously linked to other fashionable pursuits such as operational research, applied game theory, information theory and so on. Statistical decision can serve the manufacturer and the military strategist; its usefulness in other areas of human affairs has yet to be demonstrated. Bross explains some parts

of the method very well, but he is apt to labor self-evident matters while leaving the reader hung up on sharp technical hooks.

Some Aspects of the Conflict between Science and Religion, by H. H. Price. Cambridge University Press (75 cents). This is an A. S. Eddington Memorial Lecture by the Wykeham Professor of Logic at Oxford University. The scientific outlook has to all appearances "won a complete or almost complete victory" over the religious, at least among educated people of the Western world, says Price. But at the very moment of victory a new force which may indirectly bolster the religious cause has entered the contest. It is psychical research, which has discovered certain "queer and disconcerting facts" that do not square with scientific beliefs as to the range of mental powers. While these facts do not justify the conclusion that the religious conception of human personality is the right one, they do justify the conclusion "that it is not certainly and obviously false," according to Price. In other words, religion is to justify its transcendental claims on the basis of the ability of some men to see through the backs of playing cards, to predict the fall of dice, to sense the death far away of Uncle Clarence; and if science validates these phenomena, religion itself can aspire to the rank of a respectable scientific theory. An extraordinary conception.

Snow Crystals, by Ukichiro Nakaya. Harvard University Press ($10.00). The first scientific records of snow crystals were sketches published in Amsterdam in 1635 by Descartes. Thirty years later Robert Hooke presented drawings of snow and frost crystals based on microscopic observation. From time to time thereafter studies of these exquisite water jewels were published by various persons—Martens, the German Arctic traveller; Rossetti, the Italian mathematician; Scoresby, the English whalefisher; Toshitsura Doi, a feudal lord of Japan; Hellmann of Berlin and Nordenskjold of Stockholm, meteorologists. The American W. A. Bentley devoted his whole life to the making of some 6,000 photomicrographs of snow crystals. His astonishingly beautiful pictures were widely reproduced and introduced many persons to a fascinating subject. This book by Nakaya represents 20 years of patient research by the author and his colleagues at Sapporo and Mount Tokachi near the center of Hokkaido Island, Japan. It contains upwards of 1,500 photographs, some 200 charts and diagrams, together with a text which discusses the method of observation of snow crystals and the frequency of occurrence of the major types, their physical properties, artificial production of frost and snow crystals, the mechanism of snow-crystal formation in nature and kindred topics. Bentley's images, on a black background, gave an effect "like a diamond placed on velvet." Nakaya and his group, like Bentley, used transmitted light but gave up the black background and by a skillful use of oblique illumination were able to bring out the ruggedness of the crystal surface as well as the boundary shape and the internal structure. Their pictures unquestionably are the finest ever made. The text, though dense in scientific details, will give pleasure to anyone who enjoys reading about the difficulties, the intricacies, the rewards of meticulous research. An exciting, stunningly beautiful book.

THE POTATO IN HEALTH AND DISEASE, by T. Whitehead, T. P. McIntosh and W. M. Findlay. Oliver and Boyd (60 shillings). This is a revised and enlarged edition of an old handbook. No agricultural crop, the authors point out, possesses so wide an appeal as the potato. It is the staple food in some countries and is important in almost all; in its "monstre" form it "vies with the weather, the vegetable marrow and fish which just escaped the angler's gaff, as an antidote for melancholia and a lucrative subject for the professional humorist." The potato yields several times its own weight of produce, however clumsy the grower's thumb and crass his ignorance. It is also the object of unfriendly attention of armies of beetles, bugs, flies, moths, lice, centipedes, slugs, thrips and worms, the victim of various blights, rots and other diseases which are the subject of solicitous researches by agricultural scientists the world over. This valuable compendium provides data of use to "seedsman and scientist, farmer and frier, student and salesman."

AN AMERICAN IN EUROPE, by Egon Larsen. Philosophical Library ($4.75). This is a diverting account of the life of Benjamin Thompson, Count Rumford, the remarkably gifted American whose accomplishments ranged from a famous recipe for potato soup to the demonstration of the quantitative relation between heat and work. Born a farmer's son at North Woburn, Mass., in 1753, Thompson by the time he was 27 was Undersecretary of State in Lord North's Government, and three years later was knighted—partly as a reward for his services as a paid informer on American military matters, partly because of his good looks and pretty ways. Thereafter he entered the service of the elector of Bavaria as a political adviser and administrative reformer. He set up workhouses for beggars in Munich, established industrial schools, drastically reorganized the army so that others besides roughs and scoundrels were willing to serve in it, designed and built Munich's celebrated "English Garden," invented a new type of kitchen range, conducted cannon-boring experiments, held office simultaneously as the Minister of War, Minister of Police, Major General, Chamberlain of the Court and State Councilor of Bavaria, and enjoyed not only the fervent admiration of the population but also the more tangible esteem of the Elector, who made him an Imperial Count. On a visit to London he introduced the "Rumford Stove," which is still the most common type of fireplace in England. Another of his creations was the Royal Institution, which he conceived as a practical organization for diffusing the knowledge of "useful mechanical inventions" and for teaching the application of science "to the common purposes of life." Rumford was a difficult and contradictory man. He had genuine sympathy for the wretched in the large, but he abandoned his first wife, ruined the life of his daughter Sally by frightening off her suitors and divorced his second wife, Lavoisier's widow, whom he called "a female dragon." In 1814 he died of a "sudden violent fever." Larsen's readable biography gives a good picture of the man and of his relation to the life of his time.

INTRODUCTION TO THE PSYCHOLOGY OF MUSIC, by G. Révész. University of Oklahoma Press ($4.00). By psychology of music is meant the study of such matters as the concept and testing of musical capacity, the variants of musical talent and its relationship to mathematical and other aptitudes and talents, the development of musicality, the inheritance of musical capacities, the receptive and productive musical accomplishments of the deaf, the pathology of musical perceptivity. All these problems are here treated by a Dutch scientist who has carried out extensive researches in the psychology of sound and music. An introductory section presents a summary of what is known of the physical and physiological basis of sound.

WILD FLOWERS OF WESTERN PENNSYLVANIA AND THE UPPER OHIO BASIN, by O. E. Jennings. University of

Pittsburgh Press ($60.00). These two impressive volumes represent a notable achievement of the science of botany and a happy collaboration of author, illustrator and bookmaker. O. E. Jennings, director emeritus of the Carnegie Museum of Pittsburgh and retired head of the University of Pittsburgh's biology department, spent 50 years gathering the material for the text of the first volume, one of the finest accounts ever given of a single botanical region. His presentation includes a botanical history of Pittsburgh and the western Alleghany plateau, sections on the geology, physiography, climate and plant geography of the region, a bibliography, an excellent gazetteer, distribution maps for all species, meticulous descriptions of each flower, information as to the places where it can be found, when it blossoms and so on. The 200 water colors comprising the second volume are by the late Andrey Avinoff, Jennings' predecessor as director of the Carnegie Museum and, at a somewhat earlier date, a gentleman-in-waiting to Tsar Nicholas, and a "passionate lepidopterist." (On a butterfly hunt in Tibet Avinoff made a happy man of Baron Rothschild of England by finding on a white Tibetan mouse a rare flea long sought by the Baron to complete his vast collection.) Avinoff's paintings, the specimens for which were picked by Jennings and brought to the artist while still fresh, are bold, handsome and admirably faithful in displaying the important taxonomic features.

American Seashells, by R. Tucker Abbott, with illustrations by Frederick M. Bayer, D. Van Nostrand Company, Inc. ($12.50). This recent addition to Van Nostrand's New Illustrated Naturalist Series is a treasure. It is a book, as Abbott says in his preface, that belongs to the amateurs because their enthusiasm and curiosity have dictated its contents. Abbott presents an excellent natural history of seashells which tells you what mollusks have meant to man and *vice versa*; how snails grow, feed, breathe, reproduce; how clams burrow and swim; how the squid and octopus make their living. He tells you also how to collect seashells and how to identify them. The bulk of the book is devoted to identification of the various forms by means of clear, authoritative descriptions and a rich assortment of illustrations, including 24 color plates.

Music Therapy, edited by Edward Podolsky. Philosophical Library ($6.00). A collection of articles on the uses of music in the treatment of emotional and physical disorders. Aristotle ascribed the beneficial effects of music to an emotional catharsis. The Roman writer Cassiodorus stated that "it doth extenuate fears, furies, appeaseth cruelty, abateth heaviness, and to such as are watchful it causeth quiet rest." Pythagoras lauded music as a therapeutic agent. Celsus, a Roman physician, used it to treat the insane. In recent years music therapy has been more and more widely employed in mental institutions, and the papers in this book describe individual cases and programs. Podolsky reports on musical "cures" for dementia praecox and on the marked improvement brought about in a case of catatonic schizophrenia by "daily doses of Chopin's works." Ira Altshuler gives an account of music therapy at the Wayne County General Hospital, where much use is made of the "iso" principle, *i.e.*, the mood or tempo of the music must be fitted to the mood or tempo of the mental patient. Clinical psychologists discuss the melodic treatment of depression, anxiety, high blood pressure, gastric disorders and emotional fatigue; and a group of surgeons explain the use and therapeutic value of music in the hospital and operating room. It is reported that Gilbert and Sullivan's *Trial by Jury*, together with selections from Bach, Beethoven, Brahms and Bizet, cleared up the "morbid depression" of an unfortunate chap who had failed to win a promotion he had been expecting for three years. Gounod's *Soldiers' Chorus* and Rimsky-Korsakov's *Flight of the Bumblebee* are recommended for "moderating hatred brought on by any circumstances." For intense feelings of jealousy Antheil's *Piano Sonata No. 4*, Bizet's *Fair Maid of Perth Suite* and Scarlatti's *Cat's Fugue* are urged as specific antidotes. The music of Wayne King, Sammy Kaye, and the singing of Vaughn Monroe are, it is said, the very thing to dispel the tension of patients waiting to be wheeled into the operating room.

THE PRINCIPLES OF PHYSICAL OPTICS, by Ernst Mach. Dover Publications, Inc. ($3.50). This is an unabridged republication of the English translation of a work whose purpose Mach described in the preface as follows: "I have endeavored to show, from a critical and psychological standpoint, how the ideas concerning the nature of light have been moulded at the hands of prominent individual workers, what transformations these ideas have had to undergo on account of the revelation of new facts and by reason of the views associated with them, and how the general concepts of optics develop from these." The moderately-priced volume retains the original illustrations and is another of Dover's solid contributions to the study of the history of science.

American Indians in the Pacific, by Thor Heyerdahl. Rand McNally and Company ($15.00). In this 500,000-word, generously illustrated volume the energetic young Norwegian explorer who organized and led the Kon-Tiki raft expedition submits a detailed brief for his theory that the Polynesian islanders are not of Asian but of American origin. His argument rests on similarities which he and other scholars have detected between Polynesian and South American customs, legends, tools, statues, dress, language and so on. Many of his points are pretty thin, and the cultural resemblances which he emphasizes can be interpreted in different ways; nevertheless his book contains much of general interest and is an impressive example of enthusiastic scientific advocacy.

Studies in Schizophrenia, by the Tulane Department of Psychiatry and Neurology. Harvard University Press ($8.50). This is a transcript of meetings held two years ago which reviewed studies in schizophrenia at Tulane University. The department applied to its study of the disease "the disciplines of psychiatry, psychology, physiology, biochemistry, neurology and neurosurgery." Its basic hypothesis was that schizophrenia manifests itself in disturbances in pathways in the brain, disturbances which may be studied through electrical recordings. The various experiments reported here seemed to confirm this hypothesis. The results are too tentative to permit of firm recommendations as to clinical procedure, but research in the field is continuing.

Notes

Radiation Biology, edited by Alexander Hollaender. McGraw-Hill Book Company, Inc. ($17.50). This is the first of three volumes which will deal with the biological effects of radiations from the high end of the energy spectrum to the infrared region.

The Vitamins: Chemistry, Physiology, Pathology, edited by W. H. Sebrell, Jr., and Robert S. Harris. Academic Press Inc. ($16.50). Specialists contribute some 50 articles on vitamin A and carotenes, ascorbic acid, vitamin B_{12} and biotin; extensive bibliographies are provided to direct the student to the original papers. The full work, of which this is the first volume, promises to be an invaluable guide in a complex, prolific field.

Progress in Biophysics and Biophysical Chemistry, edited by J. A. V. Butler and J. T. Randall. Academic Press Inc. ($9.50). This is the fourth volume of a series of reviews of recent progress in selected areas of biophysics. Its subjects are polyelectrolyte gels, the transference of the muscle energy in the contraction cycle, the structure of nerve fibers, the nucleoprotein complex of the cell nucleus, chromosome breakage, X-ray studies of the crystalline proteins, facts and theories about muscle.

The Proteins, edited by Hans Neurath and Kenneth Bailey. Academic Press Inc. ($14.00). This volume is part of a "comprehensive, integrated account of the chemical, physical and biological properties of the proteins" for advanced students and workers.

Scientific, Medical and Technical Books Published in the U. S.—Second Supplement, edited by R. R. Hawkins. R. R. Bowker Co. ($10.00). This very useful work, prepared under the direction of the National Research Council, supplies descriptions of the outstanding scientific, medical and technical books by Canadian and U. S. citizens in the period 1949-1952.

Modern Developments in Fluid Dynamics, edited by L. Howarth with the assistance of H. B. Squire and C. N. H. Lock. Oxford University Press ($17.00). A symposium of 14 papers in two volumes, dealing with the theoretical and experimental aspects of compressible flow at subsonic and supersonic speeds.

Electrical Breakdown of Gases, by J. M. Meek and J. D. Craggs. Oxford University Press ($10.50). The authors present a survey for physicists and electrical engineers of present knowledge of the growth of electrical discharges in gases.

The Physical Chemistry of the Silicates, by Wilhelm Eitel. The University of Chicago Press ($30.00). A monumental monograph of 1592 pages, based on the author's own work and a survey of the world literature.

Dimensional Methods and Their Applications, by C. M. Focken. St.

Martin's Press. ($6.00). This book of unusual merit presents not only a clear account of the application of the dimensional technique to practical problems but a thoughtful analysis of the meaning of the concept of dimension in light of the special theory of relativity.

THE VAN NOSTRAND CHEMIST'S DICTIONARY, edited by J. M. Honig, M. B. Jacobs, S. Z. Lewin, W. R. Minrath, G. Murphy. D. Van Nostrand Company, Inc. ($10.00). Designed for the use of the working chemist.

ADVANCES IN ELECTRONICS, edited by L. Marton. Academic Press Inc. ($9.50). Volume V includes articles on beta-ray spectrometers, solid-state luminescence, the steady-state theory of the magnetron, on color television and on transistors.

PHYSIOLOGICAL ACOUSTICS, by Ernest Glen Wever and Merle Lawrence. Princeton University Press ($10.00). A monograph by two leading research workers.

WHO'S WHO IN BRITISH SCIENCE—1953. Leonard Hill Limited ($9.00). Brief résumés of more than 3,000 scientific workers in Britain.

THE COLLECTED PAPERS OF OTTO FENICHEL, edited by Hanna Fenichel and David Rapaport. W. W. Norton & Company, Inc. ($6.50). These essays were addressed mainly to specialists by a psychoanalyst and teacher who died in 1946 and is best remembered for his book *The Psychoanalytic Theory of Neurosis.* A second volume of his papers is in preparation.

GERMANY—A GENERAL AND REGIONAL GEOGRAPHY, by Robert E. Dickinson. E. P. Dutton & Co., Inc. ($10.00). Dickinson's authoritative manual considers land, climate, growth and spread of peoples, various types of rural and urban settlements, economic development, industrial, agricultural and commercial regions, foreign trade, politico-cultural groups, topography and so on.

THE ACTINIDE ELEMENTS, edited by Glenn T. Seaborg and Joseph J. Katz. McGraw-Hill Book Company, Inc. ($11.75). This volume is a record of research done under the Manhattan District and the Atomic Energy Commission on the chemical and nuclear properties of uranium, protactinium, thorium, plutonium, neptunium, americium, curium, berkelium and californium.

THE AMATEUR SCIENTIST

Largely about an artist's earnest attempt to depict the particles of modern physics

Conducted by Albert G. Ingalls

Superficially considered, art and science appear to stand at opposite poles. One confines itself largely to spiritual and emotional values; the other deals directly with the concrete, precise and measurable. Yet it is not uncommon to find individuals with strong interest and even talent in both art and science. Judging by the correspondence that reaches this department of SCIENTIFIC AMERICAN, many artists turn to science for their avocation.

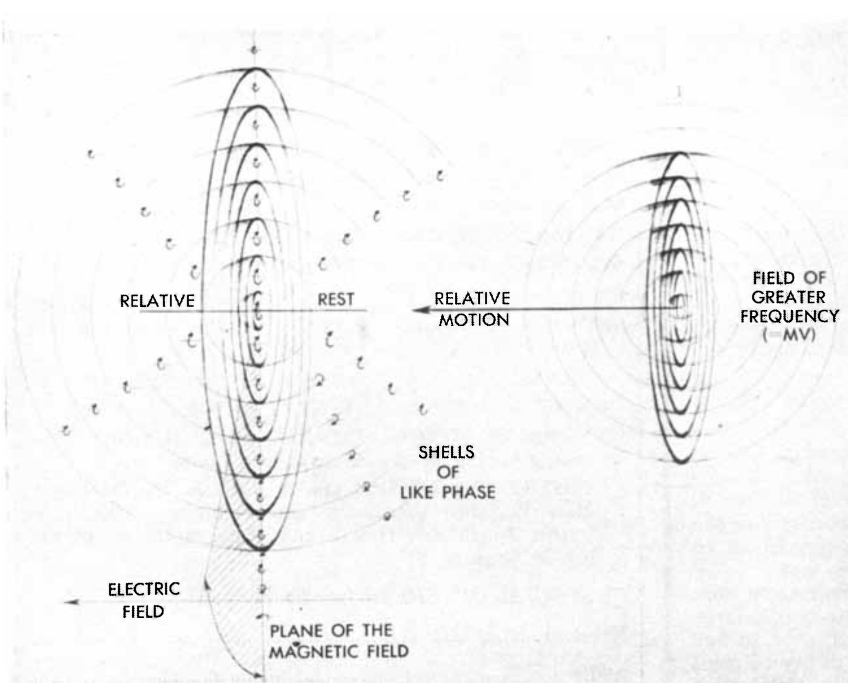
Douglass Crockwell, a professional painter and an amateur physicist, is a case in point. Crockwell's paintings have decorated the covers of leading U. S. magazines for the past quarter-century, and his scientific speculations have attracted the interest of physicists.

"The artist," writes Crockwell, "can no more escape the temptation to look for order in his sense-data than the physicist can ignore the esthetic qualities inherent in both his materials and his equations. The physicist and the artist strive toward a common goal. The concept of space, for example, is the special creation of the physicist. The portrayal of its nature is the problem of the artist.

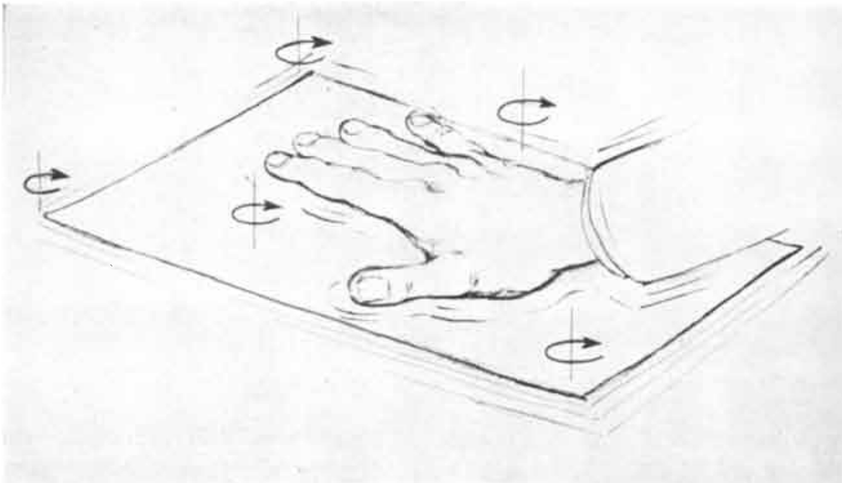
"My active interest in physics grew naturally out of abstract painting. For 18 years I have been producing abstract animated films for little-theater audiences, and for 15 of those years I have been trying to develop an acceptable visualization in a motion picture of matter and energy as conceived in modern atomic physics. The motion picture is still just a dream. But I have had 15 years of fun trying to paint an object capable of behaving simultaneously as though it were a microscopic particle and a macroscopic wave.

"Experimental evidence indicates at least 20 different subparticles below the atom with as many different associated fields. Esthetically and intuitively, however, it is felt that there should be but one general particle with one general associated field, and that from these, all individual particles and fields should be derivable as special cases. Unfortunately the mathematicians, whose quantum scaffolding so well encloses the atom, do not have another Fraunhofer ladder to bridge the mysterious gaps between the various particles. Their dedicated floundering has brought the charge from many educated but nonscientific persons that the physics of our day has become absurd, a view shared by at least a few of the scientifically educated. Louis de Broglie, for example, feels that physics is in urgent need of a more down-to-earth structure for its fundamental particles. Physics, he says in his *The Revolution in Physics,* 'has found itself very much hindered by the exclusive use of the statistical *psi* wave to describe the particles. It prohibits the use of any structural image for these particles. It is permissible to believe that a change in viewpoint embodying a return to spatio-temporal images will help this situation.'

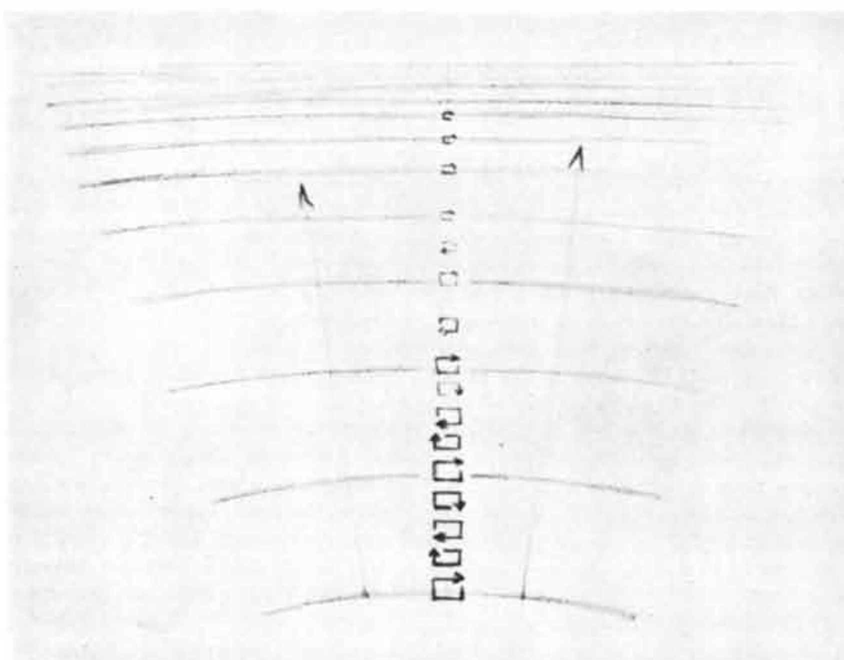
"In attempting to account for conflicting sense-data derived by experiment, our formal logicians have withdrawn ever farther into the realm of abstraction until, in adopting Heisenberg's principle of uncertainty, they have even placed a restriction on what it is possible for man to know. Herbert Dingle, professor of history and the philosophy of science at University College in London, sees the current dilemma as a product of confusion between sense-data and postulates. He calls attention to the sharp philosophical distinction between the green glow on the face of an oscilloscope as reported to the brain by the eye and the concept of the electron that was invented by man's imagination to account for the glow. The electron, he points out, is not necessarily an independently existing physical object. Certain sweeps of a pointer across a dial can be accounted for *if* a something exists in the form of a wave. Certain sweeps of other pointers across other dials can be accounted for *if* a



Basic particle visualized by Crockwell is characterized by circular translation



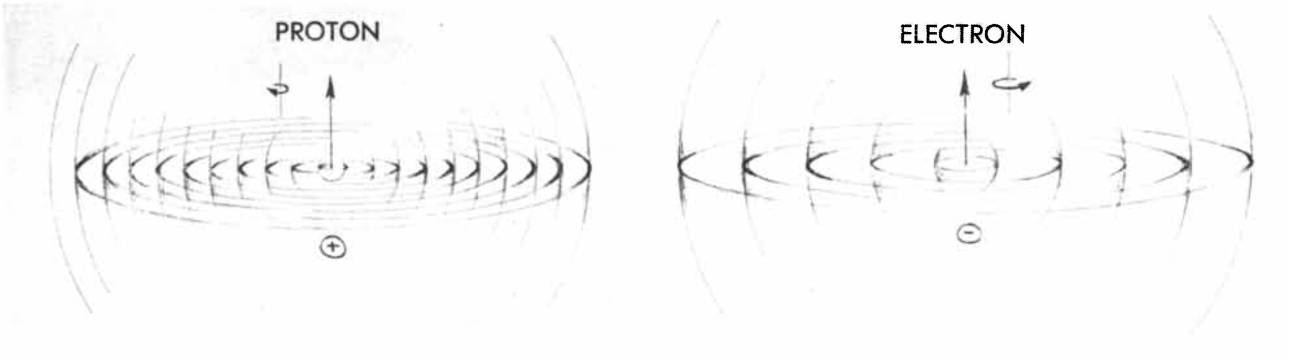
Circular translation is demonstrated with a piece of paper on a smooth surface



Shells of like phase are explained by a lag in circular translation

something exists in the form of a particle. The dilemma arises, says Dingle, when we insist that both 'somethings' must be the same thing and then compound our befuddlement by attempting to confer upon these incompatible postulates the independent physical reality reserved by nature for our sense experiences. It strikes me as fortunate that the electron is not necessarily an independently existing 'thing,' but merely an invention of reason. We may discard it with impunity—as we discarded phlogiston and the luminiferous ether—without impoverishing nature in the least. The question is, what is to take the electron's place? With fingers crossed, I offer the following generalized particle-field.

"It seems reasonable, as a first thought, to accept each particle-field relationship as an inseparable something, which is perceived sometimes in one fashion and sometimes in another. We might also think of the particle portion of the effect as that which is received along the course of particle-field motion and the field portion of the effect as that which is experienced radial to the course or potential course [*see illustration on the opposite page*]. We know that some relationship of this sort exists, whether or not it is exactly as stated. Variation of one effect is accompanied by a reciprocal variation in the other effect. In other words, the more the particle-field manifests itself as a particle, the less it manifests itself as a field, and



Electron and proton differ in the direction of translation and the spacing of phase shells

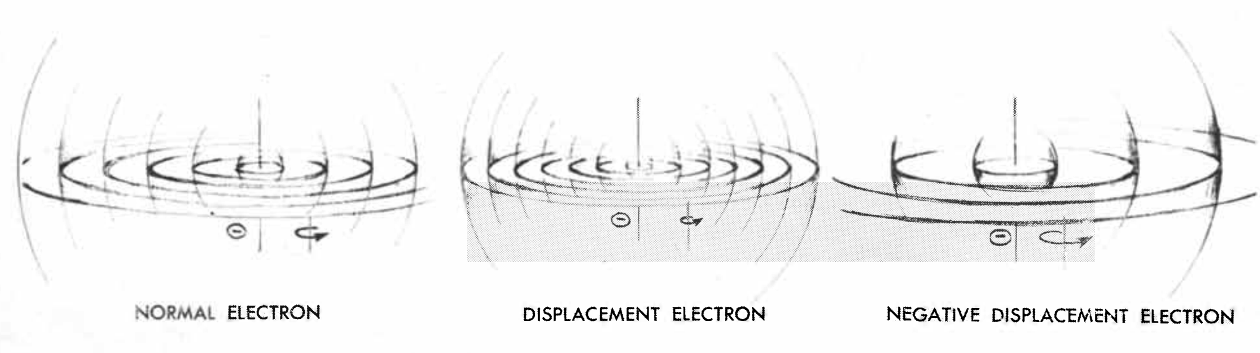
vice versa. Further, the intervention of another particle-field produces a potential state of variation.

"We also know that charged particles in motion exhibit a 'sense' or quality of right- or left-handedness which characterizes their charges. The field of a 'negative' particle seems to match the field of another negative particle when the two are in like parallel motion. This is also a property of positive particles. Fields of unlike charge seem to match when the particles move in opposite directions. From this we can infer a kind of tangential motion in space around the course of a particle—a motion which differs between particles of unlike charge. But we have learned to reject the idea of flow around the moving particle. Is another type of circular motion possible and, if so, would it not make an interesting starting point for our model?

"In consideration of these observed tangential field qualities, I should like to suggest a three-dimensional field in which every point describes a continuing motion of *circular translation*. Some of the fields are to be in left translation and others in right translation. Translation, strictly defined, is a form of motion in which all points of the moving body have the same velocity and direction at any instant. Strict circular translation can be demonstrated in two dimensions by placing a sheet of paper on a smooth desk top and rotating it by hand without losing parallelism between the edge of the paper and the edge of the desk top [*upper drawing on the preceding page*]. All points in my particle-field concept will have a similar circular motion but, since the response of the field is not instantaneous, the phase of rotation will vary from the center outward [*lower drawing on preceding page*]. In the latter illustration the circular translation has been sketched as arrow-tipped rectangles in order to indicate more clearly the lag in rotation of various areas as the field is explored along a radial path from the center. It is important to remember that the field does not rotate as a unit. The areas of the field vary only in the diameter and the phase of translation. As the field is explored from the center outward, the phase of rotation lags progressively. Hence its structure can be considered as a series of concentric phase shells, each 360 degrees out of step with adjoining neighbors.

"The field and particle are one, and at all points the action is similar. The diameter of translation is greatest when the particle is at relative rest. An increase of particle-field velocity is accompanied by an increased *rate* of rotation but a smaller *radius* of rotation. In other words, with increased velocity, a specific point in the field rotates faster and describes a tighter circle. Outer regions of the field are characterized by similar translation but of lesser amplitude, and the lag in phase progresses radially with the velocity of light. As previously noted, shells of like phase, but each lagging 360 degrees, exist concentrically throughout the field. The greater the relative particle velocity, the more rapid the circular translation, the less the radius of translation and the closer the spacing of like-phase shells. The term 'frequency' may be applied to the density of the shell structure, and the shells may be thought of as standing wave fronts—but *not* as electromagnetic waves.

"The greater the phase frequency of the field, the greater will be the apparent mass or velocity of the particle. Momental mass is a property shared by bodies in relative motion, and appears in the field as a frequency shared by the two bodies. A single particle in a free space could have no velocity, momental mass or phase frequency. Absolute assignment of the portions of the shared frequency is impossible. Actually no difference appears between rest mass and momental mass in the observed field structure. When observed as a proton, the particle-field has a relative rest frequency 1,835 times that of a particle-field in opposite rotation



Distortion of field gives rise to displacement (current-carrying) and negative displacement (mass defect) electrons

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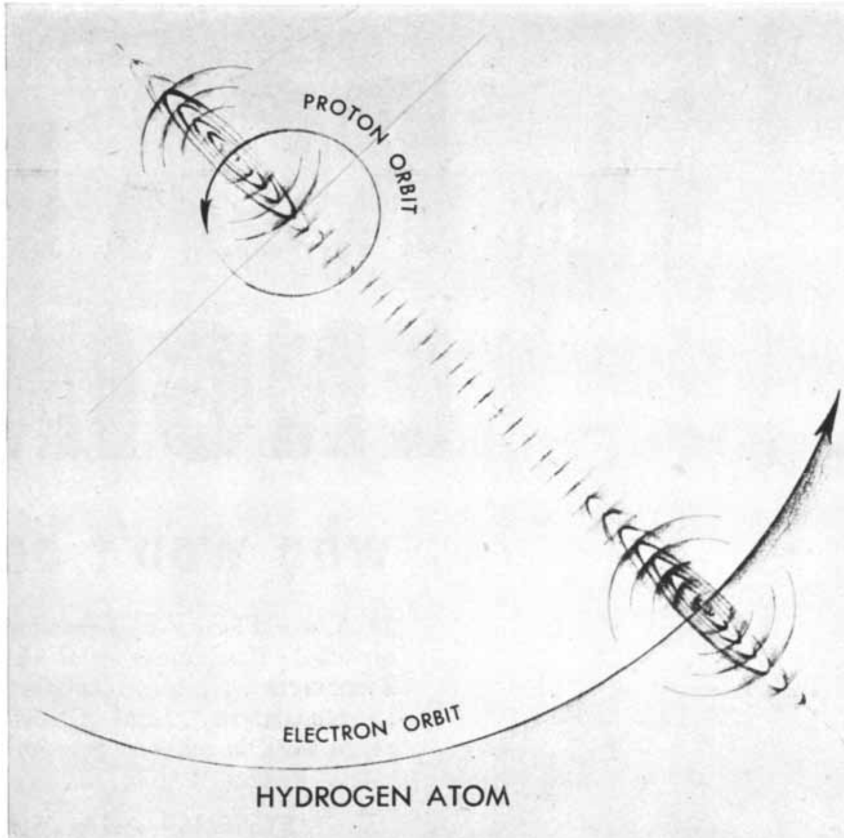


Greater momentum of an electron in an atom meshes its shells with those of a proton

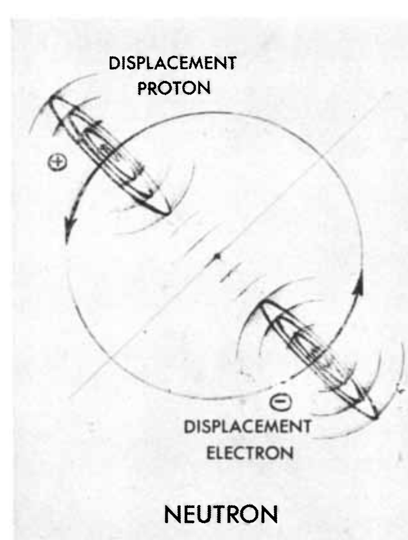
which is observed as an electron [*see drawings at top of page 174*]. These two particle-field states are in effect stable. The charged meson states, however, are unstable, and may represent distortions of the basic electron and proton states.

"Neutral particles are all believed to be multiplets of charged particles in rotative association, as shown in the drawing at the right. In atomic groups this is generally true. In the neutron and neutral mesons this is less certain, but may be indicated by the decay products. Within the neutron (and mesons) the basic proton and electron particle-fields (of which they are composed) are probably subjected to field distortions so extreme as to render them temporarily unrecognizable.

"Particle-field distortions occur when environmental restrictions prevent a complete reciprocation of particle and field effects. Thus we may have, if external motion is restricted, an abnormal phase frequency which might be interpreted as displacement current, electric field potential or excess mass. If internal tension reduces the phase frequency to less than it should be according to external velocity, then mass defect is observed (or a meson).

"Just why all protons should have one translation and most electrons another is not understood, although some system of priority exclusion may operate. Just why there should be two stable mass levels is also not understood, but these are problems shared by all theory.

"Particle motion always takes place along the axis of circular translation as the particle-field passes through other environmental fields. The fields appear to exert a combing action on one another. (One particle in a free space



Proton and electron mesh in a neutron

Carl Vrooman, icing tunnel group head, studies hot-air cyclic de-icing test on wing section of C-130 transport. The tunnel has a temperature range of —40° F. to +150° F. and maximum air speed of more than 270 mph.

New icing tunnel speeds thermodynamics research at Lockheed

Designed to meet a constantly increasing volume of thermodynamics work, Lockheed's new icing research tunnel now provides year 'round testing in meteorological environments normally found only in flight. It is the first icing research tunnel in private industry.

Lockheed thermodynamics scientists were formerly limited to testing time available at installations such as Mt. Washington. Now they are able to study in greater detail problems such as: thermal anti-icing; cyclic de-icing; various methods of ice removal; distribution of ice; rate of temperature changes in aircraft components; thermodynamic correlation between laboratory and flight testing; and development and calibration of special instrumentation.

C. H. Fish, design engineer assigned to the tunnel, measures impingement limits of ice on C-130 wing section. The tunnel has refrigeration capacity of 100 tons, provides icing conditions of 0 to 4 grams per cubic meter, droplet sizes from 5 to 1000 microns.

Thermodynamicist Ed Dean monitors main control panel in picture at left. Temperature, air speed, water flow rate, air pressure and other variables can be regulated independently.

B. L. Messinger, department head, analyzes test results with Thermodynamics Engineer E. F. Versaw and Thermodynamicist Tom Sedgwick. The report was in their hands *only two days* after it was decided to conduct the test.

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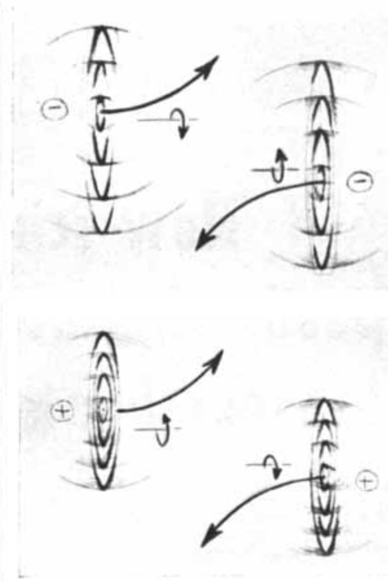
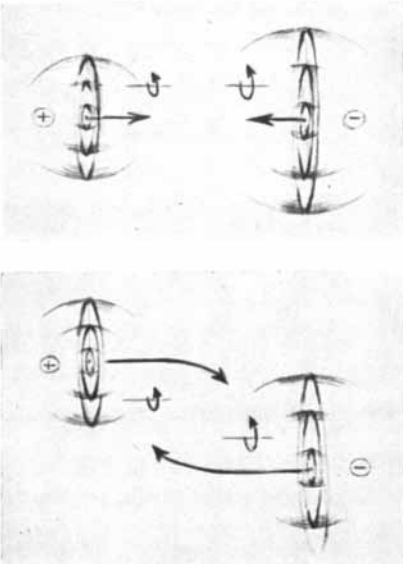


Opposed motion with like fields

could conceivably have any external motion.) Particle-fields of opposite circular translation (that is, of unlike sense conjunction) tend to move apart. Particle-fields of like sense conjunction tend to move in parallel paths. A proton and an electron follow parallel paths when moving in opposite directions or rotating about one another, and two electrons do so when moving in the same direction. There is a tendency for the spacing to remain constant. Acceleration of both particle-fields causes them to move together. Deceleration of both causes separation.

"Passage of one particle-field through another of like translation results in a matching adjustment between the fields. This adjustment is oscillatory, and, if the contact is short, most of the frequency (phase-shell spacing) shifts from one field to the other. If the contact is extended, the fields may nearly match and share the total frequency and external motion. Under the Pauli exclusion principle, however, their field states could not be identical. This could be a picture of energy partition or transfer through induction. With trivial differences, it could also be a picture of energy transfer through classical particle contact. In a closed system the total frequency of the particle-fields is constant and shared mutually.

"The fields of a proton and an electron revolving about one another on their respective sides of the axis at the center of mass would have, in effect, the same direction of circular translation or sense. The much greater radius of the electron would contribute just enough velocity, and hence momental mass, to establish a stable, rotating sys-

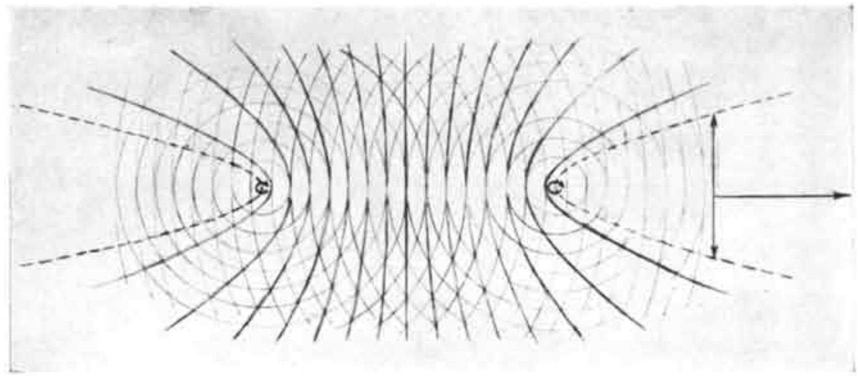


Opposed motion with unlike fields

tem. In the absence of external influence, the field mesh would, therefore, remain constant and the pair would continue in stable rotation indefinitely. An approaching external field or changing portion of field would cause a change of frequency, first in one and then in both particle-fields. A remeshing would be required to maintain the stability. The nearer the particle-field centers approach one another, the greater the environmental change necessary to alter the meshing. A limiting or normal state is implied.

"At each remeshing of the fields, areas of intensification and interference shift throughout the two fields. These areas are most prominent along a common radial line. They move outward at the velocity of light. With oscillatory adjustment of the particle spacing, these areas change periodically, and may be thought of as electromagnetic waves or photons.

"In a more complex atom than hydrogen, the protons and electrons might be again visualized moving in a single orbital plane. Fields would all be oriented to this plane. Thus all fields would mesh in the same sense or direction of circular translation. Certain particle-field distortions would occur because of the complex adjustments needed. In the complex atom, the orbit of neutron doublets would be located in the common plane of the atom, probably nearer the axis than the protons. The whole complex phase-frequency mesh would revolve as a unit with the relative motion of negative and positive particle-fields compensating for individual differences of sense translation. Energy transfer can take place only



Meshing phase shells in like translation results in interference phenomena

between shells of like phase or between harmonics arising through interference between these shell states. Obedience of energy-state transition to the laws of quantum mechanics is implied. Binding energy would appear as a mass defect caused by particle-field distortion.

"This atom would seem to have the simple geometry necessary for building molecular lattices. In addition, it has the attractive feature of demanding no mysterious and unknown pair of field forces—one to keep electrons from collapsing upon the nucleus and one to prevent the explosion of protons in the nucleus.

"Here, then, is a proposed model which appears capable of accounting for at least some of the conflicting sense-data reported during the past half-century by experimental physicists. The approach is certainly nonprofessional and nonmathematical—perhaps noncerebral also. It is hoped that the results are not too contradictory as far as known experimental evidence is concerned. Perhaps this attempt, even though it is an amateur one, will encourage others to try. In defense of models generally I submit a line from the great James Clerk Maxwell's preface to his theory of electromagnetic radiation: 'In several parts of this treatise, an attempt has been made to explain electromagnetic phenomena by means of mechanical action. . . .' "

Is there any justification for low-grade optical workmanship? In last month's issue James L. Russell of Cleveland, who has taught hundreds of amateurs to make their own telescopes, described one justification—expediency. He had observed that many beginners bogged down and quit before finishing their first mirror, in the mistaken belief that a less than perfect mirror would fail to function. He was able to increase the percentage who finished by deliberately encouraging the candidates not to try for perfection, since even a poor mirror will perform well enough to please its owner for at least a season until his observing skill has become sophisticated. I described Russell's practical methods of teaching the art and promised to explain in terms of physical optics why even a poor mirror will work, to give a revised criterion for good mirrors and to show why an experienced observer needs one. What follows is not an over-all letting-down in standards but the provision of several widely differing standards for different observers' needs.

It has been said many times that in any reflector the famous Rayleigh criterion calls for precision of the surface to one eighth of a wavelength, or one 400,000th of an inch. So often has the term "good, honest, eighth-wave optics" been used in speech and writing that many have supposed it an inexorable standard. Actually the tolerance is relaxed at the outset to one 200,000th of an inch by the fact that in use of the mirror the eyepiece may be adjusted to an average focus. This is explained by F. B. Wright and by J. R. Haviland in the *Amateur Telescope Making* books. Alan E. Gee now explains it graphically [*drawings on page 182*]. He writes: "In the first diagram, the curve being hyperboloidal, the observer automatically focuses the eyepiece at the best focus, *b*, where the circle of confusion is smallest, ignoring *a*. In the second the curve is spherical (undercorrected mirror) and he again selects *b* instead of *a*. For regular undercorrection or overcorrection this ability to focus results in a reduction of the *effect* of the spherical aberration by a factor of four. For the effect of zones no such statement can be made. The observer will still work at best apparent focus; however, where this will be, and how good it will be, depend upon such factors as the relative area or areas of the zones producing the errant rays, their intercept on the optical axis, and

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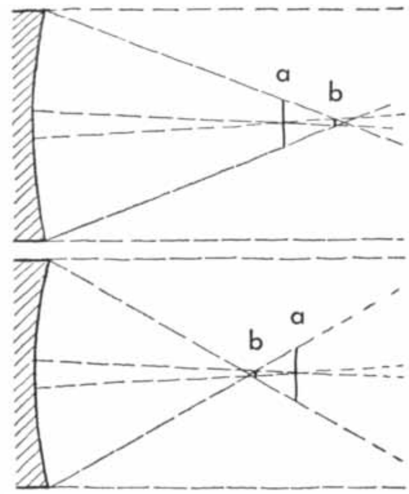


The eye helps the mirror

their angular subtense. Based on the Rayleigh limit, Wright's tolerances in *Book One* are all too stiff by a factor of two. A six-inch mirror is about at the Rayleigh limit if left spherical at $f/8$. I suspect more of these $f/8$ mirrors are worsened by attempted parabolization than are improved."

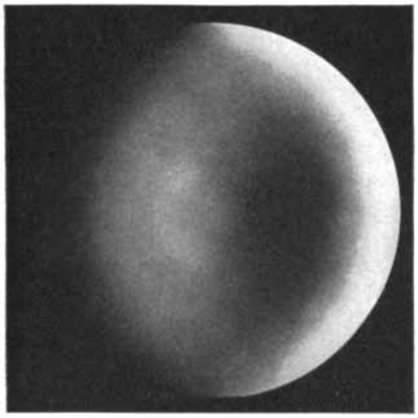
In this fundamental matter, governing all amateur telescope makers' exertions, Wright now assents with Gee and others who have challenged his standard as too exacting, saying, "I based my limits on smooth curves of surface viewed from the position of best average focus, then made the limits twice as strict as this calls for to take care of imperfect measurements or imperfect focusing, and from just plain conservatism."

Other reasons why poor mirrors work well enough to please uncritical users are: (1) A novice observer is likely to look most often at the moon, because it is such a spectacle, and, as Horace H. Selby has pointed out in *Book Three*, with a low-powered eyepiece almost any telescope will give a good impression of the moon, because the iris of the eye contracts so strongly under the high illumination that the aberrations have little effect on the sharpness of the image. (2) On many nights the turbulence of the earth's atmosphere tends to reduce the observational difference between a fine mirror and a poor one.

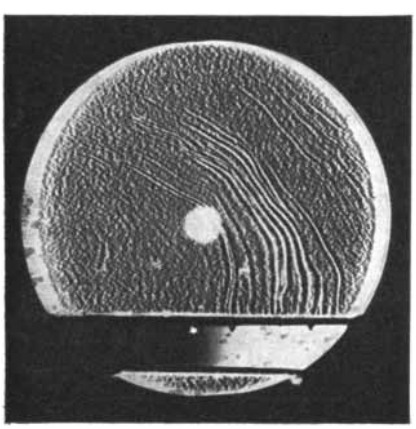
These reasons may seem to provide an alibi for sellers of poor telescopes. As a matter of fact, the complaint against such merchants is not that their instruments are too poor for use by the average beginner but mainly that their claims of precision sometimes are too strong.

Having dealt with the soft side of the Rayleigh limit at least as generously as the facts of physical optics permit, let us now climb over the fence into the rarefied realm of the perfectionists. True as it is that few observers are expert enough and few nights of seeing good enough to exploit the superiorities of a fine mirror, for many amateurs much of the enjoyment of the hobby consists in the pride of achieving a precision within one millionth of an inch. The amateur telescope makers' chief contribution to science has been in producing precision optical instruments.

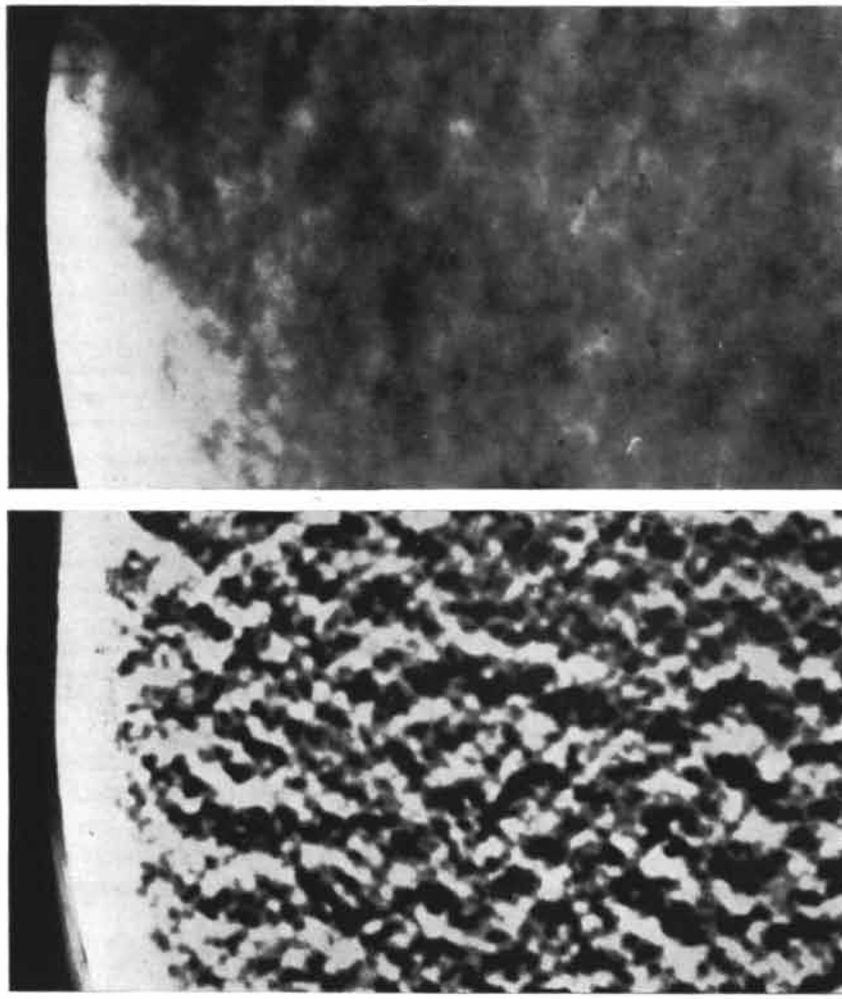
Furthermore, precision is not to be belittled even when it comes to ordinary use of the telescope. The one kind of observing for which it is profitable to approach and surpass the Rayleigh limit is the close observation of fine detail on the moon and planets. And this is just what most interests the average amateur. The detail is made visible by contrasts between adjacent areas. Without the contrasts there is no detail, and all is flat. These contrasts are heightened in proportion to the quality of the telescope. This can be proved by physical optics but observing demonstrates it dramatically. Here J. R. Haviland's statement in *Book Two* that perfection beyond the Rayleigh



Mirror made by Jean Texereau



Testing a mirror by the Lyot method



Same surface by focogram (top) *and lyot-gram* (bottom)

limit will not noticeably improve the image is inadequate. It has been shown that, for the faintest perceptible contrasts, the efficiency of a mirror rises from 62 per cent when corrected to the Rayleigh limit, to 92 per cent when the correction is carried to one fourth of that limit. The optical designer James G. Baker says in a private communication: "At very low contrast levels, such as obtain on the planetary disk, a mirror made as poorly as the Rayleigh limit will not perform well and a much better mirror should be the goal. Recent research has refined the rule-of-thumb tolerances expressed by Conrady in favor of more exact rules. French observations in the laboratory indicate that there is no real lower limit to the accuracy requirements for the observation of maximum contrast of faint details. For example, if the contrast level is as low as 1.01 to 1, it may be necessary to have the optical system perfect to within one fiftieth of a wavelength. Any amateur sincerely interested in a high-quality mirror is likely to continue, as at present, seeking the best curve he can obtain."

Related observations and experiments have been made by André Couder and Jean Texereau. Couder is astronomer at the Observatory of Paris and co-author with André Danjon of the basic work *Lunettes et Télescopes.* Texereau began as an amateur in 1938 with *Amateur Telescope Making* and is now a professional optician, one of his most recent pieces of work being a 24-inch Cassegrainian for Meudon Observatory, another a 20-inch Cassegrainian with its secondary supported on a plane-parallel glass plate instead of an obstructing spider. He is the author of *La Construction du télescope d'amateur* and leader of the amateur telescope-making group of the Astronomical Society of France. The upper photograph on the preceding page is a Foucault focogram from an eight-inch $f/6$ mirror he figured.

Couder and Texereau have studied the harmful effects of extremely small mirror defects, using a powerful optical lever—a phase-contrast photographic

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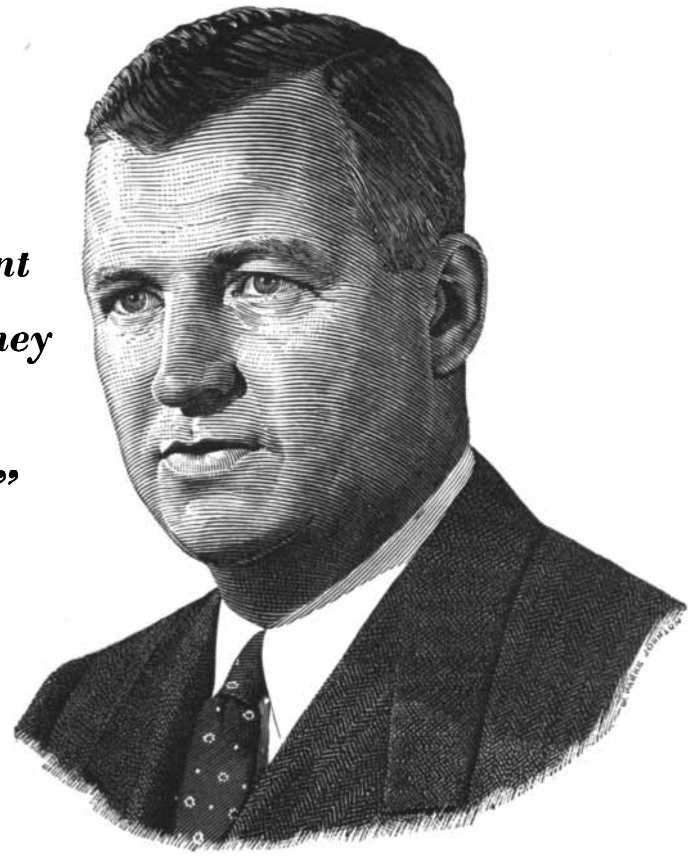

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method of testing devised by the French astronomer Bernard Lyot. The Lyot test clearly discloses defects only one 500-millionth of an inch deep—one half angstrom!

The photograph at the bottom on page 183 is a Lyot picture of an ordinary five-inch mirror polished on a pitch lap painted with wax. The crosswise strip is the image of the photometric wedge used in the Lyot test. This test employs the basic Foucault setup, plus a phase plate and camera, but unfortunately requires that the mirror be made of optical glass because of the striae in plate glass and Pyrex. The prominent streaks are striae within the glass and must be ignored. Remaining are myriads of tiny defects about one 100-millionth of an inch deep. Not one of the little bumps (together called *micromamelonnage*) would be even faintly visible with the visual Foucault test, and this glass would have a featureless polish if directly examined with a 40-power microscope at the reflection from a concentrated light beam. Nevertheless these defects diffract enough light to lower a mirror's efficiency when used in observing faint contrasts on the moon or planets.

The two photographs on page 184 compare a focogram with a picture of the Lyot type, which we might call a "lyot-gram." The upper picture is a focogram four times magnified, near the edge of a typically lumpy surface polished with HCF. It shows a mottled surface. Below it is a lyot-gram of the same area; it reveals the depth of the *micromamelonnage* to be about eight 100-millionths of an inch.

The phase-contrast method has also proved that polish on paper with rouge, on waxed pitch with rouge and on pitch with cerium oxide or with Barnesite gives smoother surfaces than polish on HCF. The smoothness is in the order named. None of these gives nearly as smooth a surface as pure unwaxed pitch with rouge, especially when the final "wet" is almost completely dried up.

Our investigation of the easy and difficult sides of the Rayleigh limit has shown that there is no cut-and-dried standard of quality for a telescope mirror. Instead there must be a separate standard for each observer. A rather poor mirror will give pleasing images of stars and nebulae and of the moon and planets when viewed as a whole. But those who wish to resolve close double stars or observe details on the moon and planets, as well as those who take pride in their workmanship, will not aim at anything less than perfection.

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SEPTEMBER, 1954

BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

MAN THE FIRE-MAKER

PROTEINS AND REPRODUCTION. William A. Albrecht in *The Land*, Vol. 11, No. 2, pages 207-212; Summer, 1952.

SOIL FERTILITY AND THE HUMAN SPECIES. William A. Albrecht in *Chemical and Engineering News*, Vol. 21, pages 221-227; February, 1943.

A GEOGRAPHICAL SKETCH OF EARLY MAN IN AMERICA. Carl O. Sauer in *The Geographical Review*, Vol. 34, pages 529-573; October, 1944.

WHY THE GREAT PLAINS ARE TREELESS. Omer C. Stewart in *The Colorado Quarterly*, Vol. 2, pages 40-50; 1953.

WHAT IS HEAT?

THEORY OF HEAT. Max Planck. The Macmillan Company, 1932.

A NUCLEAR SPIN SYSTEM AT NEGATIVE TEMPERATURE. E. M. Purcell and R. V. Pound in *The Physical Review*, Vol. 81, pages 279-280; January 15, 1951.

HEAT AND LIFE

THE KINETIC BASIS OF MOLECULAR BIOLOGY. Frank H. Johnson, Henry Eyring and Milton J. Polissar. John Wiley & Sons, Inc., 1954.

TEMPERATURE AND HUMAN LIFE. C.-E. A. Winslow and L. P. Herrington. Princeton University Press, 1949.

LIFE AND DEATH AT LOW TEMPERATURES. B. J. Luyet and P. M. Gehenio. Biodynamica, 1940.

HIGH TEMPERATURES: FLAME

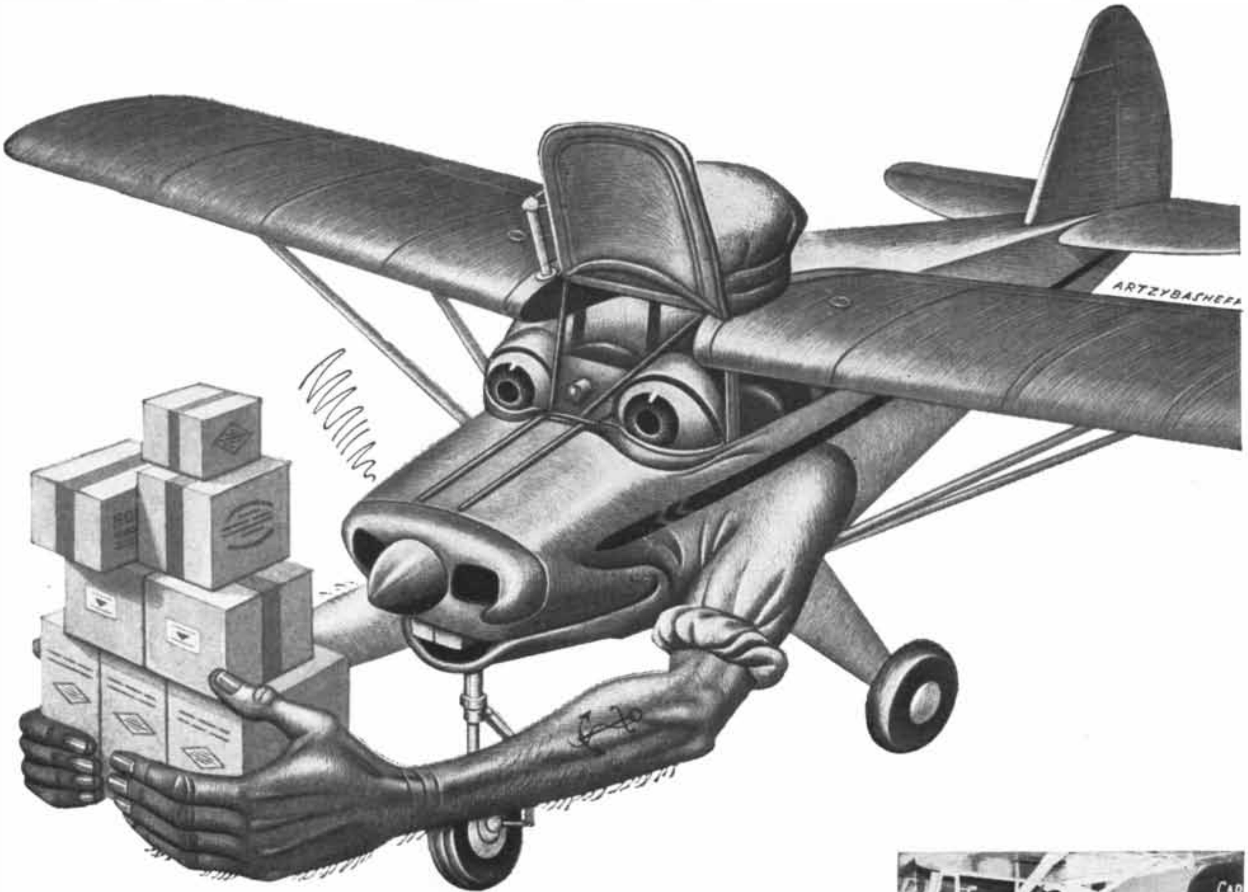
COMBUSTION, FLAMES AND EXPLOSIONS OF GASES. Bernard Lewis and Guenther von Elbe. Academic Press, Inc., 1946.

EXPLOSION AND COMBUSTION PROCESSES IN GASES. Wilhelm Jost. McGraw-Hill Book Company, Inc., 1946.

FLAMES: THEIR STRUCTURE, RADIATION, AND TEMPERATURE. A. G. Gaydon and H. G. Wolfhard. Chapman and Hall, Ltd., London, 1953.

HIGH TEMPERATURES: MATERIALS

METALS AT HIGH TEMPERATURES. S. H.



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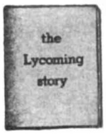

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Manufacturing plants in Stratford, Conn., and Williamsport, Pa.

Clark. Reinhold Publishing Corporation, 1950.

REFRACTORY HARD METALS. Paul Schwarzkopf and Richard Kieffer. The Macmillan Company, 1953.

SYMPOSIUM ON MATERIALS FOR GAS TURBINES. American Society for Testing Materials, 1946.

HIGH TEMPERATURES: CHEMISTRY

THE THERMODYNAMIC AND PHYSICAL PROPERTIES OF THE ELEMENTS. Leo Brewer in *The Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics*. McGraw-Hill Book Company, Inc., 1950.

FIXATION OF ATMOSPHERIC NITROGEN IN A GAS-HEATED FURNACE. William G. Hendrickson and Farrington Daniels in *Industrial and Engineering Chemistry*, Vol. 45, pages 2613-2615; December, 1953.

HIGH TEMPERATURES: PROPULSION

ROCKET PROPULSION ELEMENTS. George P. Sutton. John Wiley & Sons, Inc., 1949.

GAS TURBINES FOR AIRCRAFT. A. W. Godsey, Jr., and Lloyd A. Young. McGraw-Hill Book Company, Inc., 1949.

VERY HIGH TEMPERATURES

THE PRODUCTION OF HIGH TEMPERATURE GASES IN SHOCK TUBES. E. L. Resler, Shao-Chi Lin and Arthur Kantrowitz in *The Journal of Applied Physics*, Vol. 23, pages 1390-1399; December, 1952.

ULTRAHIGH TEMPERATURES

SOME RECENT RESEARCHES IN SOLAR PHYSICS. Fred Hoyle. Cambridge University Press, 1949.

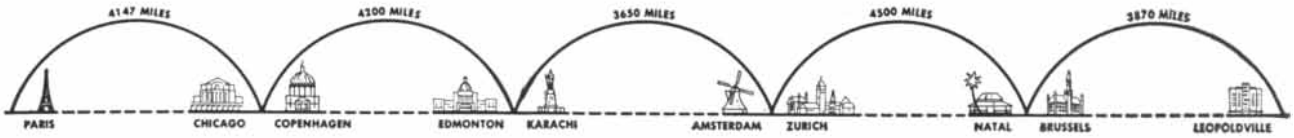
THE AMATEUR SCIENTIST

THE SCIENTIFIC ADVENTURE: ESSAYS IN THE HISTORY AND PHILOSOPHY OF SCIENCE. Herbert Dingle. Philosophical Library, 1953.

AMATEUR TELESCOPE MAKING. Edited by Albert G. Ingalls. Scientific American, Inc., 1952.

AMATEUR TELESCOPE MAKING—ADVANCED. Edited by Albert G. Ingalls. Scientific American, Inc., 1952.

AMATEUR TELESCOPE MAKING—BOOK THREE. Edited by Albert G. Ingalls. Scientific American, Inc., 1953.



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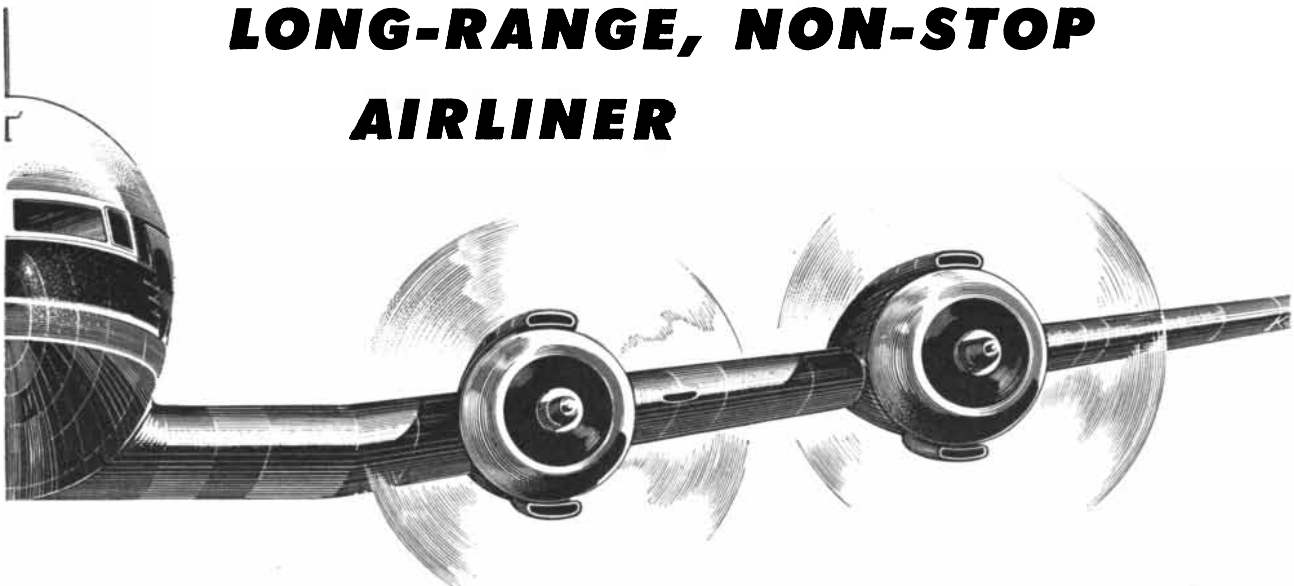

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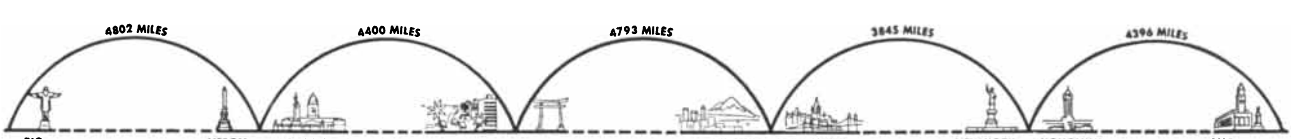

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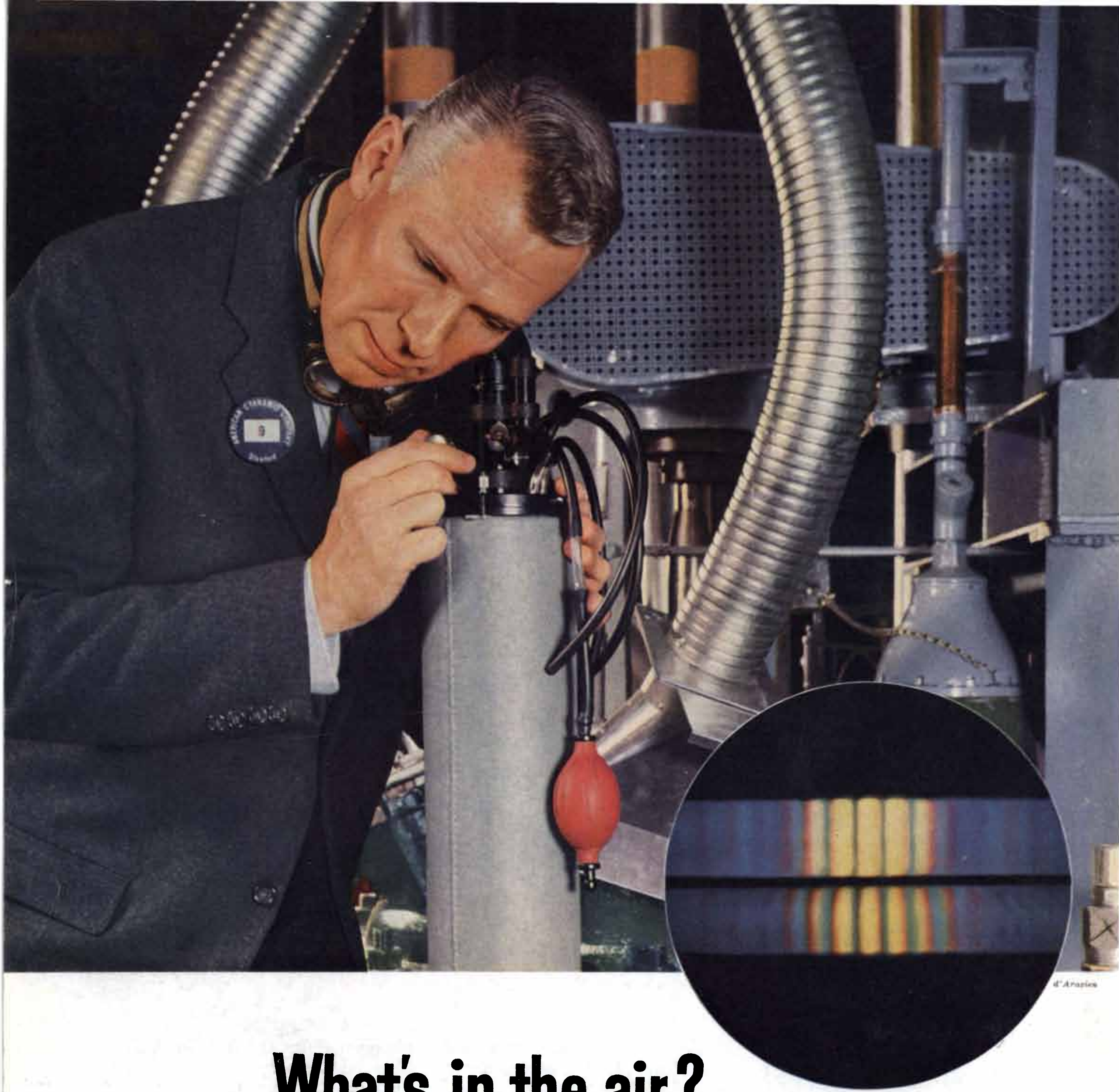

d'Arazien

What's in the air?

This man is looking at air. The unusual instrument he is using is an interferometer—one of three used in industrial hygiene in the United States. It enables him, through color patterns, to measure concentrations of vapors and gases present in the air.

This is one of many ways in which American Cyanamid Company protects the health of its employees as part of a broad program of preventive medicine. Under the direction of a Central Medical Department, a staff of doctors, nurses and industrial hygienists is organized to promote good health at each of Cyanamid's plants and offices throughout the country—and provide prompt medical aid when needed. Members of the medical department work closely with local specialists and family physicians in protecting employee health. They also cooperate with customers, and with industry and professional groups in maintaining high health standards. And they exercise constant vigilance over all Cyanamid products and processes to make sure that no health hazard exists without proper safeguards.

American Cyanamid Company believes good health is a most important asset. This is why it was one of the first in the country to initiate a modern, comprehensive program of preventive medicine.

AMERICAN *Cyanamid* COMPANY

30 ROCKEFELLER PLAZA, NEW YORK 20, N. Y.