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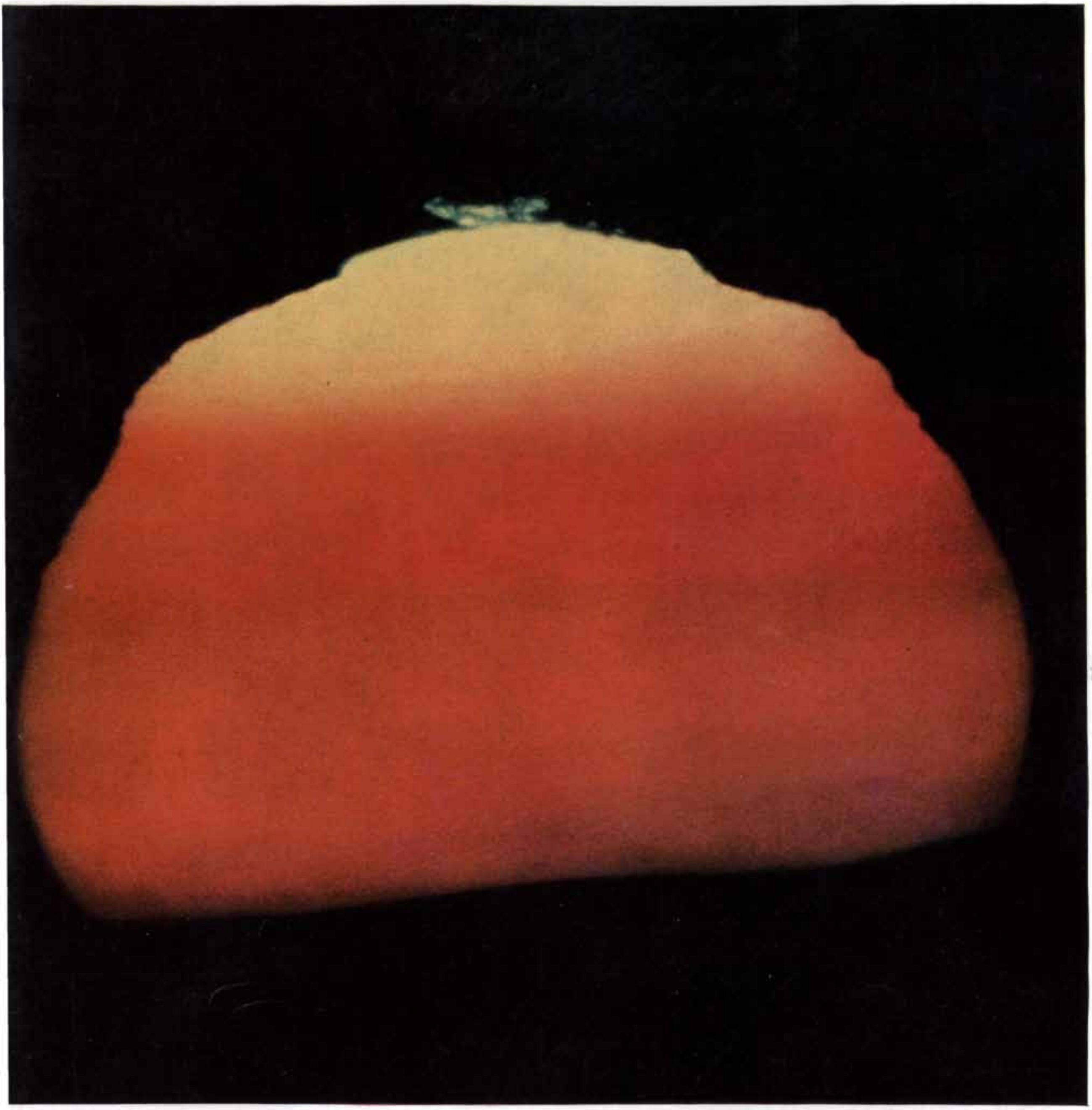
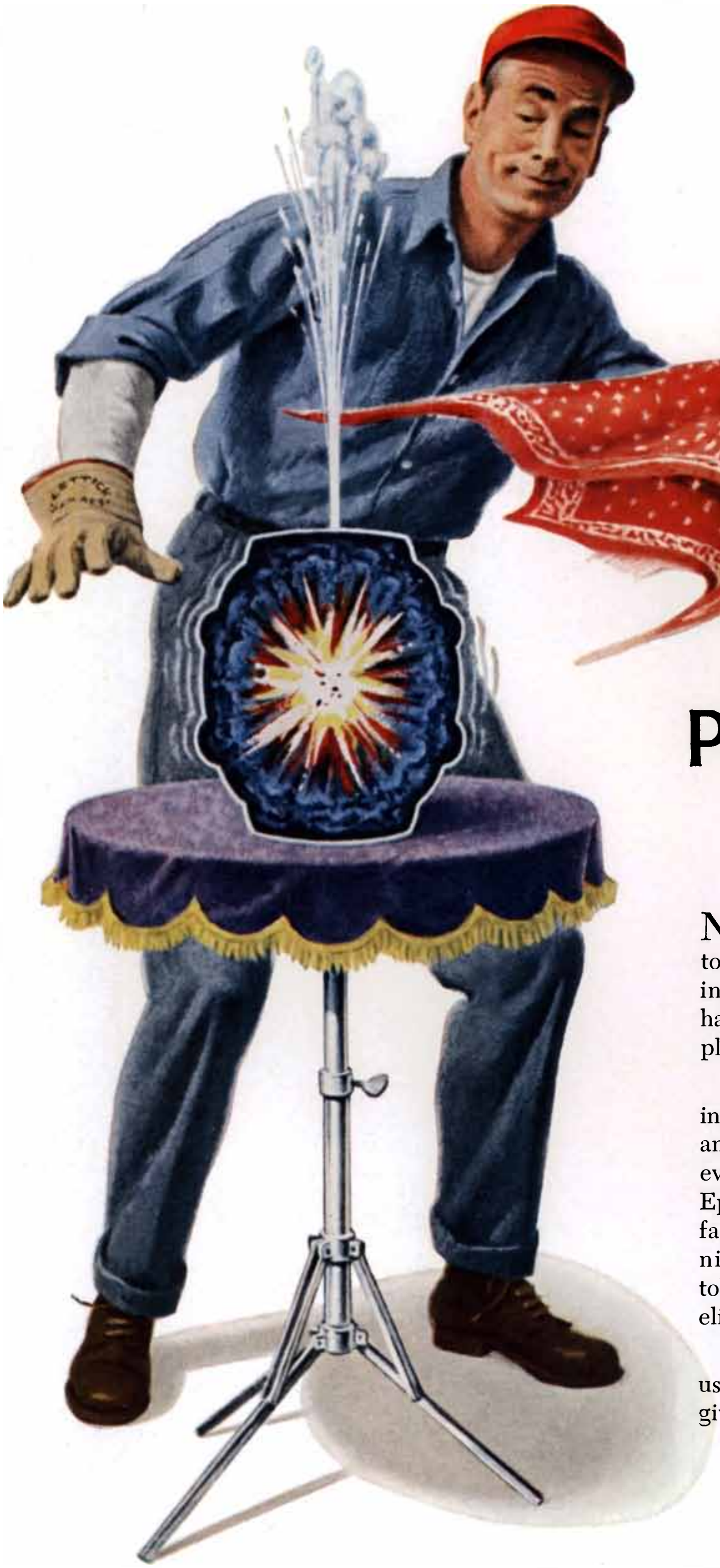


THE GREEN FLASH

FIFTY CENTS

January 1960



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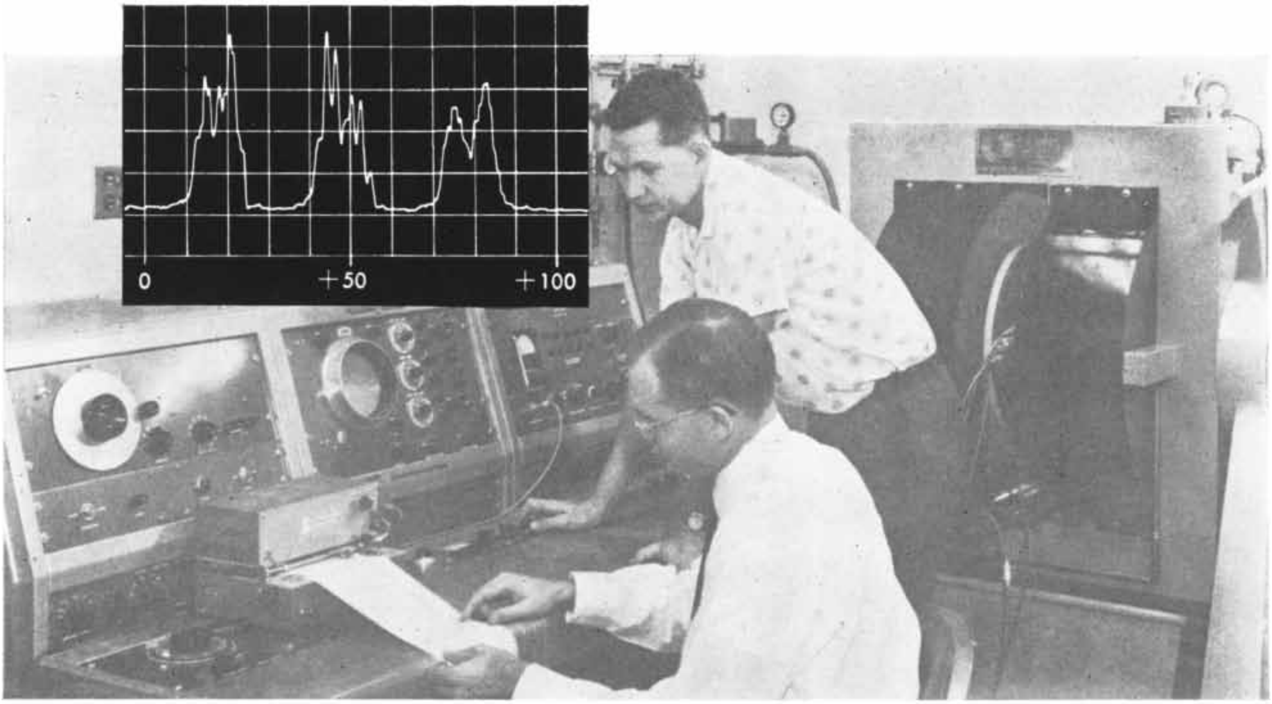

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THE COVER

The photograph on the cover shows the disk of the sun, reddened and distorted by the earth's atmosphere, as it sinks behind the Tolfa Hills in Italy. The yellow-green wisp at the top of the disk is the green flash, a rare phenomenon that is caused by the dispersion of colors in the atmosphere (*see page 112*). The photograph was made at the Vatican Observatory with a reflecting telescope having a focal length of eight feet.

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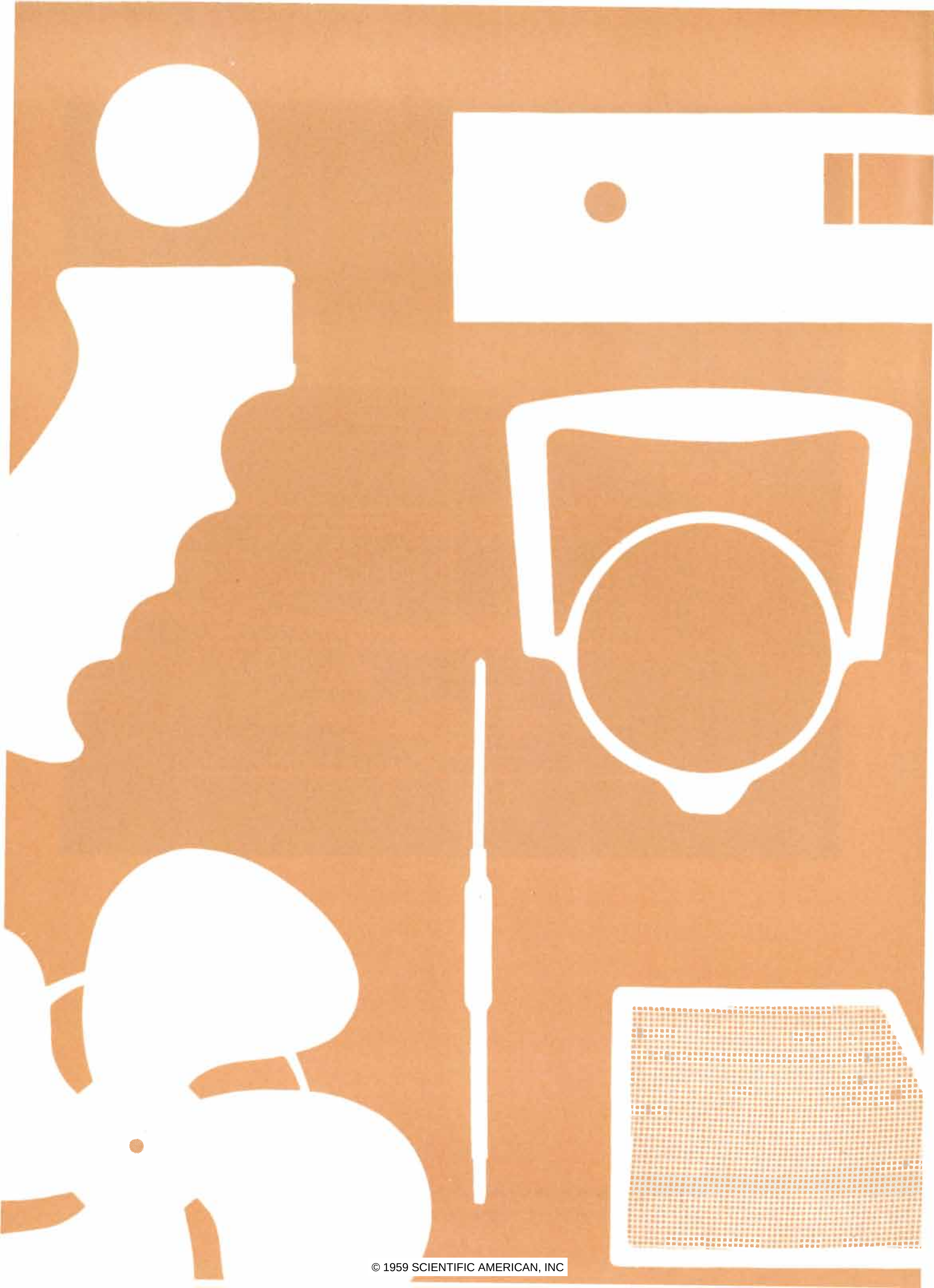

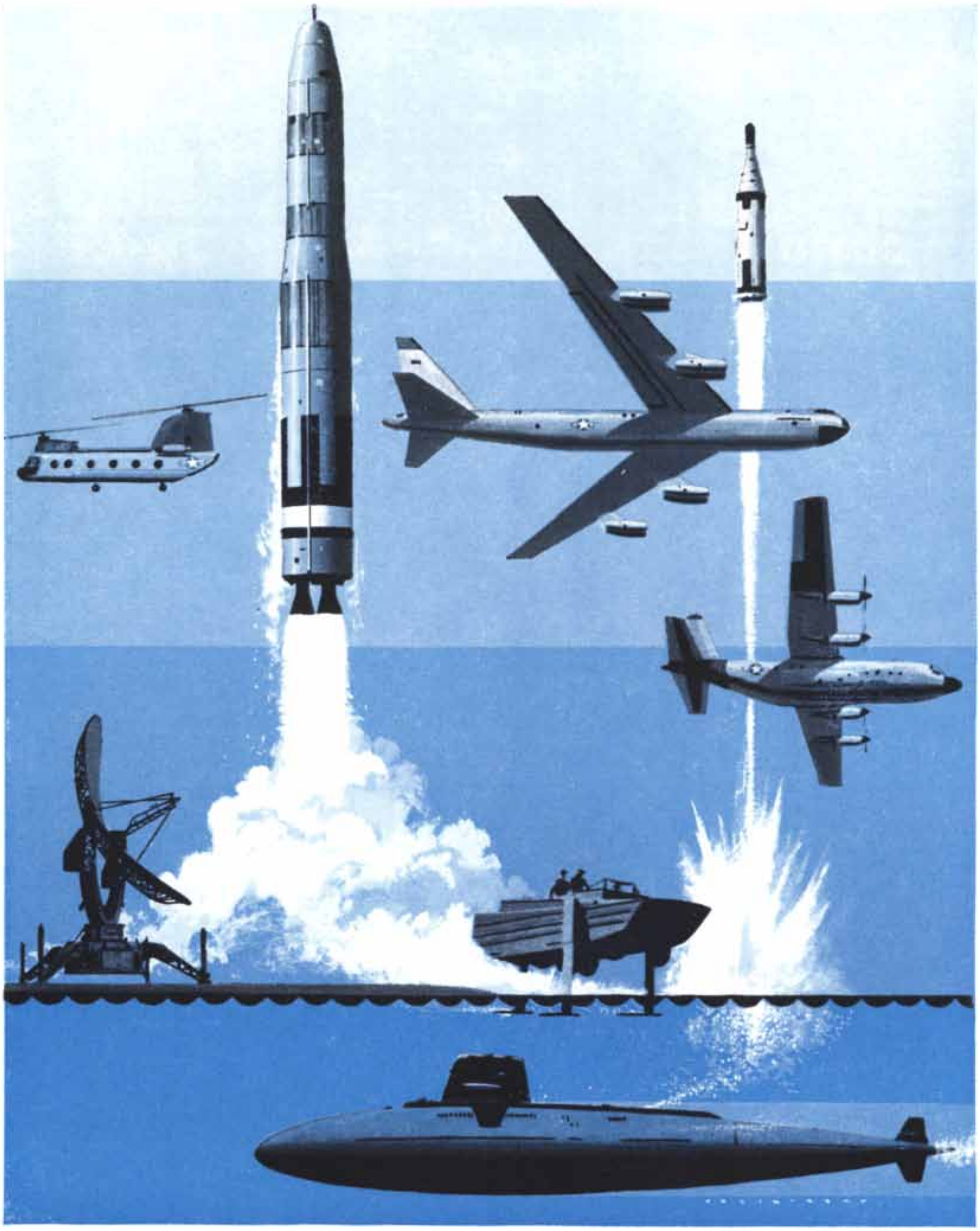

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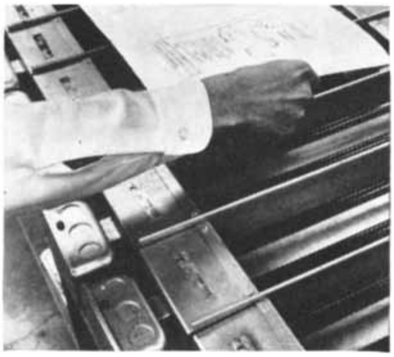
A BULLETIN OF PRACTICAL NEW IDEAS FROM CORNING

HOW TO GET MORE USEFUL HEAT PER KW



It's not much to look at, but our new VYCOR Brand Radiant Heater is loaded with advantages for those involved with drying, baking, curing or pre-heating.

The basic appeal of this unit is the kind of heat it gives you—*long wave;* efficient because it's readily absorbed.

These long waves are emitted from wire coils enclosed in tubes of 96% silica glass. And the tubes (made from one of our rugged VYCOR brand glasses) resist heat, heat shock, and corrosion.

Long wave output is just one reason why your kilowatts will yield more useful heat. This heater also has a reflector *system* that includes a platinum strip bonded to one side of the tubing, and two layers of aluminized steel with Fiberglas insulation in the housing.

Result: Between 85 and 90% of the available radiation is directed to your work.

With VYCOR Brand Radiant Heaters mounted horizontally above or below your process line, you average 20 watts per square inch of working space and get full heating (800-850°F) in three minutes, so there's no costly warm-up delay. These units cool quickly, too, so you don't need complex equipment for diverting heat after shutting off the line.

Heating tubes come in 14″, 26″, 38″ and 54″ lengths, mounted in twos or fours. You get each unit complete with frame, reflector sheet, junction box, mounting hangers and leads.

More facts? Use the coupon.

NEW MATERIAL FOR MISSILE MAKERS AND OTHERS WITH HIGH-TEMPERATURE PROBLEMS

The biggest drawback to fused silica, despite its many desirable thermal and electrical properties, has been the limitation on sizes and shapes available.

No more. Now Corning comes up with Multiform Fused Silica—a combination of a unique process and a versatile material.

With Multiform Fused Silica you can put the useful properties of fused silica to work in shapes and sizes that previously were unattainable.

For example, you can now have cylinders, domes, crucibles, rods and slabs—in sizes equal to any achieved by conventional ceramic forming processes.

Corning's new Multiform Fused Silica offers the unique thermal and electrical properties of fused silica in shapes and sizes that up to now were considered impractical.

Softening point for this new material is 2880°F; you can design for *long-term* use at temperatures over 1770°F, intermittent up to 2250°F.

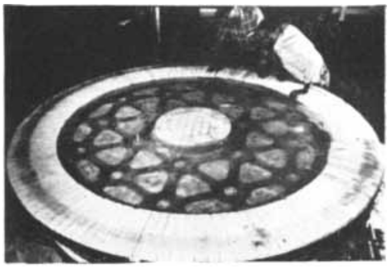
Resistance to thermal shock is high, since coefficient of expansion is 3×10^{-7} per degree F.

This new material also displays an extremely stable dielectric constant and a low loss tangent over a broad temperature range. Example: At a frequency of 8.6×10^{9} cps, the dielectric constant is 3.58 at 77°F and 3.57 at 750°F.

Through either slip-casting or dry pressing you end up with an object (a radome, perhaps?) that has an opaque, fine-grained structure machinable to tolerances of plus or minus .001 inch.

For samples of and/or detailed specs on new Multiform Fused Silica, mark the coupon and send it to our New Products Division.

A MIRROR FOR THE STARS



This is a glass telescope mirror blank that measures 84 inches across and weighs 4,000 lbs.

We made it. And we did it with a new process in which solid chunks of glass were placed in a mold and *sagged into a single piece* under intense heat.

Back in the thirties we also made some big mirrors. But then we ladled molten glass into molds and came up with a 200-inch disk for the Hale Observatory on Mt. Palomar and a 120-incher for the Lick Observatory.

Our new sagging approach improves quality. It also costs less and is less complicated.

Seven months the disk was annealed. Now at the Kitt Peak Observatory in Arizona, grinding and polishing will go on for an estimated 24 months. Final polishing will be done after the telescope is fixed on a star. Time for that? Another year.

Leading us to these facts: Patience is part of the art of the astronomer. And Corning can do almost anything with glass—be it a "one-shot," hand-tailored piece or *mass production of small items at a very rapid pace.*

Find out for yourself. The basic references are "This is Glass" and Bulletin IZ-1, "Designing with Glass for Industrial, Commercial and Consumer Applications."

Or outline your need in whatever detail seems feasible. Could be your star is just around the corner, with glass by Corning.

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FABRICATION TESTS SHOW...

New Titanium alloy takes the

...in strength...in weight...in reliability...in price!

Titanium rocket-motor cases can be built at least 30 percent stronger (or lighter) than best available alternate metals; provide permanent corrosion resistance without protective coatings; withstand temperatures from –400°F to +800°F; will not absorb moisture which distorts critical parts in storage.

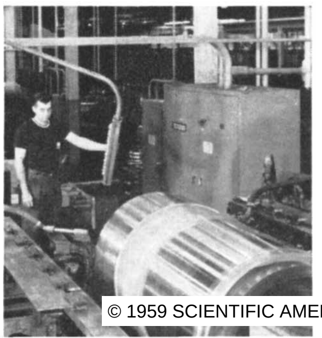
Completed assemblies give a spectacular two-way pay-off . . . immediately; provide a growth potential virtually unlimited.

The alloy: Ti-13V-11Cr-3Al, the beta titanium alloy. Now available from Titanium Metals Corporation of America at commercial lead-times (billet, 2-3 weeks), beta may well become the metals story of the year.

Welding of titanium at P&WA is based on the company's experience in production of more than 5800 jet engines containing titanium parts. Weld strength of beta titanium alloy is considerably improved by cold working the weld.

End Closure Titanium Forgings produced by Wyman-Gordon Company and machined by P & WA, will be *girth welded* to the flow-turned cylinders. Bosses are an integral part of the closures.

Flow-turning from roll-forged rings, makes feasible production of full-scale titanium rocket cases, since it yields integral cylinders, eliminates need for longitudinal welds, conserves input metal.



Pilot rocket-motor cases manufactured by Pratt & Whitney Aircraft from beta titanium alloy Ti-13V-11Cr-3Al have been consistently burst-tested at levels in excess of 235,000 psi – a burst strength/density ratio of 1,340,000.

So successful has been its titanium program that Pratt & Whitney Aircraft considers that production of full-scale titanium cases can be easily realized. Estimated initial burst strengths: a conservative 180,000 psi – a burst strength/density ratio of 1,000,000. Readily attainable: 1,250,000.

Reasons for optimism, spelled out by P&WA's engineers are:

1. **"The welded beta titanium alloy is capable of considerable plastic deformation prior to rupture. As welding has improved, the failure origins have moved into the thin wall (of the case itself). With beta titanium, the case tears, but doesn't fragment.**

2. "We have successfully tested small scale titanium cases with a steel equivalent yield strength well beyond the 300,000 psi point. Considering that the metallurgy of metastable beta titanium alloys is not far beyond its infancy, conservatively one would predict strengths substantially higher than the 320,000 psi equivalent as being quite possible.

3. **"Beta titanium has to develop (only) 140,000 psi to be equivalent to 220,000 psi steel (which is almost near steel's top limits). But titanium's great potential above other alloys is reflected in the high figure for practical (based on 5% elongation) yield strength. At 180,000 beta titanium is equivalent to steel at 280,000 psi; at 200,000 psi, beta titanium is equivalent to steel at 320,000 psi. 200,000 psi in beta titanium is possible, and obviously would mean substantially increased payload to the moon or out into space.**

4. "Apart from the strengths attainable in the beta titanium alloy, there is another property of considerable significance. Like other titanium alloys, it has excellent resistance to corrosion under normal atmospheric conditions, in salt water as well as in many other media.

"In considering the long time storage problems with rocket cases – a pit in a thin-walled casing can be catastrophic – we would regard the beta titanium alloy, as the outstanding material under consideration."

lead in rocket case construction

PRATT & WHITNEY AIRCRAFT SURVEY OF ROCKET CASE MATERIALS

GENERAL PROGRAM

The goal: "A material capable of reaching 300,000 psi yield strength in steel, with a considerable development margin."

The result: "While this goal had to be modified for steel cases, we have successfully tested small scale titanium cases with a steel equivalent yield strength well beyond the 300,000 psi point."

Conclusions: 1. "By exercising reasonable care, the development of full scale (steel) cases at 240,000 psi is perfectly feasible.

2. "Small scale (titanium) cases have been burst at stress levels as high as 260,000 psi . . . we are convinced that reliable cases can be manufactured (from titanium) at yield strength levels of 180,000 psi and over . . . at 180,000 beta titanium is equivalent to steel at 280,000 psi.

"At 200,000 psi beta is equivalent to steel at 320,000 psi. 200,000 psi beta is possible and obviously would mean substantially increased payload to the moon or out into space."

SPECIFIC COMPARISON: Strength

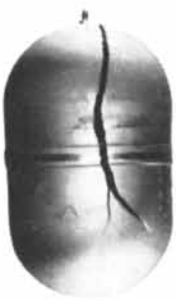
Alloy	Density	Practical Yield Strength (5% elongation)
Ti-6Al-4V	0.161#/in.³	155 ksi = steel at 270 ksi
Ti-13V-11Cr-3Al (Beta)	0.175#/in.³	180 ksi = steel at 280 ksi
		190 ksi = steel at 305 ksi
		200 ksi = steel at 320 ksi

SPECIFIC COMPARISON: Corrosion Resistance

Steel: "All of the low-alloy constructional steels which have been discussed are subject to general rusting and, far more serious, to pitting type corrosion during machining, welding, heat treatment, pressure testing and final storage. Corrosion pits can act as severe stress-raisers and, in conjunction with hydrogen, have been demonstrated to cause catastrophic failure. It therefore goes without saying that pitting corrosion is a serious hazard."

Titanium: "Like other titanium alloys, the beta titanium alloy has excellent resistance to corrosion under normal atmospheric conditions, in salt water as well as in many other media.

"In considering the long-time storage problems with rocket cases—a pit in a thin-walled casing can be catastrophic – we would regard the beta titanium alloy as the outstanding material under consideration."



Burst Test Results show titanium has provided consistent burst strengths of 235,000 psi — a burst strength/density ratio of 1,340,000. Failure occurs in the wall of the case itself – not the weld zones. Titanium cases do not fragment.

• Reliability and growth . . . the parallel

Pratt & Whitney Aircraft data reveal rocket-cases can *now* be built from beta titanium at strengths 17 percent greater than alternate metals, with beta titanium's strengths bounding forward under a minimum of development.

A striking parallel exists in liquid-fueled rocketry where titanium alloy Ti-6Al-4V was selected for helium storage bottles in the Atlas missile because of its strength/density ratio. Airite Products, Inc., a leading supplier of the titanium vessels, reports:

"Minor modifications in processing techniques and continuous tightening of tolerances and other variables have shown an increase from the original 5400 psig average burst pressure to the present average which is in excess of 9000 psig.

"This has been done without increasing the weight of the article by one ounce. Weight of the unit, incidentally is controlled to a tolerance of plus or minus one-half pound, on a weight of 79 pounds, and volume is controlled and guaranteed to plus or minus one percent."

While the performance of the titanium pressure vessels has been almost doubled, the price has been reduced almost 50 percent – and the missile has become operational.

• When a case fails, so does the missile

The price of completed beta titanium rocket-cases is now estimated at 2½ times the price of other metals, with titanium cases virtually in their infancy. Should the titanium cost difference remain, the pay-off would still be two-fold:

1. **Cost:** engineering time, would be greatly curtailed; expensive fuels (for example, 30 pounds of fuel are required in earlier stages for each additional third-stage pound) would be saved.

2. **Reliability:** titanium cases simply will not pit, rust, deliquesce, or become hydrogen embrittled.

Added together, these elements mean feasibility—feasibility supported by the commercial availability of the metal itself. Beta titanium alloy Ti-13V-11Cr-3Al is available from Titanium Metals Corporation of America at these lead times: billet, 2-3 weeks; bar, 3-4 weeks; flat-roll, 5-6 weeks. TMCA's metallurgical experience with the alloy is yours for the asking.

For further information, write for TMCA Data Bulletin 10, *All-Beta Titanium for Solid Rocket Pressure Chambers*. Extensive welding information is included.

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LETTERS

Sirs:

George Wald's otherwise authoritative article "Life and Light" in your October issue leaves the mistaken impression that carotenoids play an exclusive role as photoreceptor pigments in the phototropic responses of plants. While carotenoids indeed may function in this way, the collective evidence in favor of photoreception by some form of riboflavin conjugate is also sufficiently impressive to have merited some discussion.

I would therefore like to take this opportunity to correct the impression created by Wald's article, and to summarize briefly the pro-riboflavin evidence which was overlooked.

Let me proceed by quoting the relevant passages that stand in need of modification. On page 100 Wald says: "The red wavelengths, which are most effective in photosynthesis, are wholly ineffective in phototropism." While this is generally true, there are several exceptions that need to be taken into account. For example, Hans Mohr has demonstrated that fern sporelings show a marked phototropic response to red light; Adriaan Manten has found an effect of orange light in an alga, while other workers have reported on the phototropic effectiveness of red light in green (but not etiolated) higher plant cells. Obviously some red-light receptive pigment can be effective in phototropic perception in chlorophyll-bearing cells. Wald's generalization is thus true only for etiolated or otherwise nongreen cells.

In another sentence Wald states: "In certain instances, the carotenoids are localized specifically in the region of the plant that is phototropically sensitive." I do not believe this statement can be supported by a valid reference to higher plants, for the original evidence to this effect has been shown to be inaccurate. In fact, the extreme tip of the grass coleoptile, which is by far its most photoreceptive zone, has far less carotenoid than the relatively insensitive region one to three millimeters behind the tip. Furthermore, there are several recorded instances (corn, barley, sunflower) in which mutants completely lacking in or almost totally devoid of carotenoids are as phototropically active as the carotene-abundant wild type from which they were derived. Furthermore, fungal hyphae that have been made deficient in carotene by feeding with diphenylamine and other nutritional manipulations have apparently undiminished phototropic sensitivity. Certain other photoactivated processes in fungi having action spectra resembling that for phototropism are also unaffected by an artificial lowering of carotenoid levels. Especially interesting is the observation that diphenylamine, which completely represses carotenoid formation in *Pilobolus kleinii* is without effect on the photoactivation of trophocyst formation, while L-lyxoflavin, a riboflavin antagonist, is effective in completely checking this light-activated process. Thus Wald's general statement concerning the correlation between carotenoid levels and phototropic sensitivity needs some modification.

The crux of the matter lies, however, in this statement: "The most careful measurements of the effectiveness of various wavelengths of light in stimulating phototropism in molds and higher plants have yielded action spectra which resemble closely the absorption spectra of the carotenoids that are present." This is only approximately true, and even so, it is not the whole truth. Apparently Wald is considering only the visible peaks, at about 475, 445 and 425 millimicrons. He disregards the peak at about 370 millimicrons, observed in the most recent accurate action spectra found by investigators at Harvard University and the Smithsonian Institution. This peak, so far as I know, is *not* found in any carotenoid known to be present in any phototropically sensitive organ.

This brings us to the question of possible photoreception by a riboflavin-containing conjugate of some sort. Riboflavin itself is known to be quite active as a photoreceptor for various *in vitro* photooxidations and photoreductions. It absorbs heavily in the regions that are phototropically effective, including the 370-millimicron region. Although the absorption maximum of free riboflavin has only a single peak in the visible, this is converted to a multiple peak by conjugation of the flavin with other substances or by solution in various organic solvents. Thus, although such compounds as flavin mononucleotide (FMN) and lumiflavin have a single absorption peak when dissolved in water, they have three absorption peaks in the visible (around 470, 445 and 425 millimicrons) in addition to one in the near ultraviolet when dissolved in aqueous pyridine. I have also made the point in several publications that various flavin-containing enzymes, including metalloflavoproteins, do have absorption spectra that could fit phototropic action spectra. Such proteins include, among others, an electron-transferring flavoprotein and dihydrothioctyl dehydrogenase. These and similar compounds have the appropriate visible absorption peaks, mentioned above, as well as peaks near 370 millimicrons and 280 millimicrons which Max Delbrück and Walter Shropshire have concluded are all part of the same photoreceptor for phototropism and the light-growth reaction of *Phycomyces* (which, incidentally, appeared as an illustration in Wald's article).

These facts, plus the (at best) approximate coincidence of absorption and action spectra, would seem to me to indicate the necessity for a more adequate consideration of the flavin theory of photoreception in plants. I would also make the point that, in view of the known abundance of flavins in the eyes of certain animals, especially fish, some consideration should be given to their having some photoreceptive role here as well. Wald's brilliant work on the carotenoid photoreceptors in animal vision should not be permitted to obscure the possibility of the coexistence of other visual systems, which might serve accessory functions, such as that of wavelength transducers.

Let me conclude by summarizing my point of view. Much evidence, especially from the study of comparative biochemistry, indicates that carotenes may be

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AT RAYTHEON—

Scientific imagination focuses on HIGH-TEMPERATURE SEMICONDUCTORS

Silicon carbide, long employed as a refractory for furnaces, shows promise as a material for semiconductor operation at temperatures up to 1,000° C. Substances presently used as semiconductors—silicon and germanium—fail at 300° C. and 150° C., respectively. At these temperatures, the thermal energies of their electron carriers are too high for satisfactory semiconductor operation. In silicon carbide, the carriers have a broader energy gap to bridge in reaching conductivity and thus permit semiconductor characteristics at high temperatures.

Crystals of this man-made compound have a cubic *(beta)* or hexagonal *(alpha)* lattice structure. The highly ordered *beta* phase appears to have more desirable characteristics, including greater mobility and lifetime of electron carriers. Raytheon scientists have been investigating crystal growth of the *beta* phase by gaseous reaction and from solution. Because crystals for semiconductive devices must be of extreme purity, production techniques are far more sophisticated than those called for in producing silicon carbide for commercial applications.

Raytheon scientists responsible for these efforts are R. C. Ellis, Jr. and Dr. A. H. Smith, who are contributing to fundamental knowledge of the morphology and growth mechanisms of high-temperature semiconductors.

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important photoreceptors in plants as well as in various kinds of animals. The evidence is, however, by no means conclusive, and many objections exist to a complete acceptance of the carotenoid hypothesis of photoreception in plants. These objections include (a) virtual or complete absence of carotenoids from certain phototropically active organs and (b) noncoincidence of the action spectrum with the absorption spectra of known carotenoids, especially in the region near 370 millimicrons. Both of these objections are successfully met by riboflavin-type compounds, which thus merit more consideration as photoreceptors than Wald has given them.

Arthur W. Galston

Josiah Willard Gibbs Research Laboratory
Department of Botany
Yale University
New Haven, Conn.

Sirs:

Present-day plant physiology thrives on its controversies, and in skirting the edge of one in my paper, I seem to have landed in another. I do know Dr. Galston's views, and would have been glad, had there been space or were this the place, to discuss them. As it is, Dr. Galston has now presented very fully the case for riboflavin and against carotenoids in his letter. I think it fair to speak of this as a case, rather than a judgment. It would be easy to prepare an opposing brief, but not very useful. I am glad to agree that riboflavin should be considered in this connection. Possibly *both* carotenoids and riboflavin are at work here; though I hope for simplicity's sake that eventually it comes out to be one or the other. In my judgment the present evidence, for all its complications, favors the carotenoids.

My first concern is to reassure the lay reader that this is not an aberrant view. It may help to cite the conclusions of two groups of workers. "From the action spectra (*i.e.,* of the oat coleoptile) it is concluded that the active photoreceptor is a yellow pigment, probably carotenoid in nature. . . . A flavin photoreceptor appears unlikely" (Walter Shropshire and R. B. Withrow; *Plant Physiology,* Vol. 33, No. 360, 1958). "The photoreceptor of *Phycomyces* in the visible is very similar to, or may be identical with, that of *Avena* coleoptiles. Both are probably carotenoids" (G. M. Curry and H. E. Gruen; *Proceedings of the National Academy of Sciences,* Vol. 45, No. 797, 1959).

For the rest, I should like to make two points that may help to disentangle this argument:

(1) The carotenoid that may be involved in plant photoreception is almost certainly bound, probably to protein, and very likely is not the bulk of the carotenoid that is present. I would suppose that the same might be said of any riboflavin that might be thought to act in photoreception. In that case, however, we are concerned only with a specific, probably minor, fraction of either pigment, and what happens to the bulk of it does not matter. In that case also the very interesting photochemical properties of free riboflavin and its phosphate, not shared by protein-bound riboflavin, may be irrelevant.

(2) The mechanism of response, as opposed to excitation, in plant phototropism is differential growth. As such, it depends on everything needed for growth: oxygen, respiratory enzymes, and under certain special circumstances photosynthesis. Among the respiratory enzymes are riboflavin proteins. It would not be surprising therefore if plants deprived of riboflavin failed to bend; but that would be poor evidence that riboflavin is acting as a photoreceptor. Similarly, a phototropic or phototactic response might become dependent on the oxygen supplied by photosynthesis, and for this reason might acquire sensitivity to red light, as a secondary phenomenon.

Finally, Dr. Galston mentions the remarkable observation made many years ago that the eyes of certain fishes contain high concentrations of free riboflavin. The thought that this is acting in vision is a little clouded with the realization that the riboflavin is in the pigment epithelium of the eye, not in the receptor cells or in the neural retina. Perhaps it is playing some photochemical role in the pigment epithelium; we keep trying to find one for it, so far without success. Indeed I know of no normal physiological process that has yet been shown to involve the action of light upon free or bound riboflavin.

George Wald

The Biological Laboratories
Harvard University
Cambridge, Mass.

Pedigree of a Hound Dog

The guidance and control system of America's HOUND DOG missiles—best of breed—has a pedigree 13 years long. Created by Autonetics, the HOUND DOG's inertial autonavigation system sends this supersonic air-to-surface missile from mother-ship to target anywhere in the world, in any weather. Equipped with an invulnerable sense, HOUND DOG extends the retaliatory effectiveness of SAC's B-52G bombers by hundreds of miles.

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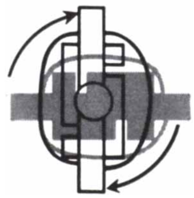

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RSENIC		1*	1*											
RSENIC TRIOXIDE		1*			1*									
BISMUTH		2	1			1	2						1*	
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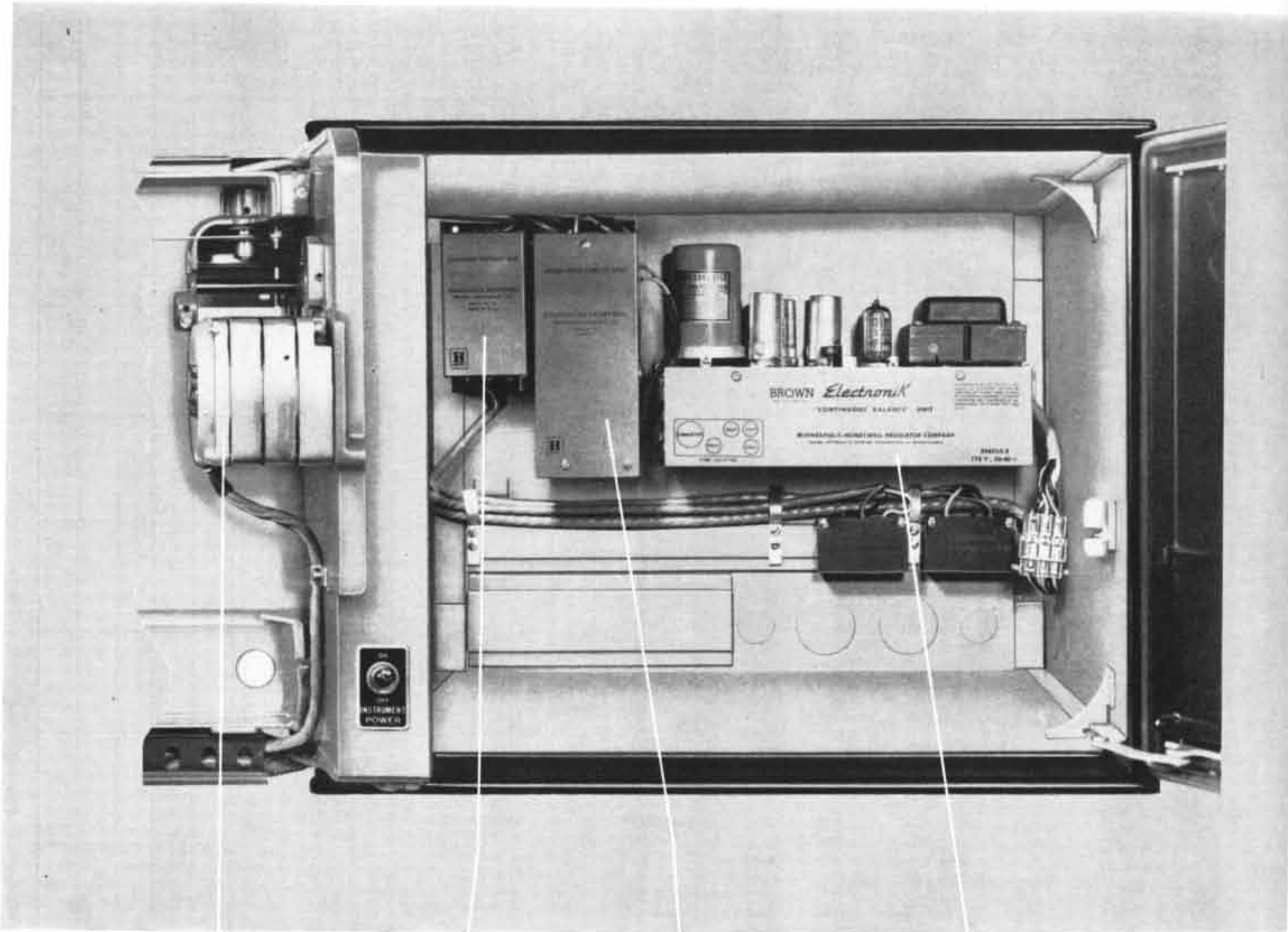
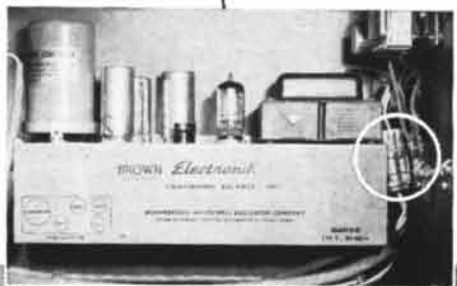
INDIUM		1*				1		1*	1					
LEAD	1*	1*	1*				1*							
SELENIUM		1*		1*						1			1*	
SILVER		1*	1*			1*					1			
SULFUR												1	1	
TELLURIUM		1*	1*											
THALLIUM	1	3	1			1			1			2	1*	
ZINC		1*	1*			1*								1*





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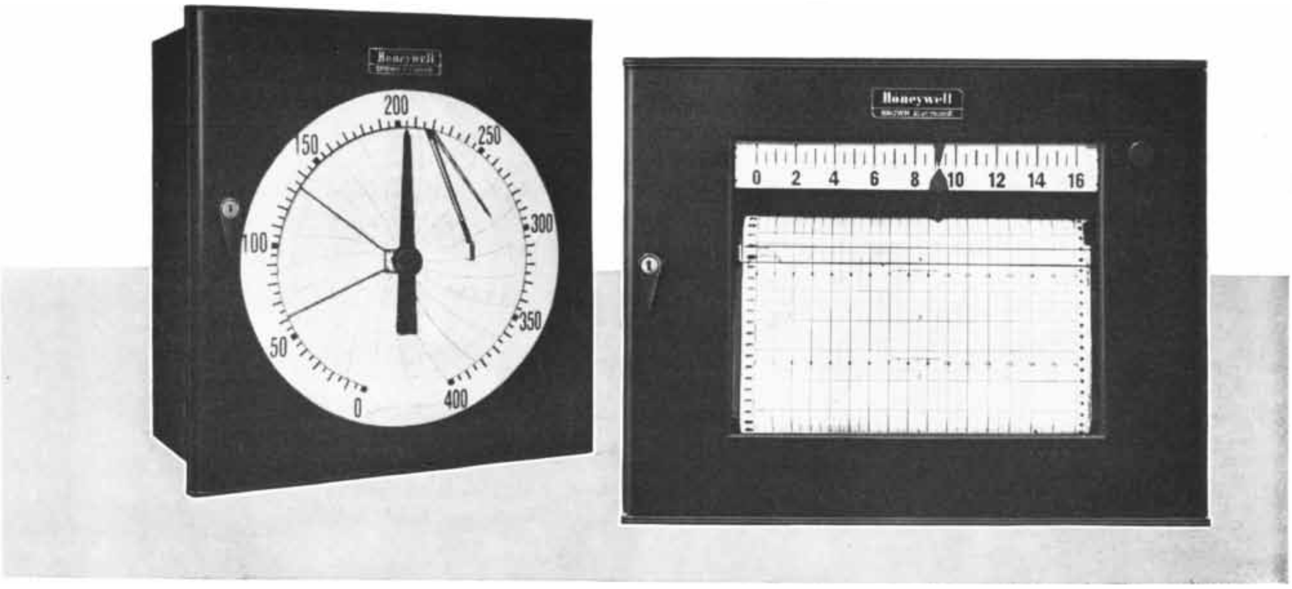

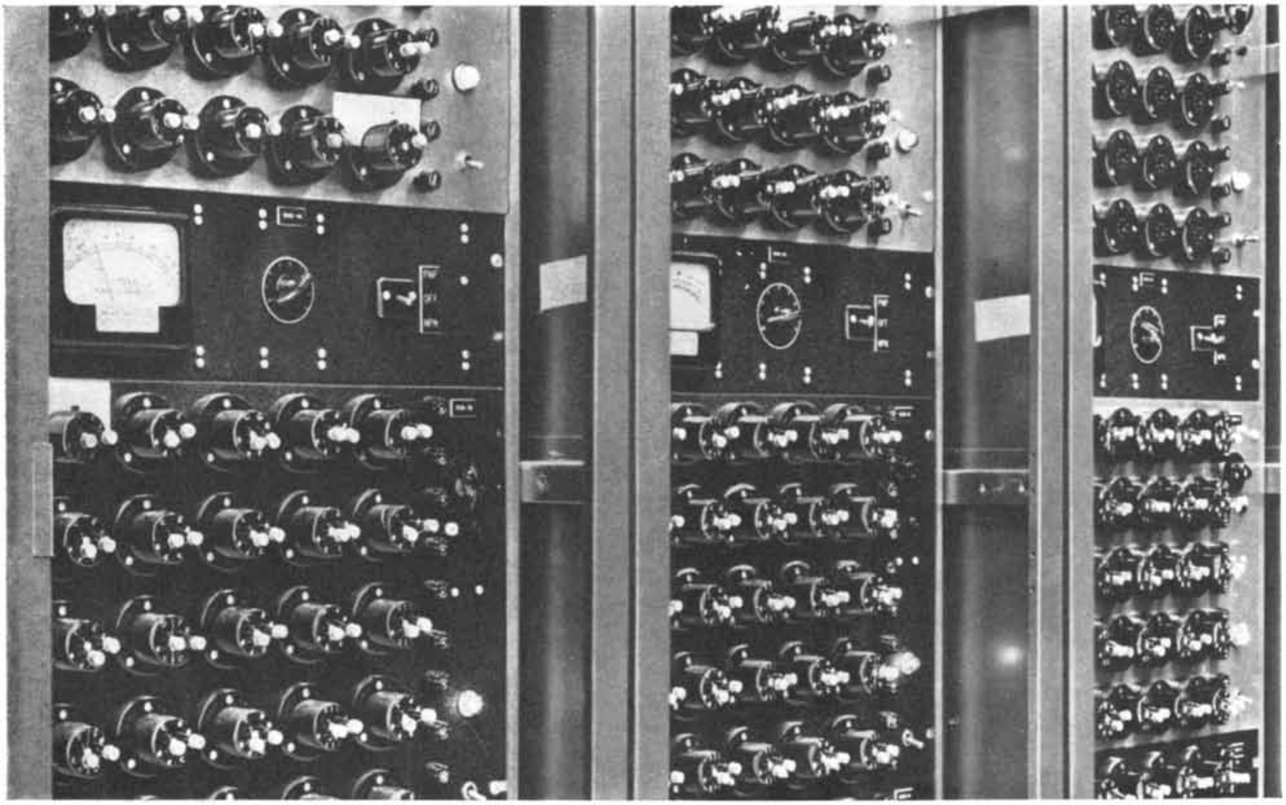

At this moment, 30,000 transistors are on test at General Electric

Among the more than 30,000 transistors you will find right now on General Electric's cycled life-test racks are Series 2N43 PNP germanium devices dating back to 1952.

Each of these 2N43's has clocked at least 40,000 hours of operating life. This represents five years of "power-on" operation without failure. And the "old" 43's still live on!

Since 1952, General Electric Company has produced and thoroughly tested well over 20-million transistors. A quarter-million of these devices have been subjected to from 1000 to 10,000 hours of maximum-rated-power.

Life testing is but one of many exacting product quality-assurance criteria *all* General Electric semiconductor products must meet. For example, on an average, 16 separate quality-level tests . . . electrical, mechanical, environmental, as well as life . . . are given every General Electric transistor.

Through its system of stringent quality control, General Electric strives to continuously raise the stability/long-life reliability goals for semiconductor products—to the ultimate benefit of the user, the industry and the country at large.

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JANUARY - FEBRUARY, 1960

Using arc-melted "Electromet" columbium, The Ladish Company, Cudahy, Wis., has successfully forged a Cb-0.75% Zr ring, measuring 7¾ in. O.D. x 6 in. I.D. x ⅞ in. thick. The ring was made during a co-operative experimental program in which Union Carbide Metals supplied the columbium in the form of an alloyed ingot. An objective of this program was to demonstrate the forgeability of a columbium alloy of "commercial" purity. Much of the work to date has been based on ultra-high purity material. General data on columbium can be found in Bulletin CB2-S5.

* * *

Ferric acetylacetonate is going into semicommercial production at Union Carbide Metals. This "Electromet" metal chemical and other acetylacetonate derivatives of the transition metals (e.g., Cr, Co, Mo, Mn, V, and Ni) offer a convenient means of putting the metals in solution in organic systems. They are chelated, non-ionizing compounds, and slightly soluble in water. They form solutions which are neutral and resistant to hydrolysis. The acetylacetonates are available as pure, crystalline powders. Bulletin AA1-S5 gives property data.

* * *

Vanadium sheet -- wider than previously available -- has been produced by Union Carbide Metals Company. The sheet, measuring 19½ in. wide by 40½ in. long by 0.065 in. thick, is a new development in vanadium technology. Formerly requests for widths greater than 6 in. had not been made. Should the demand arise, wider sheet can be produced without difficulty. The high degree of workability observed during this wide-sheet production reflects the improved purity of the Company's vanadium metal. Several wire sizes are also available from stock. Union Carbide Metals offers melting stock for sale and will supply custom quantities of a range of vanadium mill products. Request Bulletin VM1-S5 for general information on vanadium.

* * *

The outstanding oxidation and corrosion resistance of chromium carbide can now be utilized on pre-formed base materials. Coating techniques such as flame-spraying and electrodeposition, currently under study, are extending the applicability of this refractory compound. New areas include coatings for such components as turbine blades, while established uses are in shapes fabricated by powder metallurgy techniques. Union Carbide Metals' field representatives are discussing chromium carbide powder and its application with users of oxidation- and corrosion-resistant coatings. Bulletin CC1-S5 gives general data on chromium carbide.

* * *

Oxidation-resistant coatings for columbium and its alloys are another area of research at Union Carbide Metals. A duplex coating, which is among those being studied, performed satisfactorily above 2000°F. during preliminary tests. The Company's field representatives are available to exchange information on coatings, their applications, and related problems. For laboratory performance data, ask for AC1-S5.

* * *

Union Carbide Metals Company, Division of Union Carbide Corporation, P. O. Box 330, Niagara Falls, N. Y. In Canada: Union Carbide Canada Limited, Toronto.

This thimble—actual size—greatly magnified on
the left, contains 1,053 PSI Micro-Diodes. The standard
subminiature diode is shown below.
(Photos by Don Mannix.)

RESEARCH TODAY---
NEW PRODUCTS TOMORROW

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The modern digital computer or "electronic brain" employs a large number of identical solid state electronic circuits much as the human brain uses many identical brain cells.

The new PSI Micro-Diode—so small that a thousand fit into a thimble and yet with performance and reliability characteristics second to none—will help make practical computers with greatly increased "brain capacity."

The Micro-Diode, a result of three years of research in the laboratories of TRW's Pacific Semiconductors, Inc., is one of the new products that should enable PSI to continue the dramatic growth that has in the last two years made it one of the nation's principal producers of semiconductor devices.

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SCIENTIFIC AMERICAN

JANUARY, 1910: "In spite of many predictions of failure, the United States government, through its Army engineers, is building the Panama Canal with a rapidity which augurs well for its opening by January 1st, 1915. Over one half of the excavation at the Culebra Cut has been done, and if we include the work done by the French, the cut may be considered as two thirds completed. On the Atlantic side between three and four miles of the entrance channel have been completed, and on the Pacific side the channel is open to full depth for about five miles. At Gatun the lock excavation is so far done that the laying of the floor and the building of the walls are well under way, and over 80,000 cubic yards of concrete are already in place. The health conditions have shown steady improvement, and the rate of sickness and mortality is now less than in some parts of the United States."

"The year 1909 has closed with only a single trial for the Scientific American Flying Machine Trophy. The conditions, which at first required a straightaway flight of one kilometer (.621 mile), were changed for 1909 to 25 kilometers (15½ miles) in a closed circuit, in view of the flights which were then being made by French aviators. Under the 1909 rules the winner is the aviator who makes the longest and best flight in a closed circuit during that year. In 1909 Mr. Glenn Curtiss was the only competitor who came forward. He easily complied with the conditions and accordingly he must be regarded as the winner of the Trophy for that year."

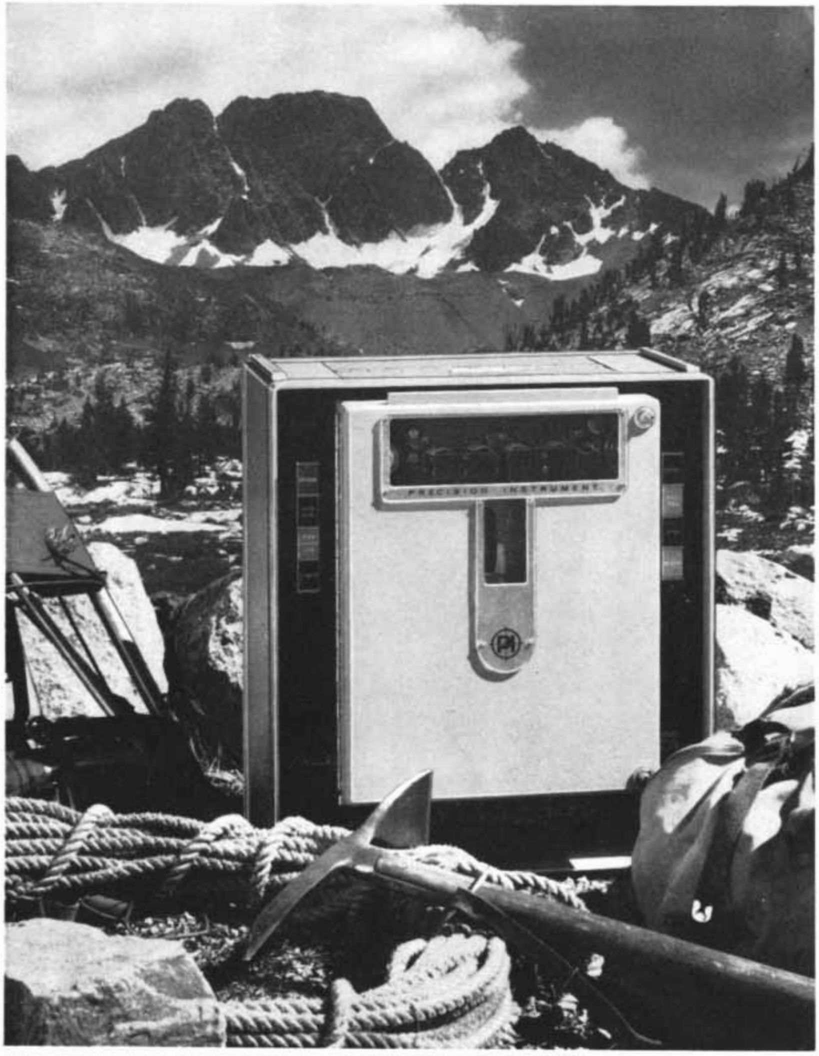
"The first aviation meeting to be held in this country opened at Los Angeles, Calif., on the 10th instant. Louis Paulhan, the record-breaking French aviator, was present with two Farman biplanes and two Blériot monoplanes. America was represented by Glenn Curtiss, C. F. Willard and C. K. Hamilton, all of whom flew Curtiss biplanes. The great event of the third day was Paulhan's successful attempt at breaking the world's record for altitude. The existing record of 3,444 feet had been made only six days before by Hubert Latham at Mourmelon-le-Grand, France. Paulhan's height, as measured from the ground, was officially determined at 4,165 feet. Lieut. Paul Berk tried dropping dummy bombs upon a measured square on the ground. While he did not succeed in hitting the mark, he came very close to it, and showed the possibility of dynamiting a warship or a town in this way."

"Convincing evidence that the automobile of to-day is as far perfected as the materials of construction and mechanical ingenuity will allow is afforded by the fact that the cars shown in the two annual exhibitions this year exhibit no novelties of a radical character as compared with the cars of the preceding year. The tendency toward standardization is even more marked this year than last, and the freak car is conspicuous by its absence. For all cars the four-cylinder, four-cycle engine, with variations in the valve arrangements, has become the standard type. Undoubtedly the present prosperity in the automobile industry is due largely to the fact that many people of moderate means, who have been waiting until a thoroughly serviceable car was placed on the market at low price, are now being accommodated. Several makers are offering a four-cylinder 20-horsepower car, having all the features of stylish design and certainty of control of the more costly designs, and for the low price of $750."

"The Scott expedition in search of the South Pole is now assured. The British government has promised $100,000 toward the $200,000 which is the estimated expense. A total of between $55,000 and $60,000 has been raised by public subscription. In all likelihood the expedition will start in July. Capt. Scott commanded the British arctic expedition of 1900-1904. Lieut. Ernest H. Shackleton, who was one of his lieutenants, has also announced that he will enter upon another antarctic expedition. The date of the expedition has not as yet been decided."

Scientific American.

JANUARY, 1860: "Combined with much success in 1859 there has also been considerable disappointment experienced in some enterprises which had



excited much public hope. The *Great Eastern*—the most wonderful effort in shipbuilding ever attempted—has not yet reached our shores, although we were all 'on the tip-toe' of excitement in expectation of her arrival about three months ago. Thus far she has not come up to the expectation of anybody, and a committee of inspection has just pronounced her unfit for an ocean voyage until many changes are made in her. The balloon voyage across the Atlantic has not yet been accomplished; neither Professor Wise, La Mountain nor the redoubtable Lowe has yet achieved the grand problem. The Atlantic telegraph cable has become mythical. Efforts were lately made to raise more capital and undertake the construction and laying of a new cable, but these, we understand, have proved abortive of any good result, and probably such a gigantic enterprise may never be again attempted, not for a number of years at least."

"The number of patents whose claims are published entire in our last volume, which covers a period of six months, is 1,864. The greatest number of patents issued for any one class in the six months is 36 for corn and other seed planters; the next largest number is 32 for sewing machines; the next, 29 for harvesters; and the next, 25 for washing machines. Agricultural machinery claimed the largest share of the inventor's attention; and this is one of the best signs of progress that could have been presented, because agriculture is the foundation of all the other useful arts."

"Dr. Hiram Cox, the Cincinnati inspector, has found that in 700 inspections of stores and lots of liquors of every variety, 90 per cent were impregnated with the most pernicious and poisonous ingredients. Nineteen young men were killed outright by only three months' drinking of these poisoned liquors. Many older men, who were only moderate drinkers, died of delirium tremens. Of 400 insane patients, he found that two thirds had lost their reason from this same liquor. One boy of 17 was made insane from being drunk only once. Seeing two men drinking whiskey that was so strong it actually caused tears to flow from the eyes of one of them, the doctor obtained some for his tests. He found it to contain only 17 per cent of alcohol, when it should have contained 40, and that the difference was supplied by sulphuric acid, red pepper, caustic, potash and strychnine. A pint of this liquor contained enough poison to kill the strongest man."

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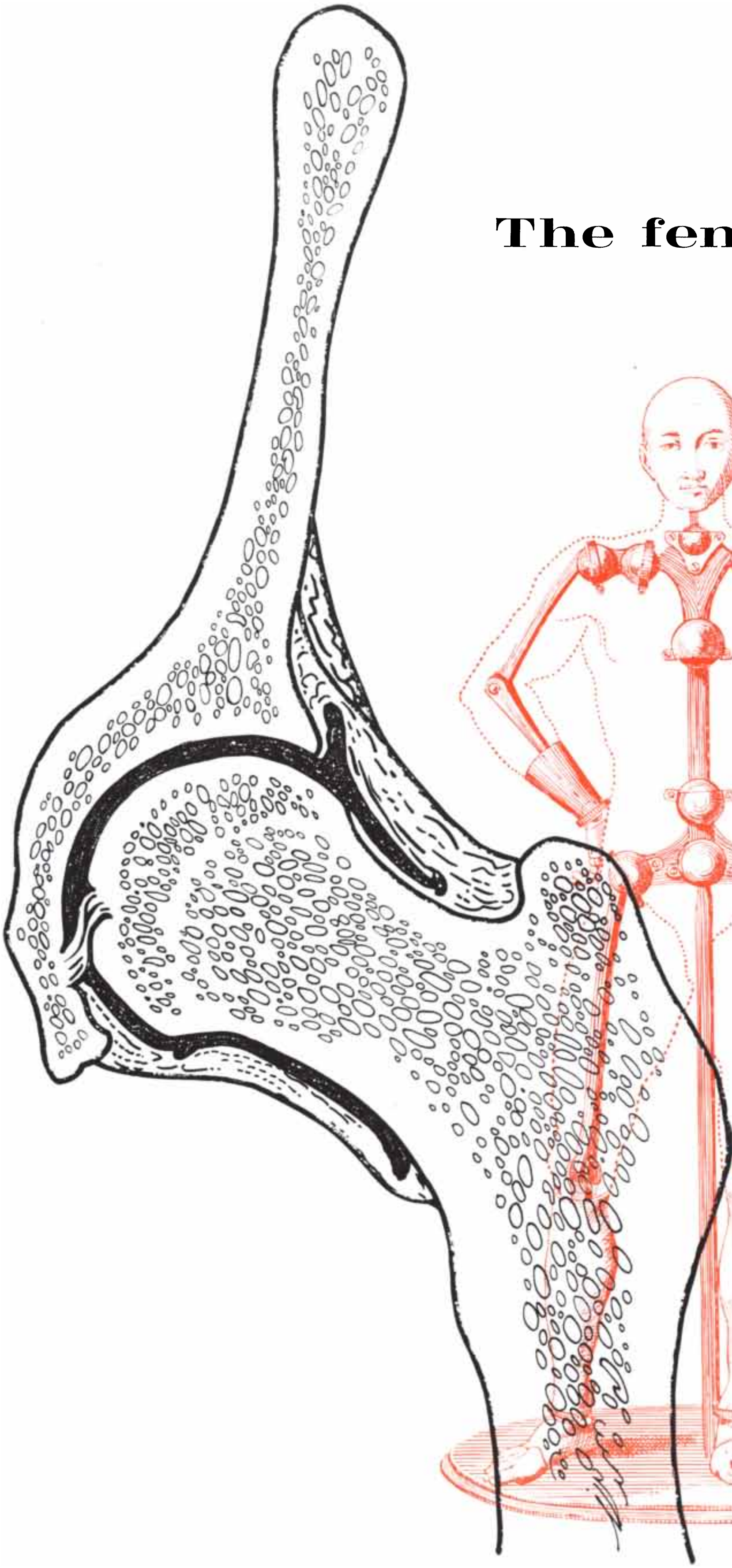
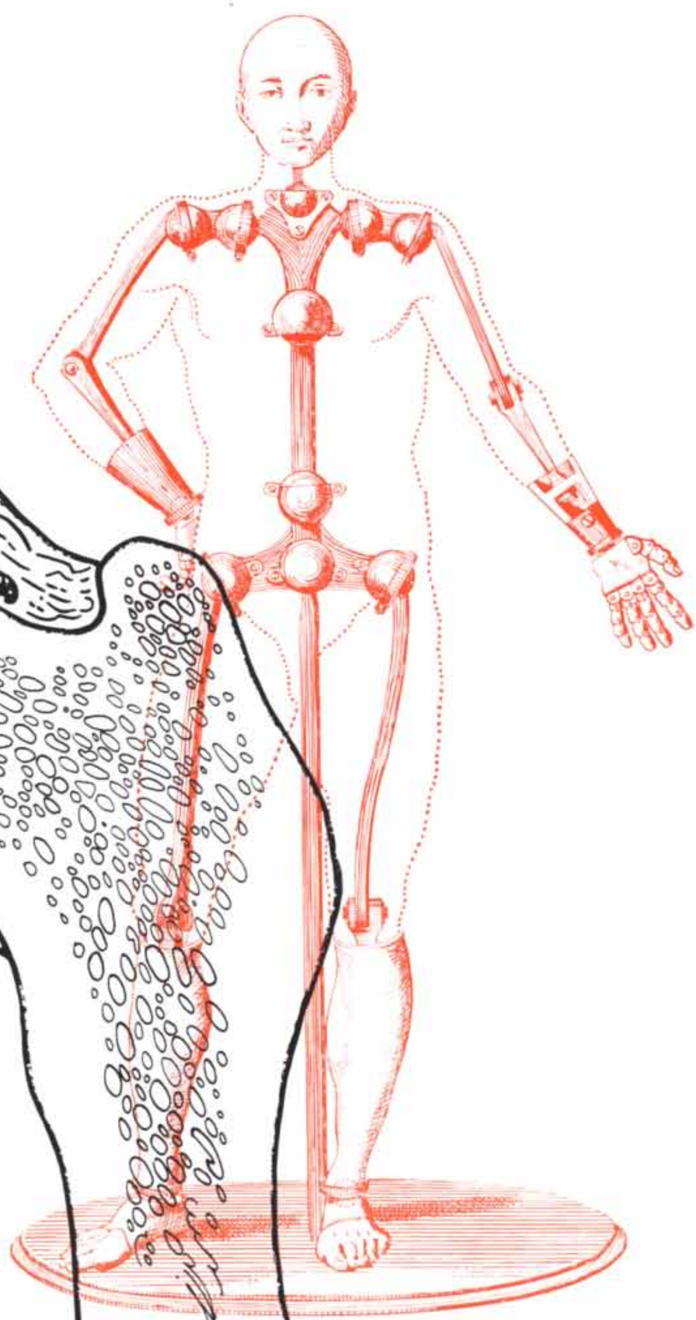


The femur... friction..



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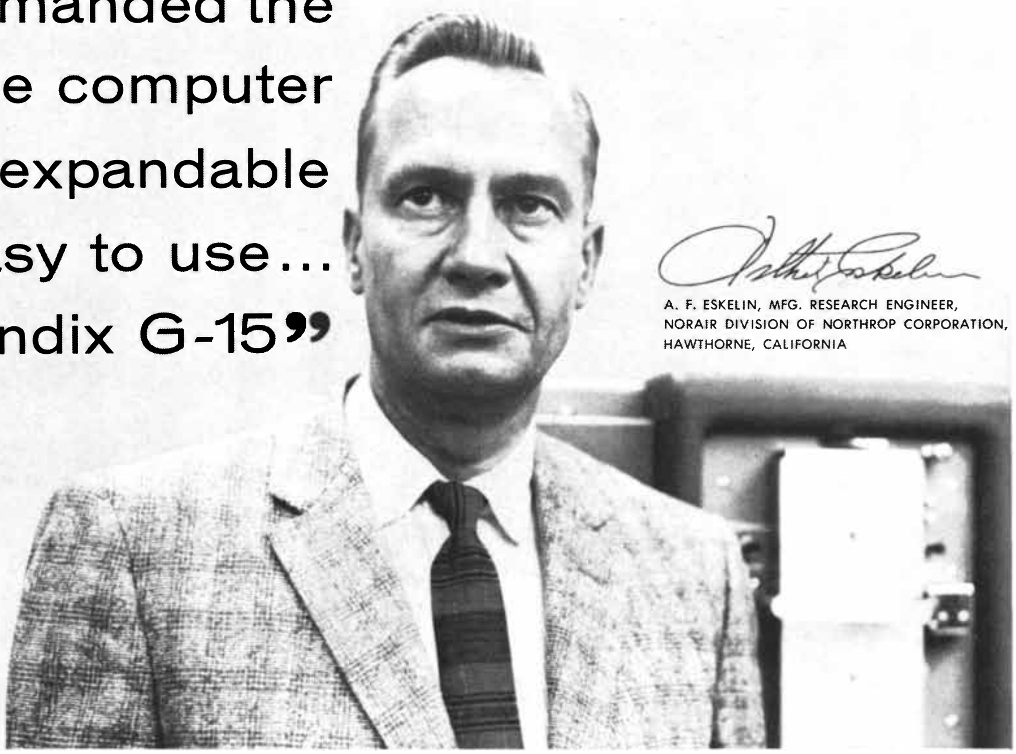

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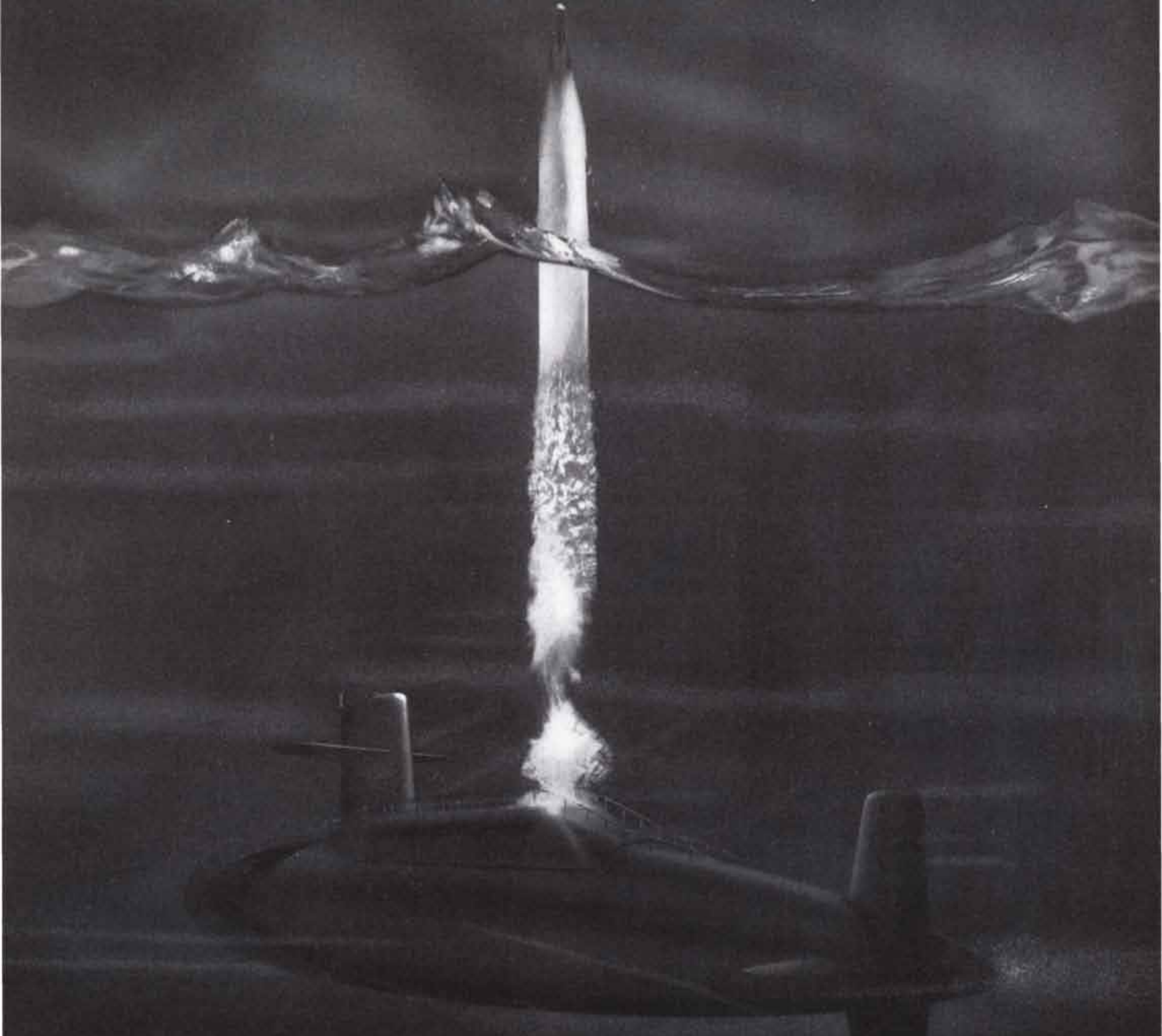

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THE AUTHORS

EDWARD F. McCLAIN, JR. ("The 600-Foot Radio Telescope") is head of the radio astronomy branch of the Naval Research Laboratory in Washington. He was born in Carrollton, Mo., in 1921 and attended the Missouri School of Mines from 1939 until he joined the N. R. L. in 1942. He worked on microwave radar until 1947, when he took charge of a project that led to the development of an automatic navigator for aircraft. He continued his schooling while working at the N. R. L., and in 1950 took his bachelor's degree in electrical engineering at George Washington University. Soon afterward he became interested in radio astronomy. He has done much work in the determination of astronomical distances by means of the absorption of the 21-centimeter radiation emitted by hydrogen in space.

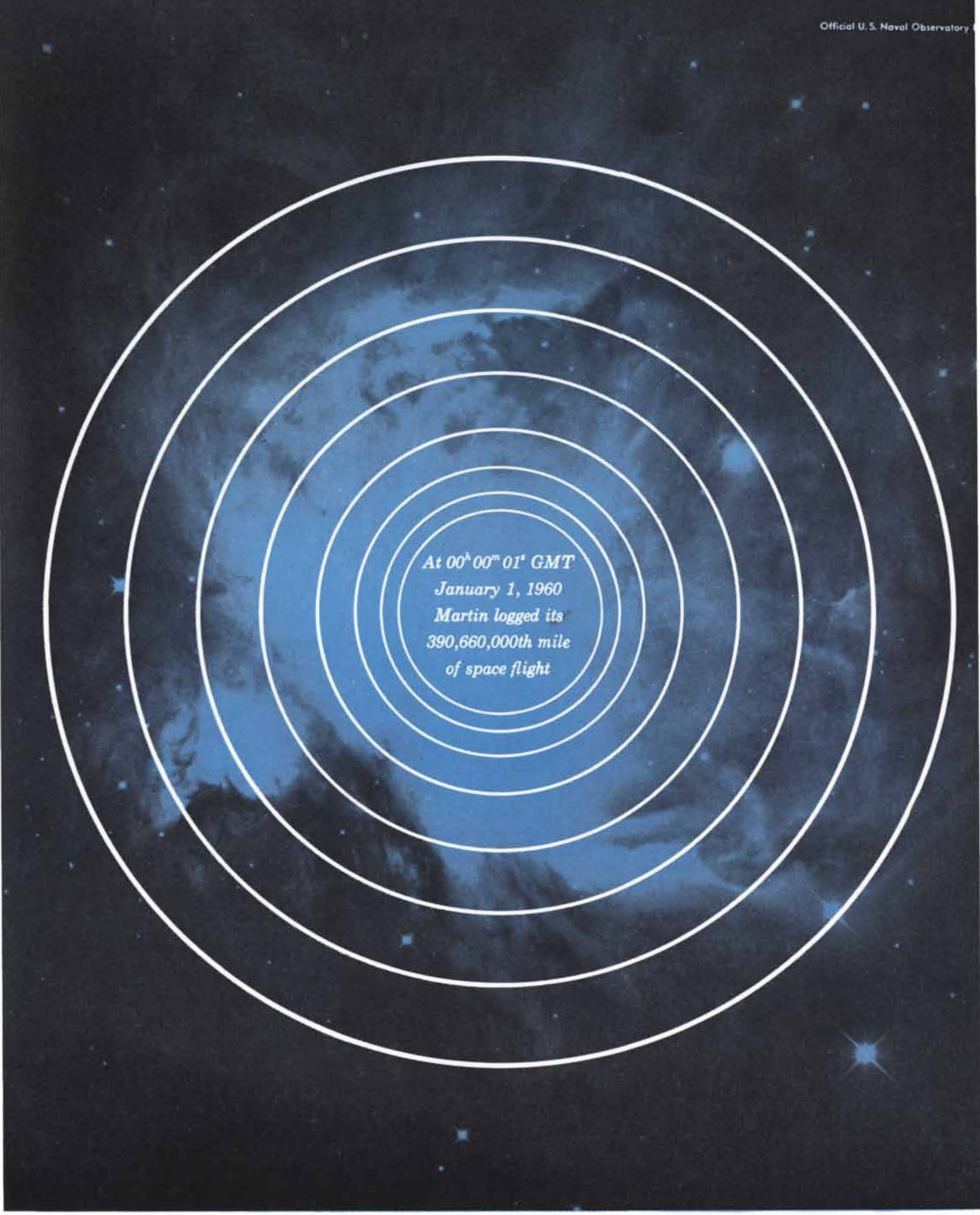
EMMANUEL ANATI ("Prehistoric Art in the Alps") is an authority on prehistoric art who is presently based at the Institut de Paléontologie Humaine in Paris. He was born 29 years ago in Florence, Italy. He migrated to Israel in 1945, fought in the Israeli Army in 1948 and 1949 and then began to study archaeology at the Hebrew University in Jerusalem. After obtaining his M.A., he directed several projects for the Israel Department of Antiquities. He was also in charge of an archaeological survey of the Negev Desert. His interest in prehistoric art was aroused one day in 1953 when he came across a prehistoric rock-carving in the Negev. He organized several research parties to the area and in a few months had discovered several thousand of these pictures. His articles on these finds attracted attention in Europe, and the French Government offered him a fellowship. In 1956 and 1957 he led expeditions for the French Centre National de la Recherche Scientifique to seek prehistoric and protohistoric art in southern Spain, the French Maritime Alps and the Italian Alps. Anati first visited the Camonica Valley, where the carvings described in his article are located, in 1956.

WILLIAM O. PRUITT, JR. ("Animals in the Snow") is a research associate in mammalogy at the University of Alaska. He was born in Easton, Md., in 1922, and as a child he always had a small animal as a pet. "I count myself as one of the fortunate people in this world," he reports. "Even with unlimited financial resources I would probably be doing just what I am doing now—studying animals." He took his bachelor's degree at the University of Maryland and his M.A. and Ph.D degrees in zoology at the University of Michigan. He has been in the far north since he went to Alaska in 1953 as a research biologist with the Arctic Aeromedical Laboratory at Fairbanks.

ALVIN M. WEINBERG ("Breeder Reactors") is director of the Oak Ridge National Laboratory. He was born in Chicago in 1915 and acquired B.S., M.S. and Ph.D. degrees in physics at the University of Chicago. From 1939 to 1942 he did biophysical research at Chicago, and then he joined the Metallurgical Laboratory of the Manhattan project. During the war he worked with Eugene P. Wigner designing the Hanford nuclear reactors, and in 1945 he was named a section chief in the Physics Division of the Metallurgical Laboratory. He directed the Physics Division for 10 months in 1948 before becoming director of research for the entire Laboratory. He was appointed to his present position in 1955. Last June Weinberg was elected president of the American Nuclear Society, and in October he visited the atomic-energy research establishments of the U.S.S.R. as a technical adviser to John A. McCone, chairman of U. S. Atomic Energy Commission.

PETER ALEXANDER ("Radiation-Imitating Chemicals") has since 1950 been a member of the staff of the Chester Beatty Research Institute of the Royal Cancer Hospital in London. He acquired a degree in chemistry in 1941 at the Imperial College of Science and Technology, where he undertook research on insecticides. In 1944 he entered the research department of a textile firm and initiated studies of the physics and chemistry of wool. This project resulted in his return to academic life in 1950. He has investigated the action of drugs that have proved useful in the treatment of cancer. The radiation-like effects of these and other substances aroused his interest in the biological effects of radiation, which he subsequently studied. He is the author of a Pelican book, *Atomic Radiation and Life,* and co-author of a scientific monograph, *The Fundamentals of Radiobiology.*

D. J. K. O'CONNELL, S.J. ("The Green Flash") is director of the Vatican Observatory at Castel Gandolfo. He was



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MARTIN

born in England and educated in Ireland, where he entered the Jesuit Order. He acquired his bachelor's and master's degrees in mathematics and physics at University College, Dublin, and his doctorate at the National University of Ireland. Father O'Connell was at the Harvard College Observatory from 1931 to 1933; then he went to the Riverview College Observatory in Australia, where he served as director from 1938 until he went to the Vatican Observatory in 1952. He is president of the Commission on Eclipsing Binaries of the International Astronomical Union.

HELEN GAY ("Nuclear Control of the Cell") is a research associate in the Carnegie Institution of Washington's Department of Genetics at Cold Spring Harbor, N.Y. A native of Pittsfield, Mass., she attended Mount Holyoke College, planning to major in languages or history. A zoology course taught by Ann Haven Morgan changed her mind, and in 1940 she took her B.A. in zoology. She obtained her M.A. at Mills College and her Ph.D. at the University of Pennsylvania. During World War II she did research at the National Institutes of Health. Since then, with three years out to earn her Ph.D., she has been at Cold Spring Harbor.

WALLACE O. FENN ("The Mechanism of Breathing") is professor of physiology at the School of Medicine and Dentistry of the University of Rochester. He received his degrees from Harvard University, taking his Ph.D. there in 1919. Among the physiological topics in which he has been interested are muscle, nerve, potassium and other electrolytes, respiration and aviation medicine. He is chairman of the Panel on Underwater Swimmer Technology of the National Research Council and is a member of the Committee on Space Research of the International Council of Scientific Unions. Fenn has served as president of the American Physiological Society, of the American Institute of Biological Sciences and of the Society for Experimental Biology and Medicine, and is now secretary-general of the International Union of Physiological Sciences.

SIR GEORGE CLARK, who reviews Volume I of *The Correspondence of Isaac Newton* in this issue, retired in 1957 as provost of Oriel College, Oxford. He has been professor of economic history and modern history at the universities of Oxford and Cambridge and has served as president of the British Academy.


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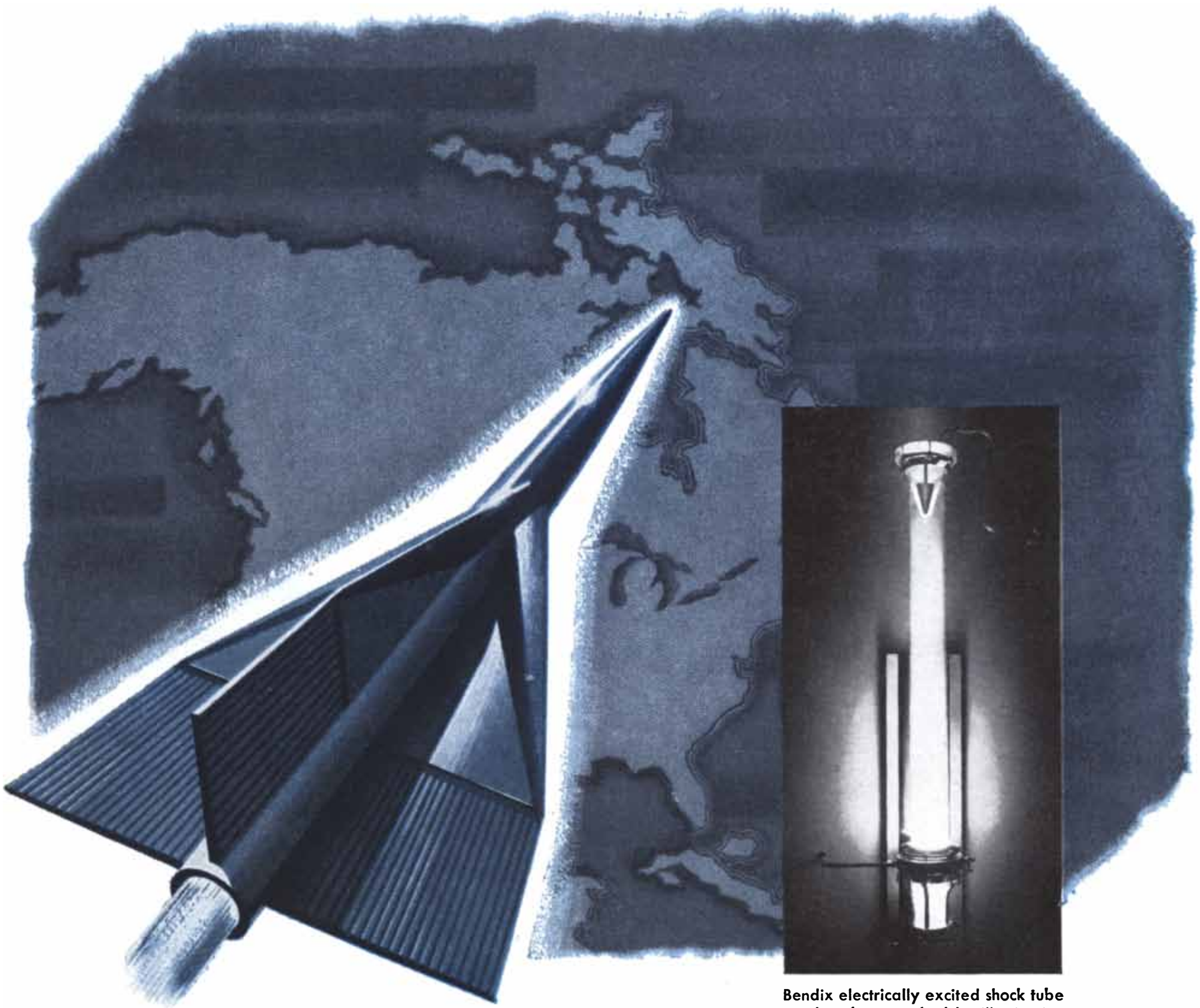

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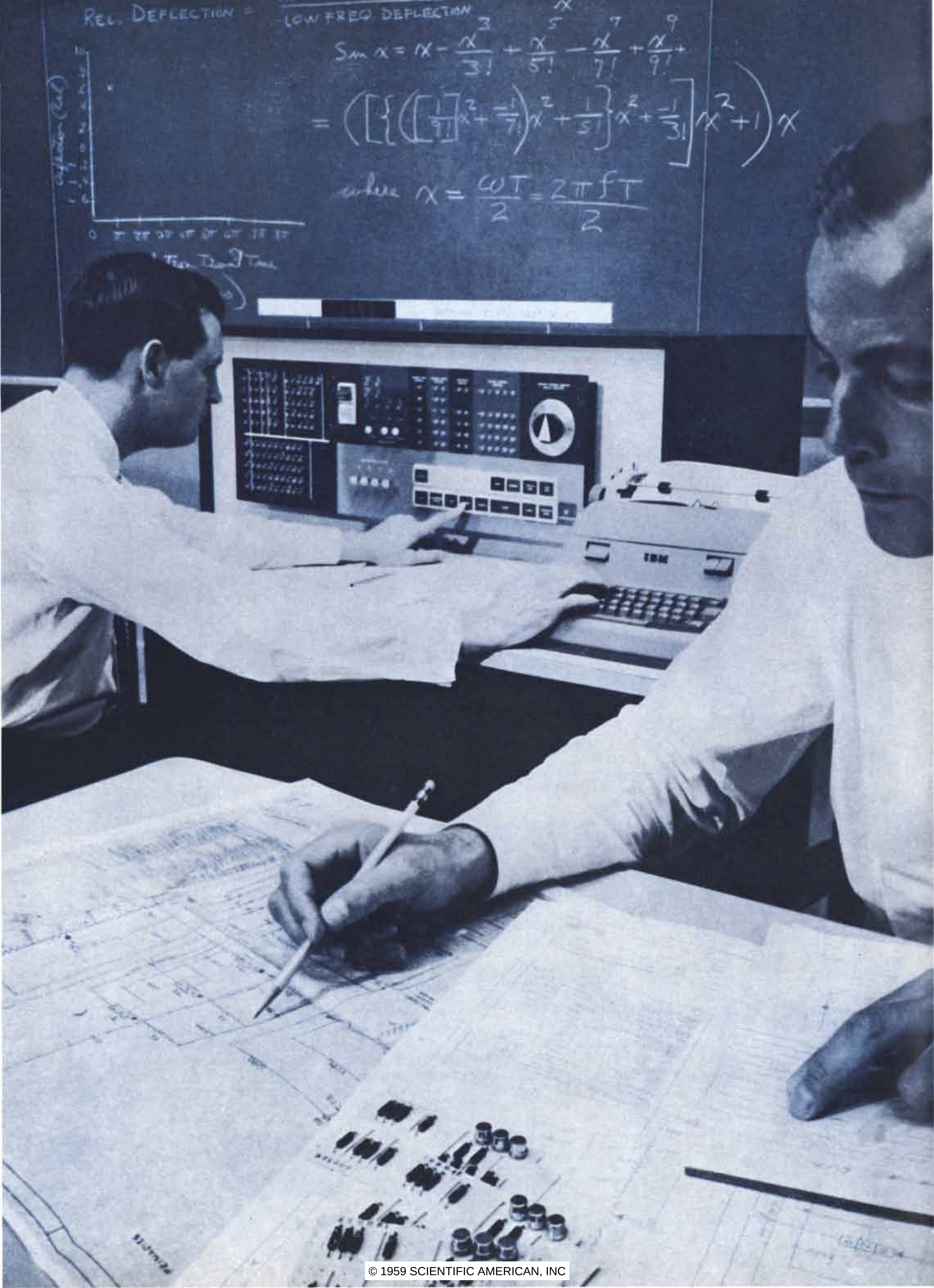
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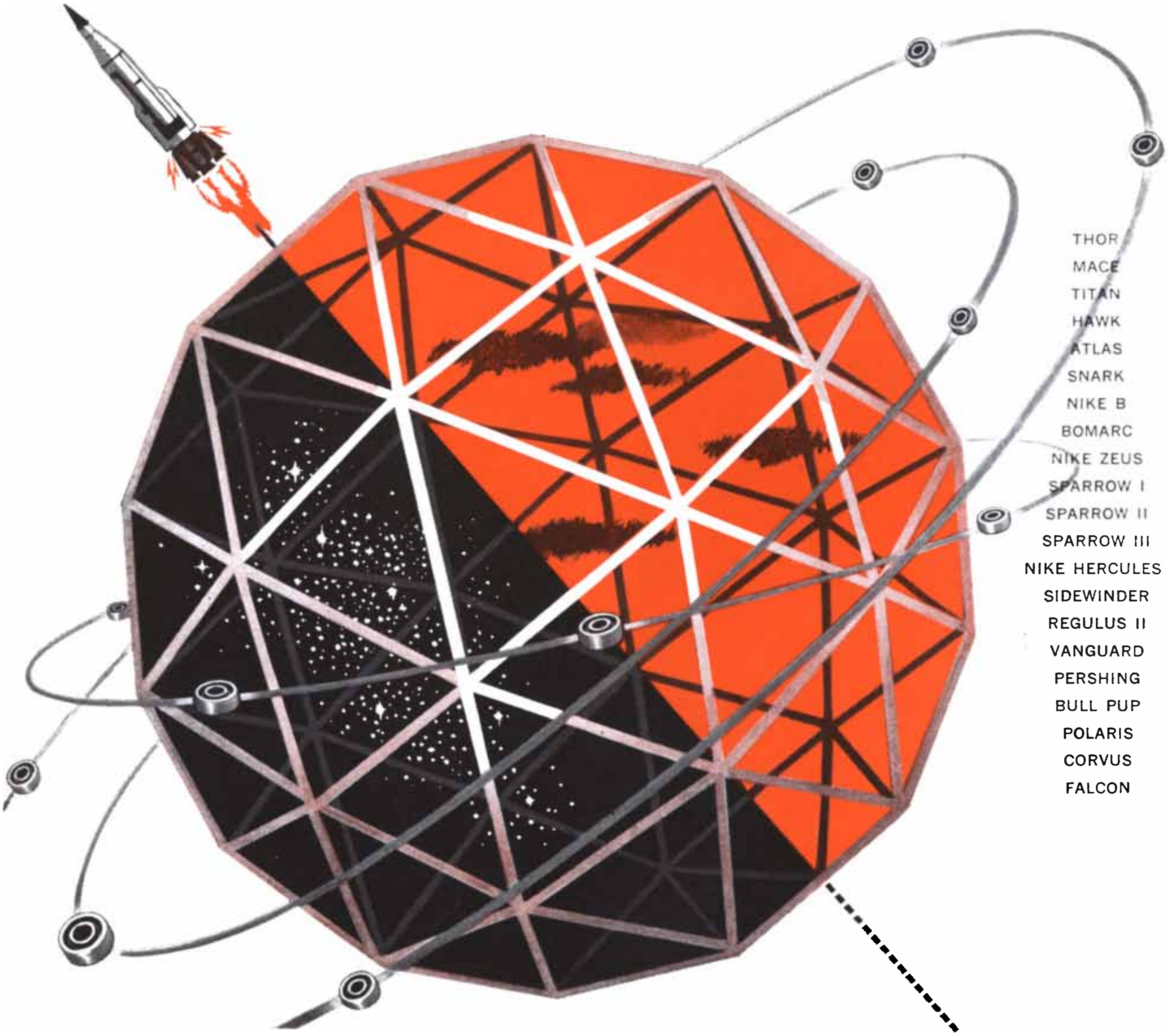

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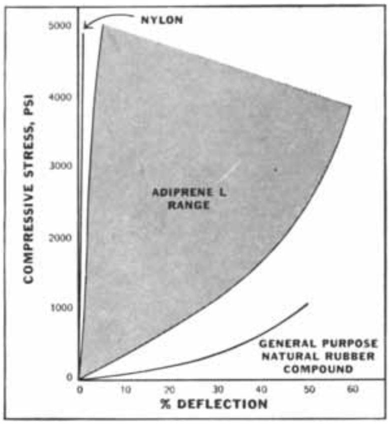

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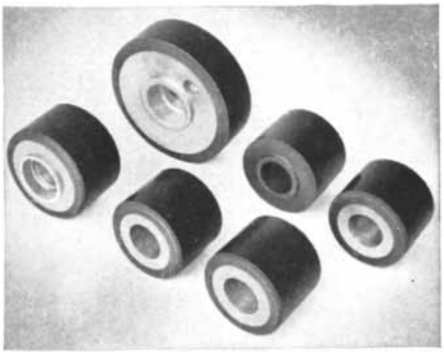

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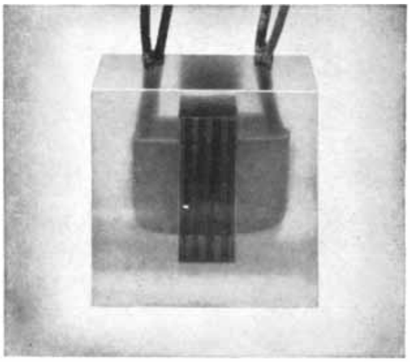

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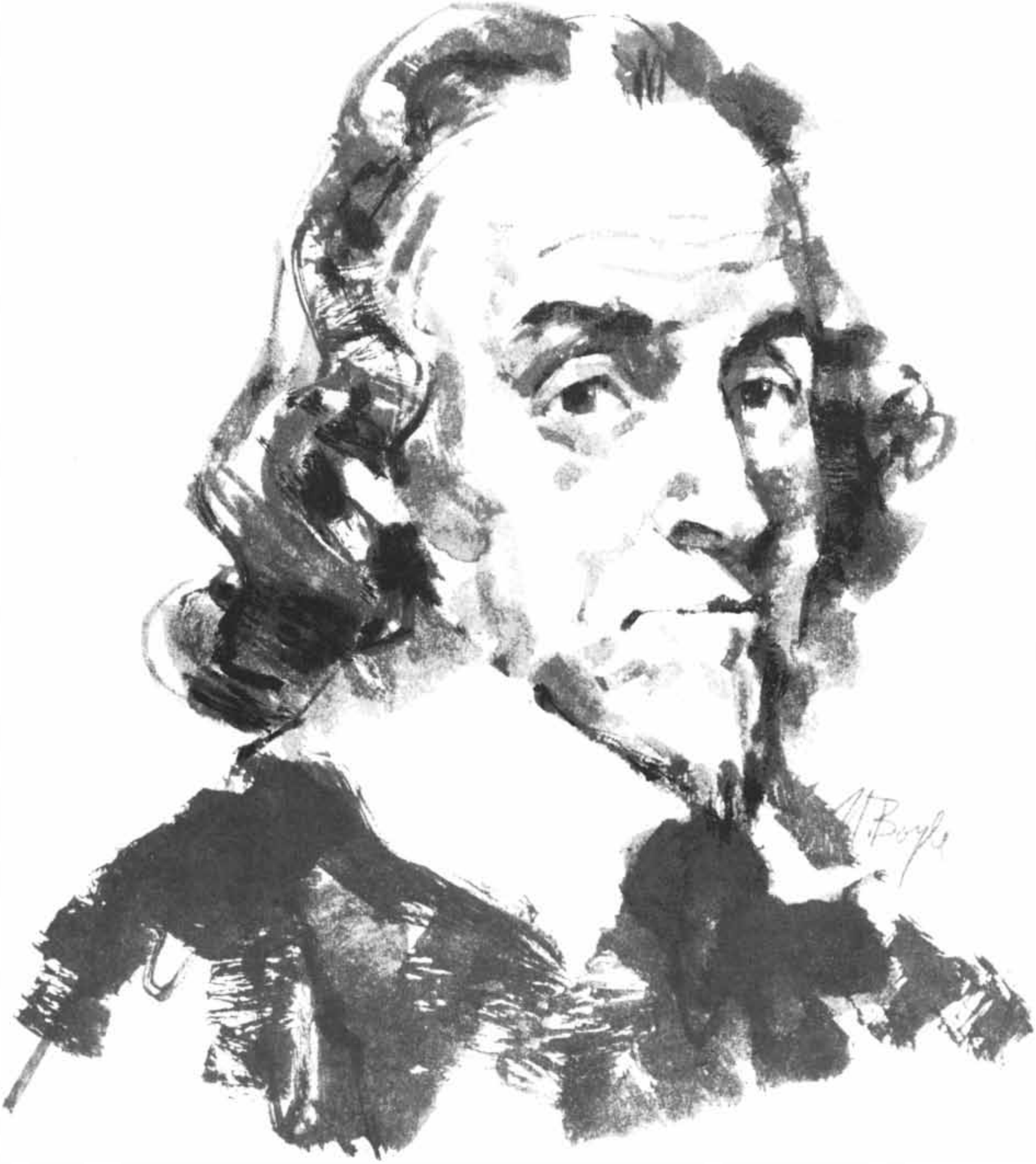

William Harvey... on the quest for knowledge

"True philosophers, who are only eager for truth and knowledge, never regard themselves as already so thoroughly informed, but that they welcome further information from whomsoever and from wheresoever it may come; nor are they so narrow minded as to imagine any of the arts or sciences transmitted to us by the ancients in such a state of forwardness or completeness that nothing is left for the ingenuity and industry of others. On the contrary, very many maintain that all we know is still infinitely less than all that still remains unknown."

—Letter to the Royal College of Physicians, 1628.

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Established 1845 SCIENTIFIC AMERICAN January, 1960 Volume 202 Number 1

The 600-Foot Radio Telescope

The world's largest steerable telescope is under construction in West Virginia. Its great power to gather radio waves and resolve celestial radio sources promises important advances in knowledge of the universe

by Edward F. McClain, Jr.

By 1962, in a secluded valley in West Virginia, a radio-telescope reflector as big as a stadium will be majestically tracking the sky. It will have a diameter of 600 feet, a circumference of nearly a third of a mile and a reflecting surface of more than seven acres. It will tower to the height of a 66-story building above the semiwilderness around it. Yet this huge instrument will be able to sweep the entire sky above it and to point at any spot with high precision.

The U. S. Navy started to build the $79-million apparatus last summer. For half of each operating day it will be used to conduct classified research for the Navy in such fields as ionospheric physics, communications and navigation. During the other half of the day the gigantic parabolic reflector will be available to astronomers for basic studies in radio astronomy, extending our knowledge of the solar system, the galaxy and the cosmos beyond.

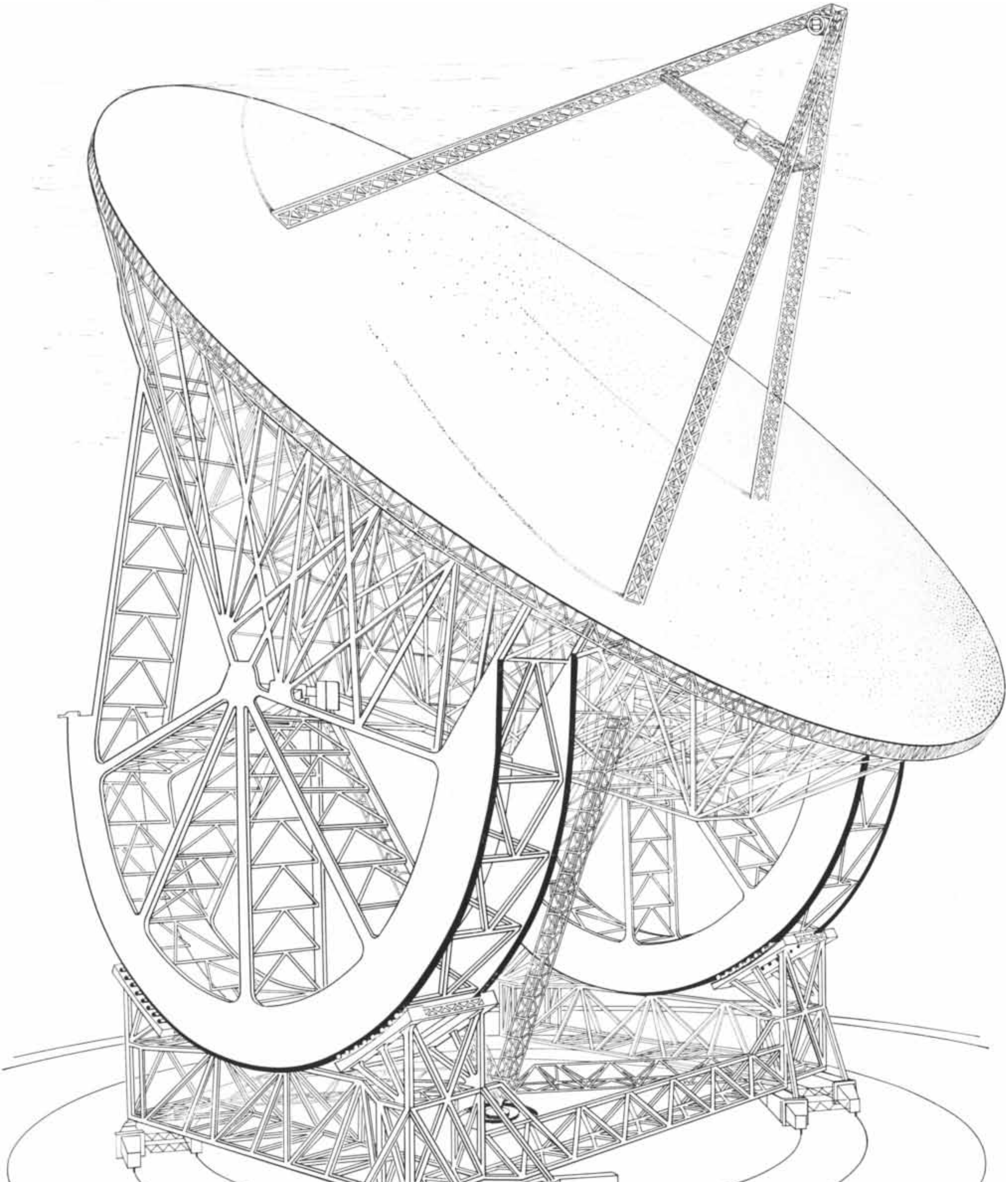
The very size of the 600-foot radio telescope is the justification for building it. Like the mirror in a light-gathering telescope, the parabolic reflector is simply a device to collect and focus electromagnetic radiation. The larger the reflector, the more radiation it can collect. The radiation-gathering power of any telescope increases approximately as the square of the increase in its diameter. The 200-inch mirror on Palomar Mountain that collects radiation in the optical part of the spectrum can gather more than 1,000 times as much light as an amateur's six-inch telescope. A 600-foot radio telescope, with a diameter 12 times that of a 50-foot instrument, collects 144 times as much radiation.

Radio astronomers have a second compelling reason to want such a big telescope. This is the need for resolving power, or capacity to distinguish celestial objects and locate them accurately. The resolving power of a telescope is theoretically equal to its aperture, or diameter, divided by the wavelength of the radiation with which it works. Since light waves are of the order of a 50,000th of an inch long, the 200-inch telescope has an aperture 10 million times the length of the waves of light. As a result it can ideally discriminate an object in the sky that has a diameter of only .023 second of arc (the best the human eye can do is about one minute of arc). The electromagnetic waves gathered by a radio telescope are hundreds of thousands and even millions of times longer than light waves. Because radio waves are so very long, a radio telescope must be extremely large if it is to have adequate resolving power.

It would take the impossible diameter of more than 1,000 miles to achieve an aperture 10 million times the length of the astronomically important 21-centimeter (8.27-inch) waves radiated by the cool hydrogen in space. The 600-foot diameter of the biggest radio telescope will be only 900 times the length of 21-centimeter waves. An optical-telescope mirror with a diameter only 900 times as long as light waves would be about a 50th of an inch in diameter. Thus the 600-foot telescope is optically minuscule in comparison with the 200-inch. Nonetheless it is as large a precision instrument as today's engineers can design and construct.

The contrast between the resolving power of an optical telescope and that of a radio telescope can be visualized in terms of their capacity to distinguish two imaginary sources of radiation on the surface of the moon, some 240,000 miles away. If the sources were two bright lights, the 200-inch telescope would recognize them as two spots when they were about 200 feet apart; the telescope would see them as a single blurred light when they were closer together. The human eye would see them as two lights if they were 72 miles apart. (It should be said, however, that the discrimination of the eye is limited not by its optics but by the coarse "grain" of the receptors in the retina.) If the sources were transmitters broadcasting on the 21-centimeter wavelength, they would have to be some 360 miles apart for the 600-foot telescope to "see" them as a pair and not as a single source. At 42 centimeters they would have to be 720 miles apart, because resolving power is halved when wavelength is doubled. On the other hand, if the 200-inch Palomar telescope were "tuned" to 21 centimeters, it would have so little resolving power as to be practically blind.

The resolving power of the 600-foot telescope will achieve a considerable



APPEARANCE OF THE TELESCOPE when it is completed is depicted in this drawing. The instrument will stand 665 feet high, and will incorporate 20,000 tons of steel and 600 tons of aluminum. Its scale is suggested by the tiny human figures at lower right.

advance on the capacity of the smaller instruments that have opened up the universe of radio astronomy. The 50-foot parabolic reflector at the Naval Research Laboratory in Washington, for example, could not even fully resolve the moon at 21 centimeters. At this wavelength it has a theoretical beam width (equivalent to resolving power) of 47 minutes of arc, while the moon subtends 30 minutes of arc in the sky. The highly productive 82-foot telescope at Dwingeloo in the Netherlands has a beam width at 21 centimeters of 34 minutes. In contrast, the 600-foot antenna will achieve a resolving power of five minutes, or a 12th of a degree.

In the early days of radio astronomy, one and two decades ago, it was not the lack of resolving power so much as the poor radiation-gathering capacity of radio telescopes that made radio astronomers want larger instruments. The workers employed their relatively small telescopes mostly for tuning in on the sun, primarily because it emits strong signals. They needed larger instruments to develop information about the far weaker radio sources that were thought to exist outside the solar system.

After World War II (and partly as a consequence of the intensive wartime development of radar) electrical engineers, physicists and astronomers in several countries entered radio astronomy. The British now have the world's largest steerable telescope, the 250-foot paraboloid at Jodrell Bank. The Australians are building a 210-foot telescope. The largest comparable instrument in this country is the 140-foot telescope nearing completion at the National Radio Astronomy Observatory at Green Bank, W. Va.

About 12 years ago two groups at the Naval Research Laboratory almost simultaneously decided that they badly needed and might obtain a gigantic telescope, 500 or 600 feet in diameter. One group was made up of radio astronomers who were planning the 50-foot telescope mentioned earlier. The other group consisted of communications engineers led by James H. Trexler, who had the intriguing idea of employing the moon as a reflector to relay communications around the world. In 1951 Trexler undertook to test his theory. Subsequent studies led to the construction of a stationary reflector 220 by 263 feet, the surface of which was set in a hole scooped out of the ground at a Navy research station in southern Maryland [*see top illustration on page 50*]. By 1956 his group was able to bounce radio signals off the moon and to achieve excellent teletype transmission between Maryland and both the West Coast and Hawaii. In 1956 the two Naval Research Laboratory groups formulated the initial specifications for a large steerable telescope in a document for the Bureau of Yards and Docks, the Navy's agency for shore construction. Exhaustive engineering studies by the Bureau and its contractors showed that the 600-foot instrument was feasible, and Congress approved the project two years ago.

Construction of the telescope is now under way in a small valley surrounded by protective mountains near the tiny community of Sugar Grove, W. Va., about 30 miles east of Green Bank. The telescope will rise to the imposing height of 665 feet above the floor of the valley. It will require 20,000 tons of steel, 600 tons of aluminum and 14,000 cubic yards of concrete. (The 200-inch telescope weighs about 500 tons.) The reflector will be cradled in two structures resembling Ferris wheels, which will tilt it to any angle of elevation from zero to 90 degrees. To turn it a full 360 degrees in the horizontal plane the entire structure will ride on trucks on a circular railroad track. The instrument will thus be just as movable as the great optical telescopes. An inertial-guidance system—controlled gyroscopes that maintain their position in space regardless of such outside influences as the motion of the earth—will direct the instrument so precisely that it will point to a spot on the celestial sphere that is no larger than a 60th the diameter of the moon, or 30 seconds of arc.

An aluminum-wire screen will provide a smooth surface for the reflector. The screen will be divided into individual panels that will be adjusted automatically by servomechanisms to compensate for distortions caused by wind, temperature changes and the immense stresses of gravity to which the reflector will be subjected when it moves. The surface must maintain itself very close to the parabolic configuration at all times if the radio reception is to be free of distortion. The surface must not vary from a true paraboloid by more than plus or minus one inch when the telescope is working at the relatively short wavelength of 21 centimeters. This may appear to be a rather large tolerance. But it is the same—an eighth of a wavelength—as that permitted in the 200-inch Palomar telescope. If the surface of the 200-inch telescope departs from a paraboloid by more than a 200,000th of an inch, the image of a star becomes fuzzy and virtually worthless for observation. The huge piece of glass is subject to distortion by gravity and even more by temperature changes. To correct the gravitational distortion, weighted-lever mechanisms are mounted at the underside of the mirror; they keep its surface true by automatically pushing at its back as it is tilted. The servomechanisms in the 600-foot radio telescope will have the same function, and they will compensate for the other distortions as well.

The radio astronomer will have a new experience when he uses the huge reflector. With telescopes having a diameter of 100 feet or less, he usually has complete control of the movement of the instrument, and he may alter his experiment at will simply by turning a knob or throwing a switch. It is probable that no human operator will ever have his hands directly on the controls of the 600-foot telescope. Instead, the astronomer will submit a detailed description of his experiment some time before it is to be done. An expert operating crew will program the experiments, along with others to be carried out that particular day, on punch cards or tape to be fed into computers that will direct the inertial-guidance system. The Naval Research Laboratory will install various types of receiving apparatus to be placed at the focus of the telescope, 240 feet above the center of the reflector. Some astronomers may wish to install their own equipment. The visiting astronomer will probably place his instruments in a gondola-like structure to be hoisted into position at the focus just before his observations begin. The data obtained during observations will probably emerge on punch cards or tapes, which the astronomer can take to his home laboratory for analysis on his own computing machines.

Since radio astronomy is concerned with virtually all physical processes that occur in the universe, from those in the earth's atmosphere to those in the deepest reaches of space, the 600-foot telescope will have a crowded agenda. The Navy has established a consulting committee representing such fields as communications, astrophysics and cosmology to assist in the selection of projects that will most advantageously exploit the unique capabilities of the instrument. Within this limitation, radio astronomers from universities and other institutions as well as from the Naval Research Laboratory will be able to use the telescope during the half of each day that it is devoted to astronomy.

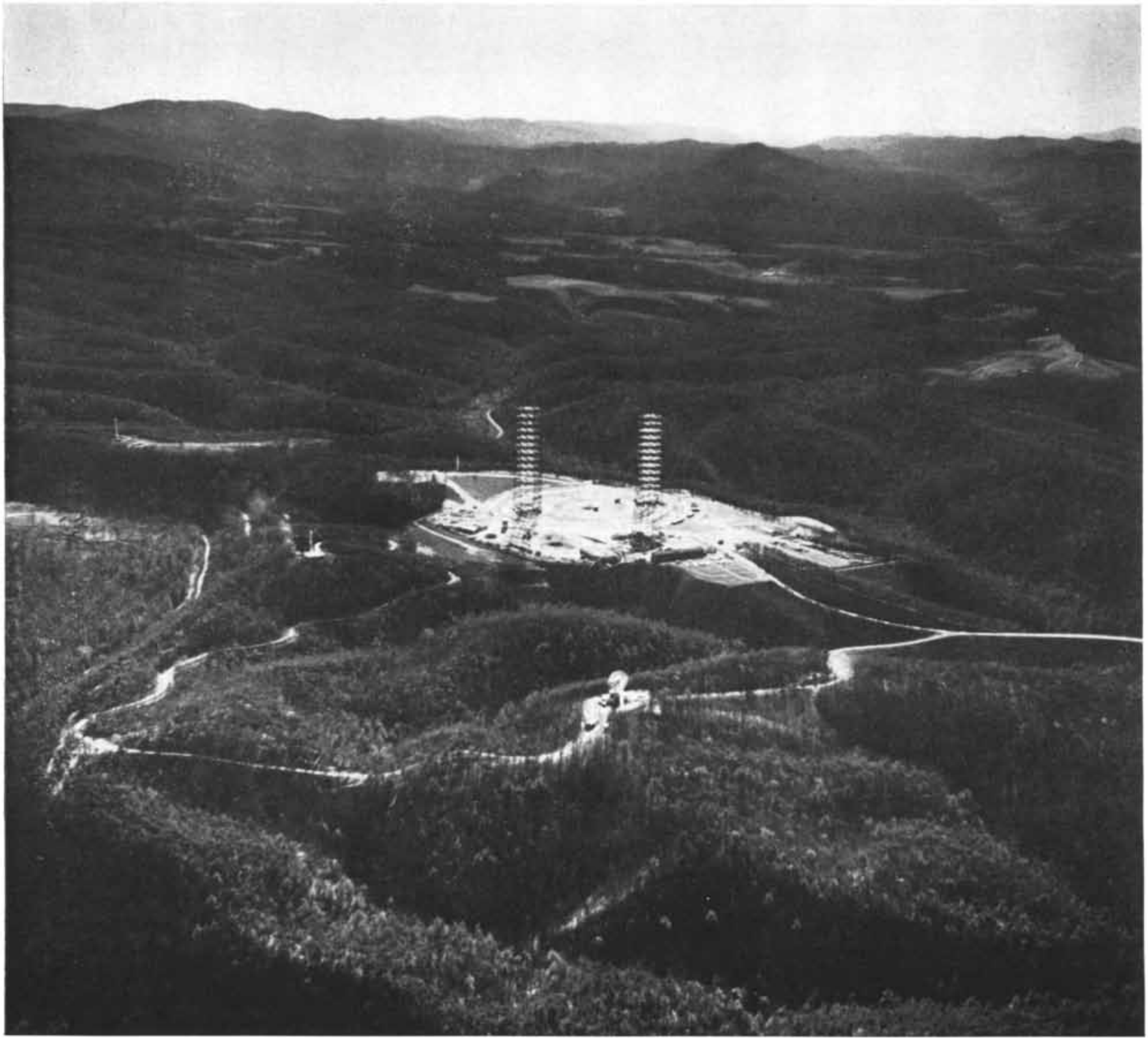
In almost every observation they make with the 600-foot telescope, astronomers will be taking advantage of both its high resolving power and its great capacity to gather radiation. The size of the reflector supplies both characteristics, and they are interdependent. For most projects, however, one is more important than the other.

The resolving power of the instrument will be especially valuable in studies of the solar system. Measurements made with smaller telescopes indicate, for example, that the surface of the moon remains warm for a time after it has turned away from the sun, and that it remains cool for some days after it has turned toward the sun. This suggests that the lunar surface is insulated, perhaps by a layer of fine dust. The resolution of present radio telescopes at wavelengths of 21 centimeters or more is so poor, however, that they can make only the crudest measurements of the difference in temperature at various points on the moon's surface. At 21 centimeters the 600-foot telescope has a beam width one sixth the apparent diameter of the moon; hence at this wavelength it could make a six-line "picture" of the moon. This is not a fine-grained picture compared with that presented by the 480 lines on a television screen, but it might help to correlate radiation temperatures with some of the specific geographical features of the moon.

The sun, like the moon, subtends 30 minutes of arc. It is the most intense radio source in the sky, and although it has been studied for years, only a few instruments have been able to distinguish among radio emissions from various parts of the solar disk. The 600-foot telescope will be able to follow single spots on the sun if they are far enough apart, and will even make measurements of the radiation from the spectacular solar flares that attend the appearance of sunspots.

The planets are, of course, too small to be resolved even by the 600-foot telescope. Jupiter, the largest of the planets, presents the largest planetary image in the sky, but it subtends an angle of only 47 seconds of arc. At wavelengths up to several meters, however, the new telescope will still receive useful radio emission from Jupiter, extending observation of the planet into wavelengths now virtually closed to radio astronomy.

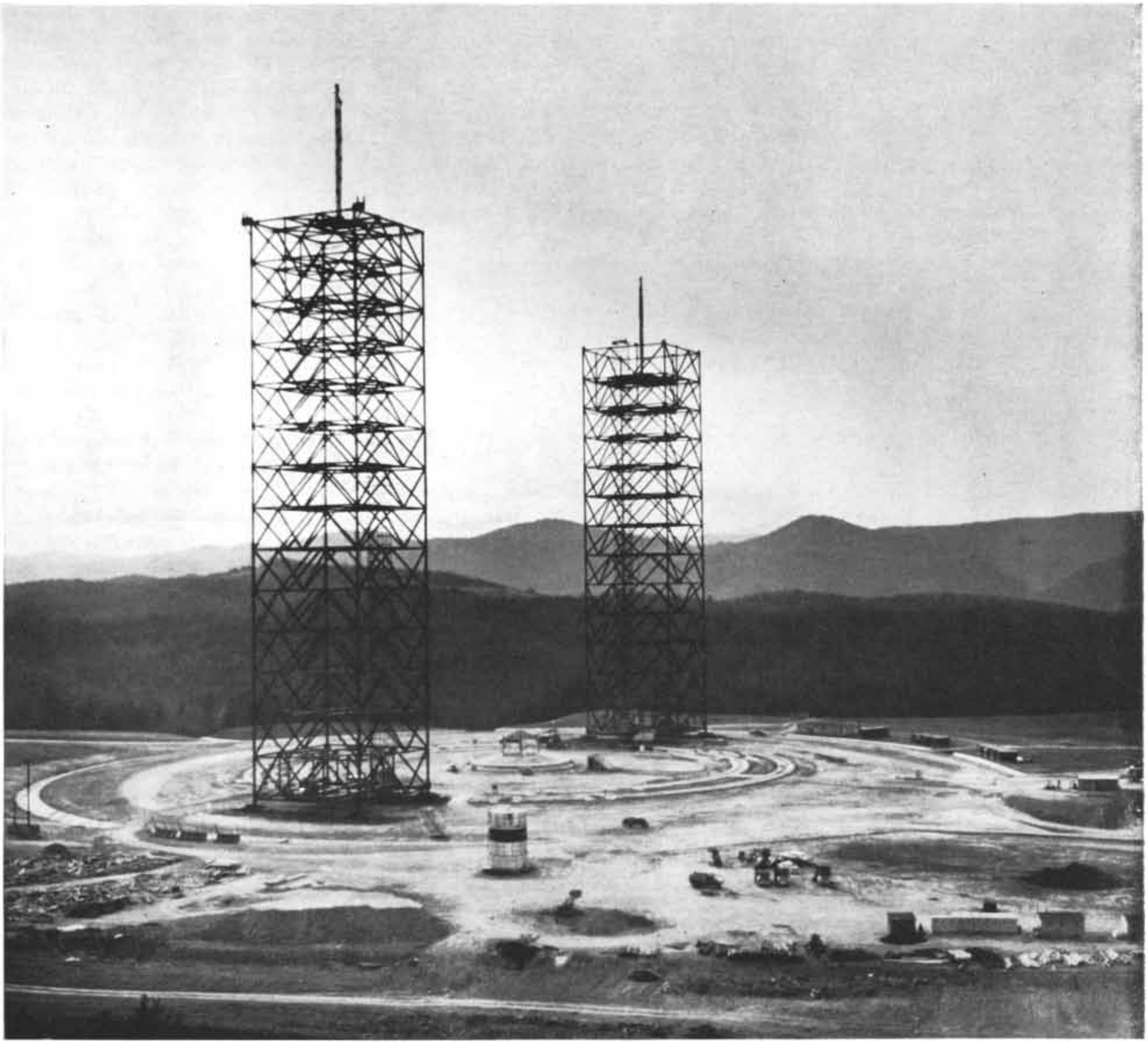
Existing radio telescopes have picked up radiation at shorter wavelengths from



SITE OF THE TELESCOPE is in a valley surrounded by hills that will protect the structure from high winds. A 60-foot radio telescope to supplement the 600-foot is visible below construction area. The nearest town is Sugar Grove, W. Va.

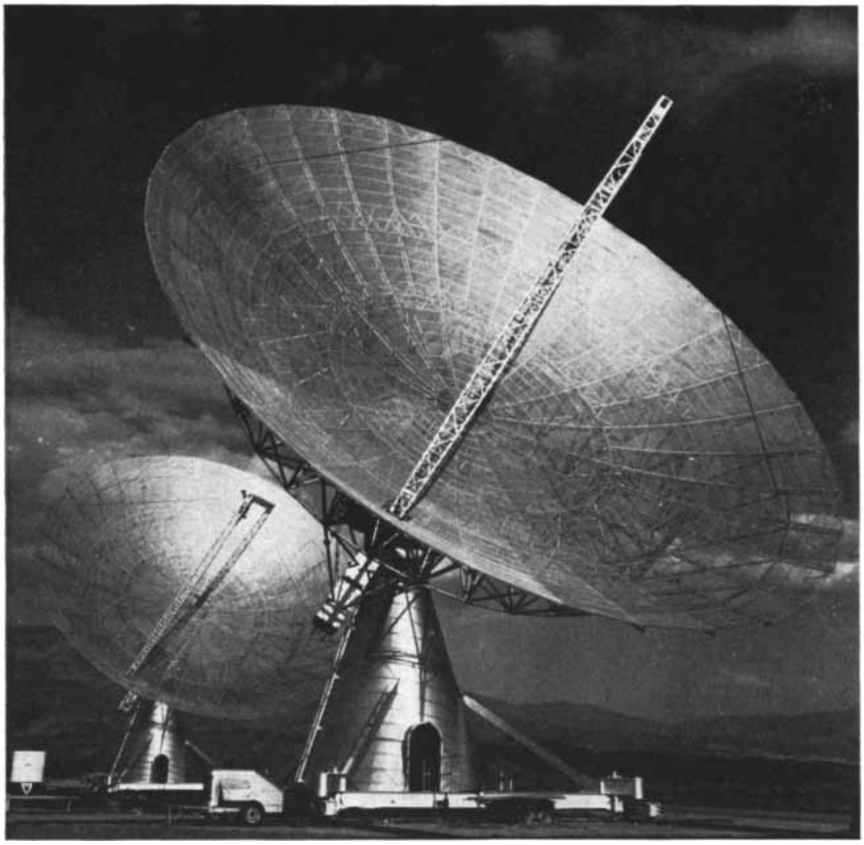
Venus, Mars, Jupiter and possibly Saturn. The results are most interesting in the case of Venus and Jupiter. With the 50-foot reflector at the Naval Research Laboratory, Cornell H. Mayer, Timothy McCullough and Russell Sloanaker have made the surprising discovery that the radiation from Venus at centimeter wavelengths indicates a surface temperature of approximately 600 degrees Kelvin (621 degrees Fahrenheit). Measurements in the infrared region of the spectrum had shown a temperature of about 250 degrees K. (nine degrees below zero F.) at the top of the planet's cloud cover. Radio measurements of Jupiter are even more startling. About a year ago Sloanaker, working at 10 centimeters, found a temperature of about 600 degrees Kelvin, much higher than optical measurements had led us to expect. At 22 centimeters, Frank Drake of the National Radio Astronomy Observatory has recently detected temperatures in the neighborhood of 2,000 to 3,000 degrees K. Such a high temperature suggests a nonthermal source of radiation, perhaps electrons accelerated to speeds near that of light by strong magnetic fields. The temperature may also have a thermal origin, perhaps a very hot layer below the top of Jupiter's atmosphere. The energy-gathering power of the 600-foot telescope at longer wavelengths may settle this question.

In contrast to Venus and Jupiter, Mars and Saturn show temperatures in the radio spectrum that agree reasonably well with those found in the optical spectrum. Radio emissions from Saturn are so weak, however, that little more than detection has been achieved. Indeed, all of the radio observations of planets lie at the limits of present instruments. The radiation-gathering as well as the resolving power of the 600-foot telescope will help put the observations on firmer ground. Radiation from celestial sources falls off to low energy-levels by the time it reaches a radio antenna, in some cases to as low as a few hundredths of a degree K. of equivalent temperature. Circuit noise inside even the best conventional receiver may correspond to temperature as high as 1,000 to 2,000 degrees. Recently masers and parametric amplifiers, both solid-state devices, have lowered receiver temperatures to around 100 degrees K. By careful control of the variation in cir-



TWIN ERECTION TOWERS to be used in building the telescope are each 90 feet square and 420 feet high. They will have derricks on top with booms 200 feet long. The towers will be removed when the telescope is completed and put into service during 1962.

"HOLE-IN-THE-GROUND" ANTENNA devised by James H. Trexler bounces radar signals off moon. Paraboloid, 220 by 263 feet, is at Naval Research Laboratory station in Maryland. Large boom over surface moves to track the moon through restricted range.



TWIN 90-FOOT ANTENNAS at Bishop, Calif., are the largest steerable paraboloids operating in the U. S. They are on tracks so that distance between them can be varied when they are used as interferometers. They are operated by the California Institute of Technology.

cuit noise, however, and by elaborate programs of analysis carried out on electronic computers, it is possible to distinguish the signal from the noise and to derive useful data. Seven acres of reflecting surface will gather a great deal of energy, considerably improving the signal-to-noise ratio and giving the data higher reliability.

The 600-foot telescope may be used as a transmitter as well as a receiver, and so will make important contributions to radar studies of the solar system. The employment of existing radio telescopes in this work has produced some tantalizing results. When the 84-foot reflector at the Lincoln Laboratory of the Massachusetts Institute of Technology was used to bounce radar signals off Venus, it took almost a year of work by a computer to differentiate the faint echo from the noise of the receiver. A similar experiment with the moon as the target kept a computer at the Naval Research Laboratory busy for seven months in 1957. Trexler was able to overcome the signal-to-noise problem with his big reflector set in the ground, but his work was limited by the immobility of the reflector, which could function only when the moon was at certain positions. With its great power-gain and high resolution the 600-foot telescope should obtain radar echoes fairly easily from the moon, Venus and Mars and perhaps even Jupiter. These measurements, apart from their inherent interest, will fix solar system distances with the great precision necessary to plan space-vehicle orbits.

Radar echoes will be especially useful in studies of the sun and its corona. Careful measurement of the time required for signals to travel to and from the sun will show how far above the sun's surface the signals are reflected. Such data will provide an independent measurement of the height at which various phenomena occur in the solar atmosphere. Closer to home, particles sent out by the sun during a flare may at times intercept a radar beam between the earth and the moon, causing measurable delays in the return of the signal. At present the signal-to-noise ratios in moon-radar systems are so small that such delays have not been detected. The 600-foot telescope should yield rather accurate measurements of the delay and thus an indication of the quantity of solar particles. The instrument may even be able to detect an echo from the particle clouds themselves.

In its work on the solar system the 600-foot telescope will greatly assist the instrumentation of deep-space probes.

At the very least it will establish the order of magnitude of some of the phenomena to be encountered. As a result of its findings a rocket to Jupiter might be equipped to measure strong magnetic fields and one to Venus to measure high surface-temperatures.

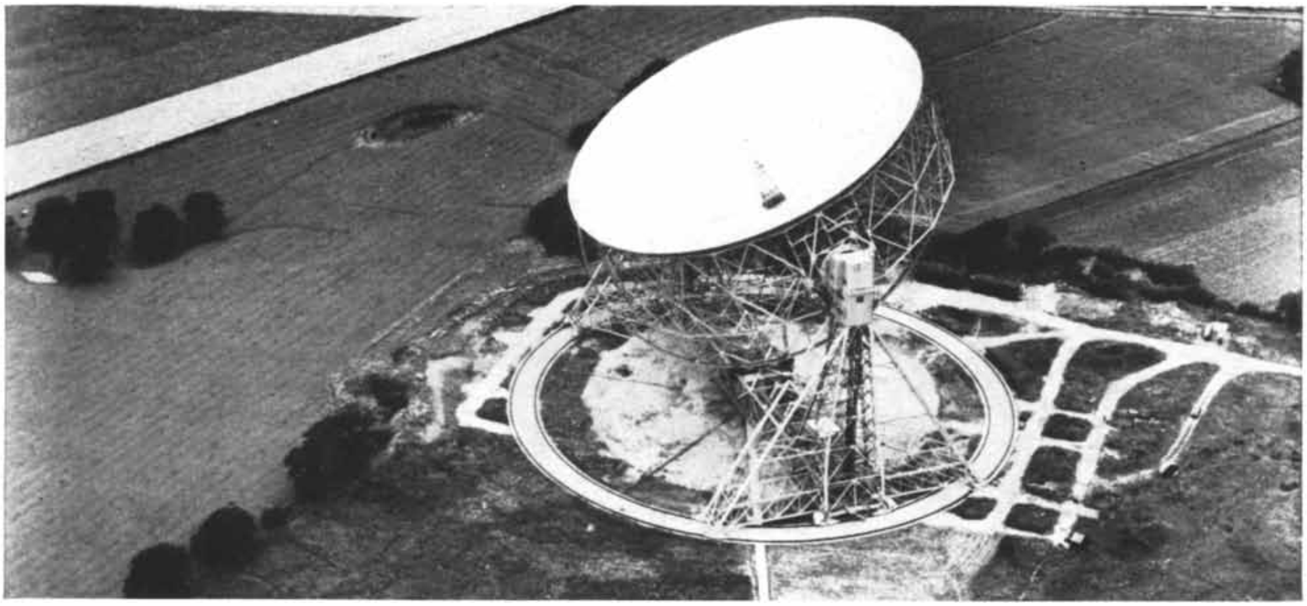
Resolving power is an important consideration in radio observation beyond the solar system as well as within it. The 600-foot telescope will help to determine, for example, whether the radiation of hot, ionized hydrogen from certain regions in the central plane of the galaxy originates from a uniformly distributed source or from a large number of discrete sources. At 21 centimeters it will resolve in much greater detail the distribution of the clouds of neutral (unionized) hydrogen that mark out the arms of our galaxy. The high resolution of the instrument at this wavelength will even play a useful role in extragalactic astronomy. The Great Nebula in Andromeda occupies five degrees of arc in the sky, 60 times the five-minute beam width of the 600-foot telescope. Thus it should be possible to make detailed maps of the radio image of this galaxy.

The great radiation-gathering power of the 600-foot telescope will demonstrate its special value in the study of certain major questions confronting galactic and extragalactic astronomy. Our galaxy, for example, is enveloped in a spherical "halo" that emits weak radio signals; the same appears to be true of the Andromeda nebula and other galaxies. Determination of the source of this radiation would clarify the processes involved in galactic evolution. The 600-foot telescope will also be used to seek radio emission and absorption lines from material other than hydrogen. Some of the materials which are possible emitters or absorbers in the radio spectrum are helium, deuterium, sodium, aluminum, potassium, chlorine and the chemical radicals OH and CH. The relative abundance of these materials has a bearing on the life history of stars. If their radio lines exist at all, they are extremely faint. The question of the distribution of matter, especially hydrogen, in intergalactic space is a crucial one in cosmology; emissions from this source, if any, have escaped detection by existing instruments.

An especially vexing question in radio astronomy is the determination of distances of radio sources. It is impossible at present to distinguish a low-intensity source inside the Milky Way from a high-intensity source located at a great distance outside, except in the few cases in which sources are clearly identified with optically visible objects at known distances. Perhaps the 600-foot telescope will find some phenomenon, analogous to the variable stars and galactic clusters of optical astronomy, to give radio astronomy its distance scale.

Astronomers are looking forward with special interest to measurements of the red-shift in the radio spectrum that have a high priority in the program of the 600-foot telescope. As is well known, the velocity at which objects recede from our position in the universe causes the emission and absorption lines in the optical spectrum of their radiation to shift to the longer-wave or red end of the spectrum. Since the velocity of the retreating galaxies increases with their distance, the red-shift constitutes the primary cosmological distance-scale. Experiments conducted some years ago by David S. Heeschen at Harvard University and by A. E. Lilley and the author at the Naval Research Laboratory indicated that the red-shift carries over into the radio spectrum and may be applied with equal confidence to the measurement of distance to extragalactic radio sources. But neither we nor other workers have been able to produce satisfactory confirmation of these early results.

One thing the 600-foot radio telescope will not do is "see" 40 billion light-years into the universe, as has been widely reported. In a static universe it could detect a bright radio object such as a pair of colliding galaxies at that great distance. But in our expanding universe the limit of radio observation is in practice the same as the limit of observation in the visible spectrum—far short of 40 billion light-years. It is the red-shift that sets the outer boundary on the reach of both kinds of telescope. In the case of the radio telescope, the red-shift creates a special difficulty; as the spectral line of neutral hydrogen moves to longer and longer wavelengths it becomes drowned in the radio noise of our galaxy, which is intense at these wavelengths. The earth's ionosphere, furthermore, is generally opaque to longer wavelengths. Within the confines of the red-shift limitation, however, the 600-foot telescope will make possible the study of a greatly increased number of objects not accessible to observation by other instruments.



THE 250-FOOT TELESCOPE at Jodrell Bank in England is now the largest in the world. Its reflecting surface is steel sheets rather than the wire mesh that will be the mirror in the 600-foot instrument. The Jodrell Bank telescope was completed in 1957.

PREHISTORIC ART IN THE ALPS

Beginning some 3,000 years ago the people of the Camonica Valley carved the rocks around them with thousands of drawings that show the Camunian way of life and the influence of other early cultures

by Emmanuel Anati

The people of Val Camonica in the north of Italy have always known of a rock slab in their valley that is covered with strange carvings. The weathered surface of the rock bears the stylized figures of animals and ancient weapons. Because the rock was well known it was seldom talked about, and so it lay buried in the casual acceptance of the villagers.

The first word of the rock reached scientific circles in 1914 when A. Laeng made a report of it to the Italian Geographic Society. He surmised that the carvings dated from pre-Roman times and were comparable in antiquity to rock carvings that had been found at other sites in the Alps. During the next few years other engraved rocks were discovered, and the task of dating the carvings more exactly began to engage the attention of archaeologists. Val Camonica became the scene of organized expeditions in 1956. These were soon rewarded with what is probably the richest concentration of European rock-carvings yet found. So far more than 600 rocks bearing some 15,000 carvings have come to light. Some rocks, more than 150 feet long, are crowded with at least 1,000 carvings of people, animals, weapons, tools, houses, carts, altars and symbols. In a veritable open-air museum that reaches from Lake Iseo to the Swiss border 75 miles away, the rock carvers had portrayed in detail the life and history of their people.

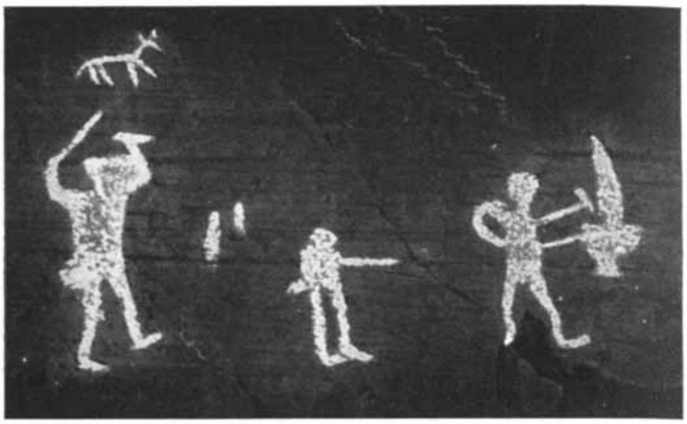
CAMUNIAN CARVINGS OF THE BRONZE AGE depict daggers of Mycenaean type and a sun (*upper right*), daggers of local design (*lower right*) and yoked oxen (*lower left*). Other carvings crowd the space between. Carvings have been chalked to increase visibility.

Val Camonica, or the Camonica Valley, is named for its ancient inhabitants: the Camunians. When they were conquered by the Romans in 16 B.C., their center was a village that still bears the Roman name Cividate Camuna. Little of the pre-Roman history of these people is reported by ancient authors. Strabo thought that they were a Rhetian tribe, Pliny the Elder called them Euganeans.

The discovery some years ago of two small fortified sites, a group of graves and some pottery indicated that the valley was inhabited between the Bronze Age and the fourth century B.C. Though numerous remains of stone walls provide evidence that houses or farms had been scattered through the woods and on the valley slopes, no large villages have been uncovered; probably none existed before the era of the Roman conquest. This is about all that was known of Val Camonica's prehistoric past before the rock carvings were found.

The record disclosed by the carvings

PICTURE OF CAMUNIAN HERO with sword and armor of Etruscan design was carved in Late Iron Age. Evidence of external influences has helped to determine chronology of Camunian culture and to check chronologies of influencing civilizations.

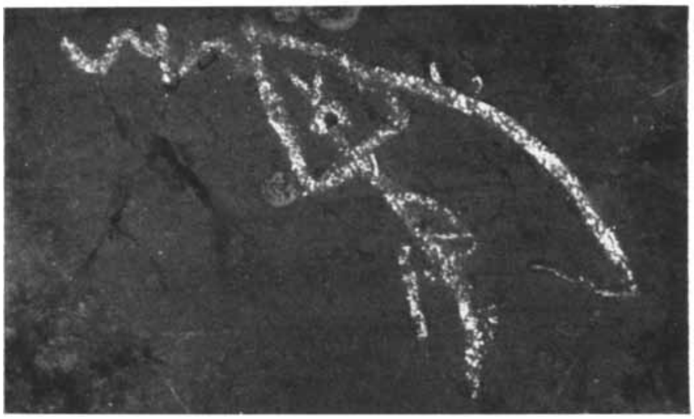


IRON AGE OCCUPATIONS were recorded by the prolific artists of the Camonica Valley. In the picture at far left a crew of farmers follows a plow drawn by a team of horses; at the right side of the second picture a metalworker swings his hammer. In the

is explicit and detailed; there are places in the valley where it is difficult to find a single smooth rock-face left bare. In the search for more working surfaces, some artists chiseled over the works of their predecessors. In some places they eradicated the older carvings; in others they left traces showing through—precious clues to the dating of their own and the earlier work. Val Camonica is now known to archaeology as the most rewarding of the many sites where such Bronze and Iron Age pictures are to be observed.

When the first rocks were discovered, the problem of dating them seemed all but insurmountable. There were so few carvings that it was impossible to assign them to dates or periods on the basis of style and subject. Because they had been found close together and seemed similar

DETAILS OF CAMUNIAN LIFE are depicted in extensive scenes carved during the Late Bronze and Early Iron ages (Camunian Periods III and IV). Among the things shown in this tracing are buildings (C 2-3 and C 5-6), a labyrinth (D 2-3), an animal and its reflection (A 4-5) and two people carrying a loom (A 7-8). Ritual scenes, as at D 3-4, where two dancers perform in ceremonial dress, are characterized by figures with arms upraised. Importance of deer in Camunian economy is suggested by their frequent occur-

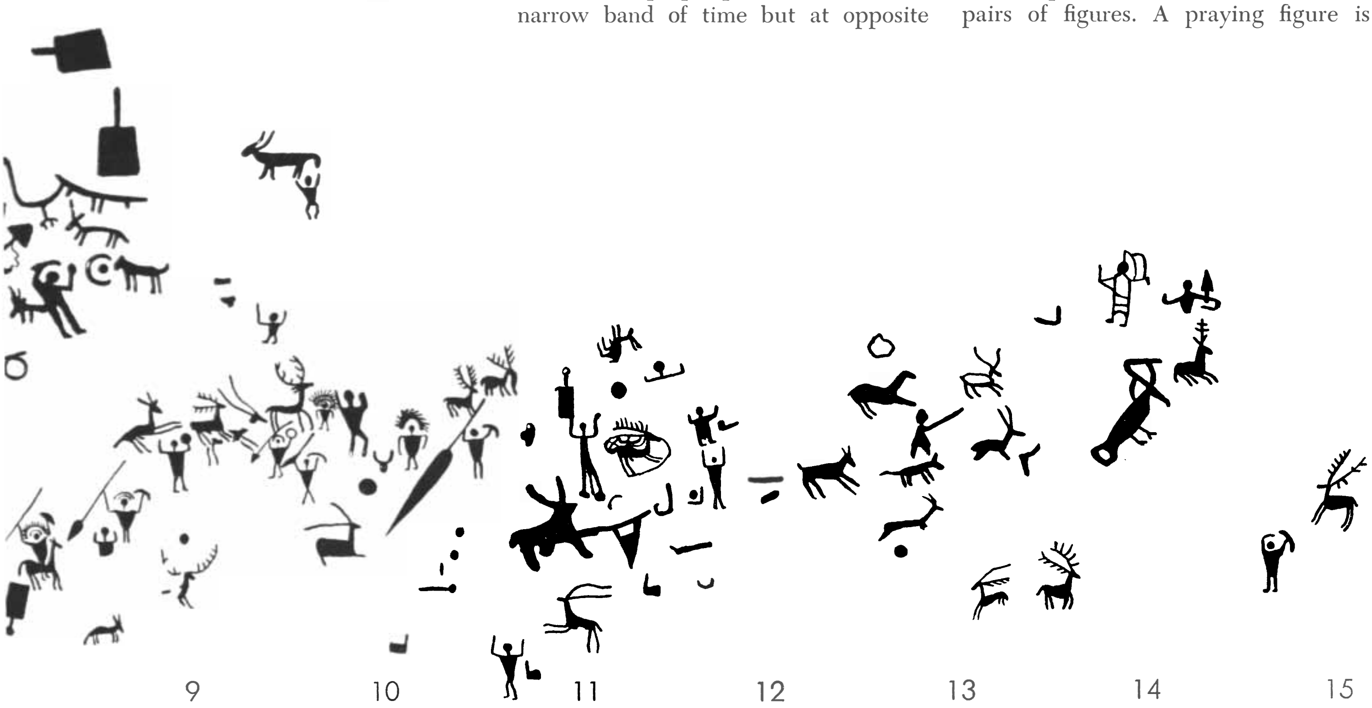


third picture a lackey leads his master's mount. The scene at the right, in which a strangely misshapen human figure dances or fights with a huge snake, is representative of the cults that supplanted the archaic Camunian religion in the latter part of the Iron Age.

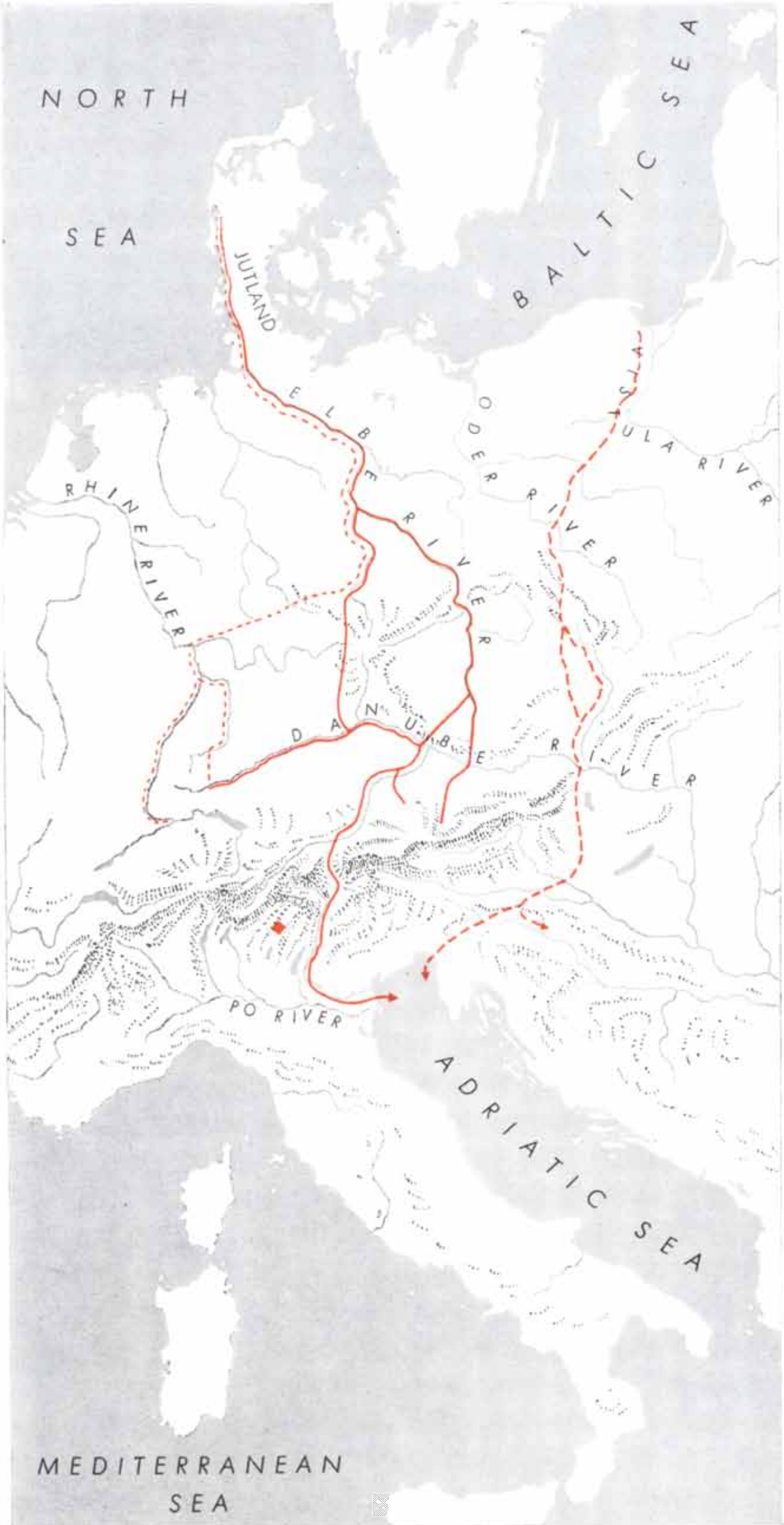
in appearance, many archaeologists tried to group the lot in a single period. On the other hand, the rocks bore such apparently contradictory evidence as pictures of weapons from the second millennium B.C. and an alphabet from the late first millennium B.C. In choosing between two dates more than 1,000 years apart some archaeologists favored the first millennium and reasoned that the second-millennium weapons had been carved in later times for reasons of tradition or cult.

The ambiguities were resolved as the wealth of carvings were uncovered and their sheer number made classification relatively easy. Such clues as the superposition of later carvings on earlier ones and differences in patination helped to determine the sequence of execution and yielded a table of relative dates and artistic periods. Two major clues established the absolute chronology of the carvings: Many of the artifacts depicted could be dated by comparing them with similar, well-known archaeological materials, and several short inscriptions in archaic Retico-Etruscan lettering fixed these in a precisely known period. Thus the weapons and alphabet, which in the beginning had been so puzzling, assumed their proper places: not within a narrow band of time but at opposite ends of a vast period that reached across 2,000 years from neolithic times to within 16 years of the birth of Christ.

As order was brought to the rich confusion of carvings, there unfolded the story of how Camunian art and religion had evolved. The artist of the late neolithic period, reflecting the preoccupations of his time, depicted the most rudimentary elements of his experience. His subjects were chiefly religious: solar disks, labyrinths, strange patterns of lines and schematic figures of people with arms uplifted in prayer. Most of the subjects are isolated and repetitive; apparently the idea of organizing them into scenes had not occurred to the artist of this first period. But there are occasional pairs of figures. A praying figure is



rence and by ceremonies centered around them (D-E 7-11). Deer at E 9 is focus of procession led by chief (E 8-9), the only one allowed a horse during rituals. Shamans, wearing ritual hats, are at D 10. Prowess of hunter at D 10-11 is probably indicated by his large spear. Among other activities are worship of deer taken in net (D 11-12), shepherd (D 13) with his dog and flock, hunter and deer (D-E 15). Carvings of deer-worship and ritual dances were added by artists of Period IV to original scene of Period III.



PREHISTORIC ROUTE by which amber was carried from northern Europe to Mediterranean civilizations was opened in the Early Bronze Age (*solid lines*). Other routes were added in Middle Bronze (*short dashes*) and Early Iron (*long dashes*) ages. Routes were reconstructed from amber found in archaeological sites. Central route carried important influences to Camonica Valley. Area indicated by small square appears on the opposite page.

shown with a solar disk or with a deer; a deer is pictured with a dagger; the symbols for male and female appear together.

Around 1750 B.C. the formal symbolism of the first period yielded to a freer narrative style. The symbolic dagger shown with an animal became a man in the act of throwing his weapon at the animal. With the new narrative freedom came the first attempts at composition. The isolated and paired figures were united in larger scenes showing such ceremonies as weddings and religious rites.

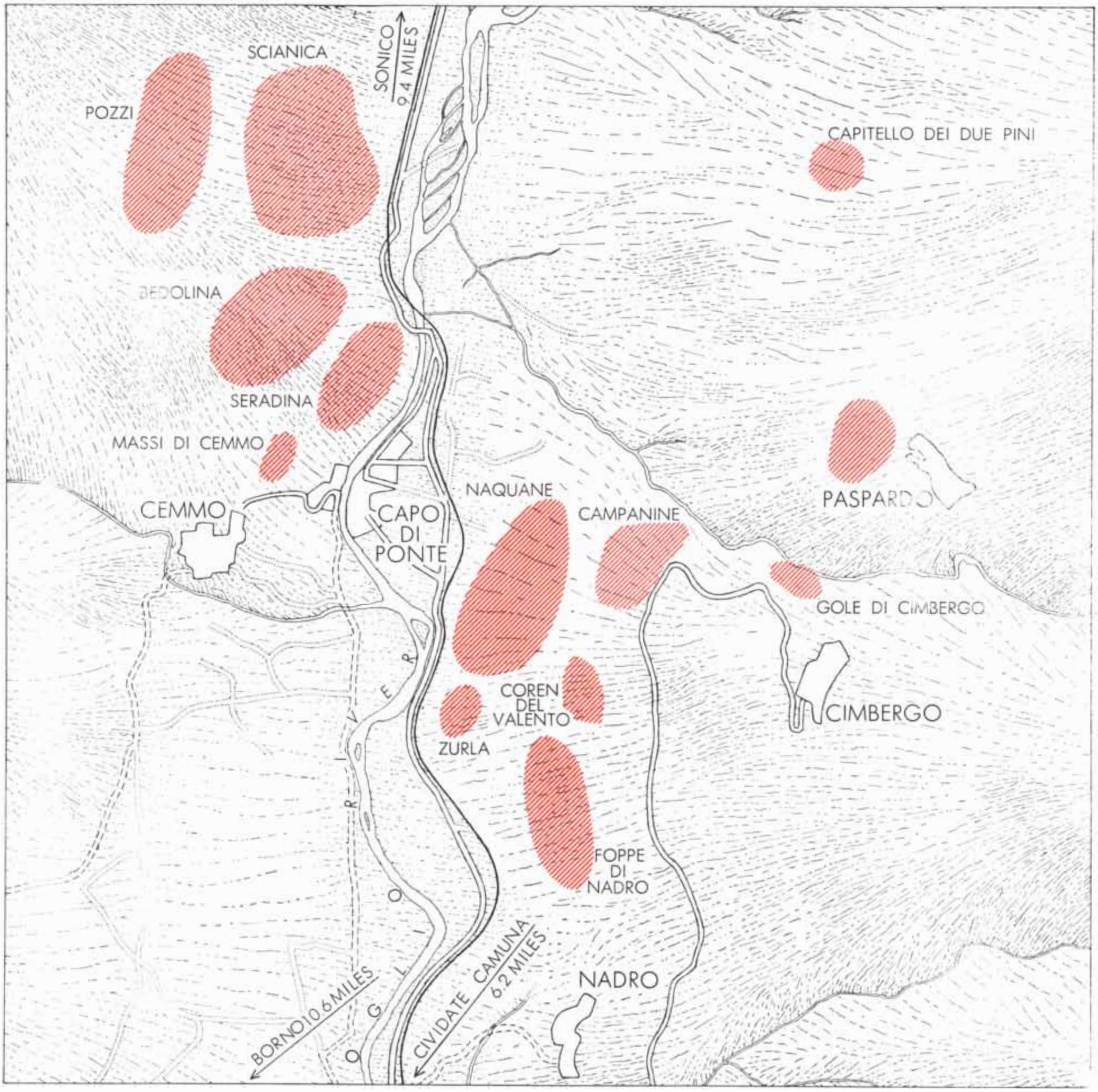
Val Camonica was not isolated from the rest of the world. The carvings of each period bear evidence of contact with other societies. The weapons depicted toward the end of Period II are very similar to those found in the regions that are now East Germany and Hungary. There are signs of influence from Spain and much to suggest daily contact with the nearby Copper Age culture at Remedello. Influences from places as distant as Greece and northern and central Europe became extensive during Period III: the Middle and Late Bronze Age.

At that time the Mycenaean civilization, which preceded the classical Greek culture in the Mediterranean, was at its peak. The evidence of its influence in Val Camonica corroborates the solution of an archaeological riddle that had been posed by the finding of amber in Mycenaean tombs. Amber, the fossilized resin of extinct coniferous trees, was prized by the ancients as a precious stone. A very important source of it at that time was the area which is now the Danish province of Jutland and the neighboring area of Germany. But what archaeologists did not know was the precise route by which the amber traveled to Greece. The puzzle was solved when J. M. de Navarro, a British archaeologist, traced a line through the European sites where amber artifacts had been found. The line ran from Denmark down the Elbe River, across the Alps, through the Adige Valley in Italy and down the Po River to its mouth, whence boats carried the amber to Greece. De Navarro bestowed on the route the name "The Amber Road."

The Alpine leg of the Amber Road came close to Val Camonica, and with it came the influences of distant cultures. Daggers and chariots like those found on the stelae of Mycenaean tombs now appear in the Camunian carvings, along with the first pictures of plows and wheeled vehicles. The influences were, of course, reciprocal. At least one blade of the Camunian type has been found at Mycenae. Contemporary rock-pictures in southern Sweden share many stylistic features with those in Val Camonica, and the chariots depicted in both places are strikingly similar to the Mycenaean. Through the traffic on the Amber Road, Val Camonica had more contact with Scandinavia and Greece, each 1,000 miles away, than it did with Mount Bego, another center of rock-engraving a scant 200 miles to the west. Mount Bego, untouched by the great prehistoric highway, underwent a very different artistic development.

Perhaps as a result of such contacts, the Camunian artist of the Bronze Age acquired a broader range of subject matter and a maturer technique to portray it. In a style that reflected his greater freedom he added fields, plows, carts and chariots to the religious scenes and symbols he had depicted earlier. He reached up from the horizontal surfaces to which he had been restricted and carved his images on vertical rock-faces. In their simplicity and easy composition these Bronze Age carvings are among the most beautiful of their kind.

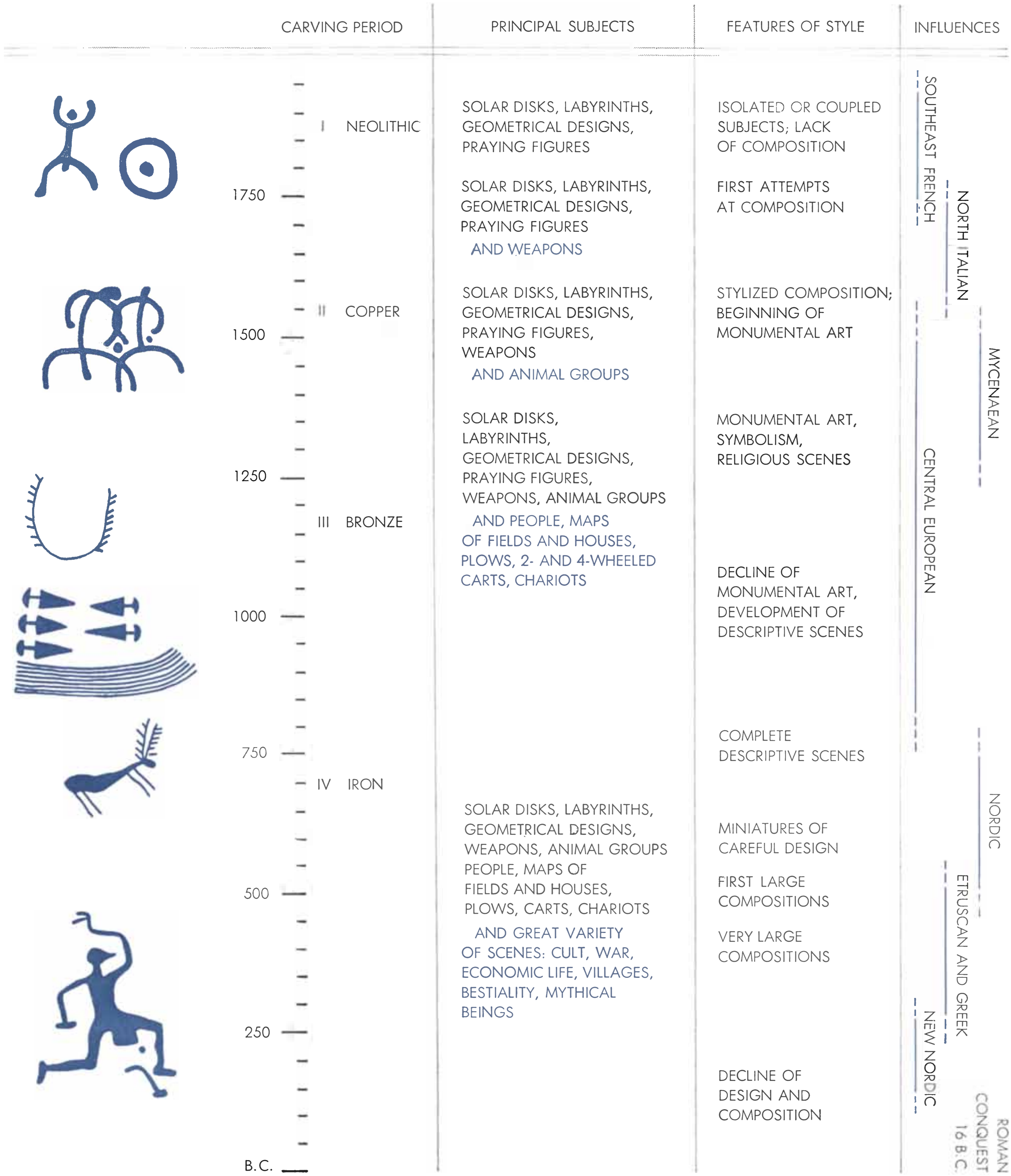
With the coming of the Iron Age, and Period IV, the Camunian artist apparently became less preoccupied with religion and more interested in depicting the material aspect of his existence. Scarcely a detail of the daily activities about him failed to absorb his attention: hunting, farming, weaving, house-building, lovemaking, metalworking, war, death. He carved scene upon scene showing entire villages with their simple huts and smaller stables or storehouses. Some buildings



AREAS IN THE CAMONICA VALLEY where rock carvings were found (*shading*) are labeled in smaller type. The names are derived from their topography or from nearby towns (*larger type*). Region depicted here is located by small square on map on opposite page.

are complicated structures of at least two stories built on piles or platforms. There are maplike depictions of cultivated fields around the village, complete with details of farming activities.

Many of these changes must have resulted from the partial cultural unification that central Europe underwent during the Iron Age. Though secondary local differences persisted, the ages in which small, isolated societies stood apart were definitely over. The Celts spread their influence southward across the Alps and the Etruscans northward from the Apennines. As early as the seventh, and perhaps the eighth, century B.C. symbols characteristic of the Celts were introduced into the Camunian record. Etruscan helmets and swords entered the engravings of the fifth century B.C. The almost total



CHRONOLOGY OF CAMUNIAN ART is charted here with tracings of carvings that illustrate changes in style. At top a male figure worships a solar disk; below it a wedding couple link arms; third is a composition with daggers; at bottom a monster gambols.

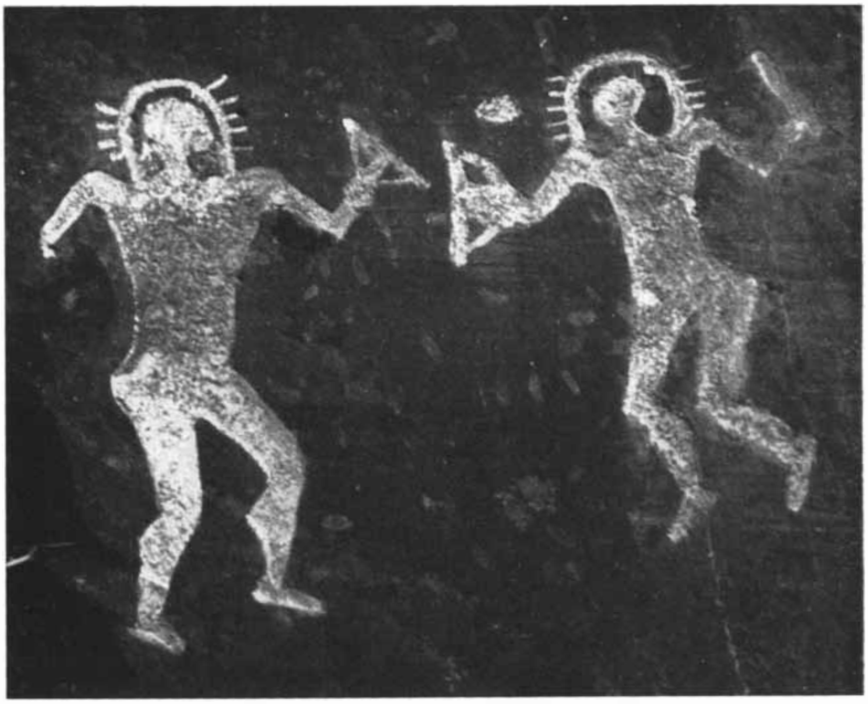
change of pattern in Camunian art reflects the impact of these more sophisticated societies upon the more primitive one. New gods appear. One with horns resembles one of the principal Celtic deities: Cernunnos. Another, representing the archetype of the craftsman and metalworker, is as yet nameless but in many carvings suggests the Teutonic artisan-god Thor.

With the new gods came new cults. The late-period carvings show human and animal sacrifices, worship of the dead, harvest rites, sexual intercourse with animals, and a supernatural world of monsters, some with horns and tails and others with human bodies and animal faces. Many scenes show men battling against enormous snakes, and there are heroic figures armed with gigantic weapons. Some connection may well be found between the Camunian supernatural world and German mythology, especially with the underground monsters of Teutonic mythology.

No less richly illustrated is the valley's economy. The rock pictures show many hunting, pastoral and agricultural scenes. In one a fisherman is shown in a small boat throwing a net or trap. Fishing must have been an important Camunian occupation, because the valley is dotted with the dried beds of little lakes beside which the Camunians must have built their pile-supported dwellings. The Camunians had a long tradition in technology. At least one Bronze Age carving shows a network of canals irrigating cultivated fields. Iron Age scenes depict weaving, metalworking, wagon- and weapon-manufacture and a house in the process of construction.

The valley was conquered in 16 B.C. by Augustus. Some Latin inscriptions testify to the Camunians' ethnic survival at least until the middle of the first century A.D. A few carvings of castles and related motifs show that their carving tradition may have been perpetuated by their successors until the Middle Ages.

As the work of interpreting the rock pictures goes on, we are learning that there were chiefs and shamans, nobles and servants, and we are glimpsing the social institutions that ordered the Camunian society. Gradually there is emerging a history of the prehistoric Camunians that is even more complete and more detailed than our knowledge of their successors who lived in the valley from the Roman conquest to modern times.



GLADIATORS armed with shields and short swords or daggers face each other in carving of Period IV. Combat scenes became increasingly common in later periods of Camunian art.

WAR AND WORSHIP are combined in this group of carvings, which is part of a larger group. At lower right a warrior with a sun between his legs engages an armed monster.

MIGRATING HERD OF CARIBOU was photographed from the air as the animals rested on snow-covered ice of a Canadian lake. In the fall they migrate from the open tundra to the forested taiga, where soft snow-cover permits them to dig down to their fodder.

Animals in the Snow

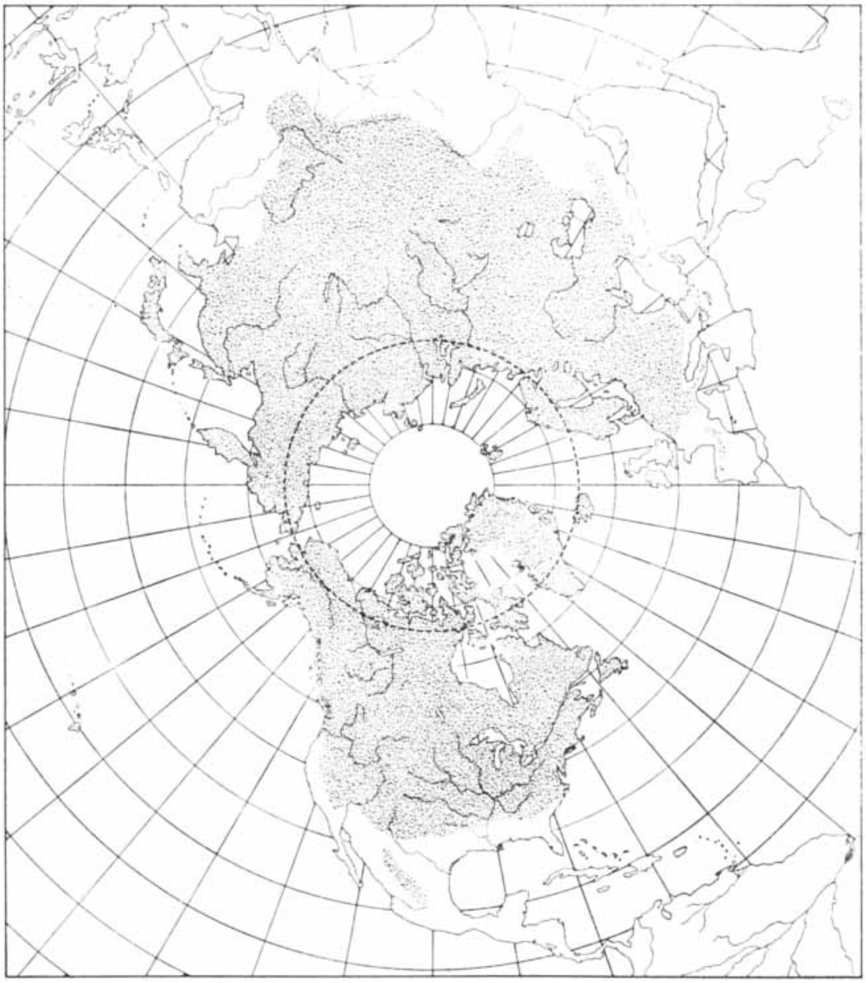
Animals that live in regions where snow persists for nine months of the year are adapted to various kinds of snow cover resulting from interaction of weather, plants and the contour of the land

by William O. Pruitt, Jr.

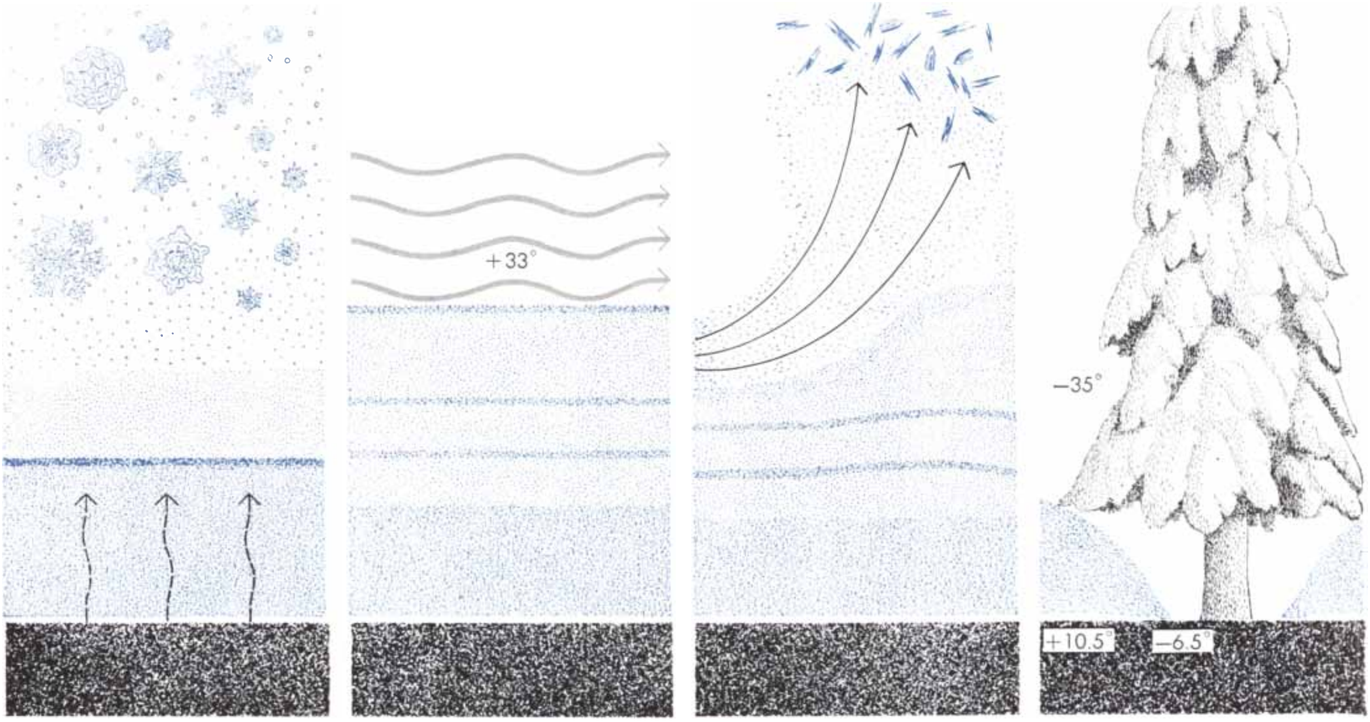
If snowflakes were rare objects, generations of graduate students would doubtless have received degrees for research into the properties and potential uses of snow. As it is, some tens of billions of these beautiful crystals of frozen water-vapor pile up in each square yard of snow of even moderate depth. In greater or lesser depth snow covers more than half of the land area of the Northern Hemisphere at some time during the year. In centers of civilization it is welcomed with shovel and snowplow; labor and equipment are speedily mobilized to clear it from sidewalks, streets, driveways, highways and airstrips. The very abundance of snow seems to have suppressed almost all but this negative interest in getting rid of it as quickly as possible. In the literature of the sciences that ought to be concerned there is little to suggest that snow is a major element in the environment of life and that it is one of life's most interesting provinces.

To our way of thinking snow would seem principally a hindrance to the locomotion and food-getting of animals. The onset of winter is the occasion for spectacular southward migrations of birds and mammals. But many creatures, by anatomy and behavior, have become adapted to survive in snow cover that may persist for nine months of the year. Some have developed snowshoes or stilts that permit them to move freely above the snow. Others have found refuge beneath the snow cover and there have occupied a dark, damp and silent world with a constant climate warmer than that of the world above.

The biologist who sets out to study the role of snow in the life history and distribution of animals must first learn something about snow itself. A snow cover is by no means simple and homogeneous. The snow cover varies greatly in texture and structure from place to place and presents sharply contrasting environmental situations. On this diverse subject the wisest instructors are the subarctic Indians and the Eskimos. Long ago they fashioned quite different technologies to take advantage of the special properties of the snow cover in the regions they inhabit. They each succeeded, for example, in making snow do the service of the wheel. On the wind-hardened snow of the open Arctic tundra the Eskimo sled, or "komatik," rides

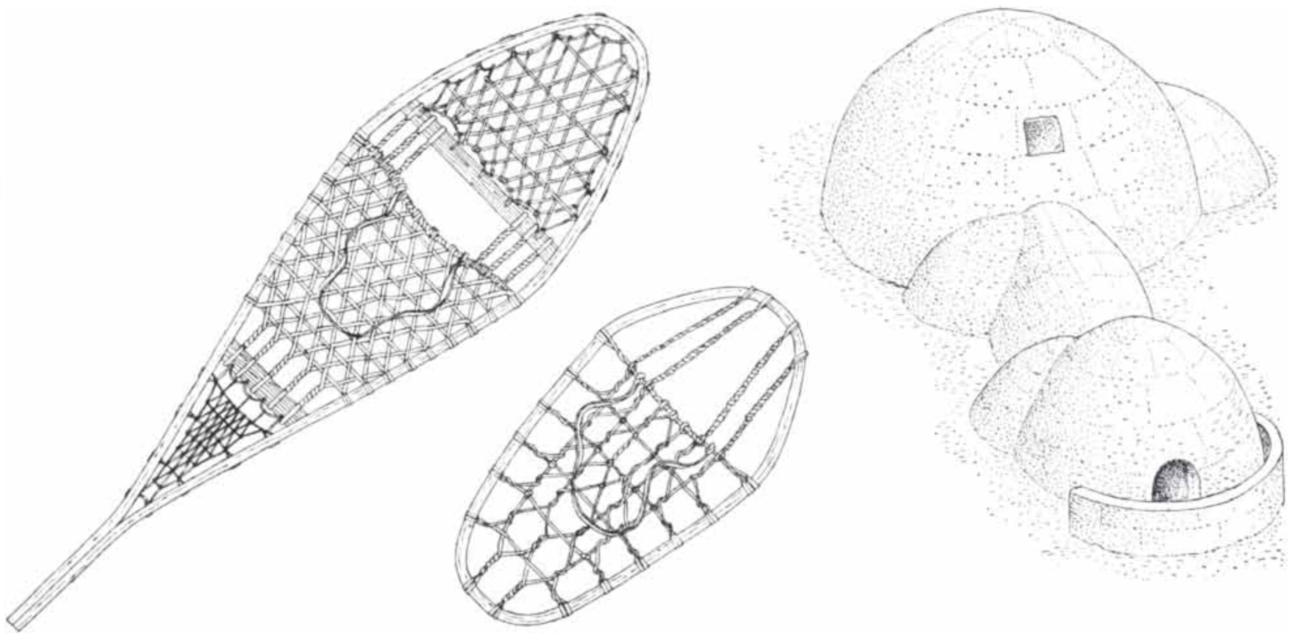


SNOW COVER lies at some time in the year on more than half of the land mass of the Northern Hemisphere. The limits of the snow-covered (*shaded*) area are approximate.

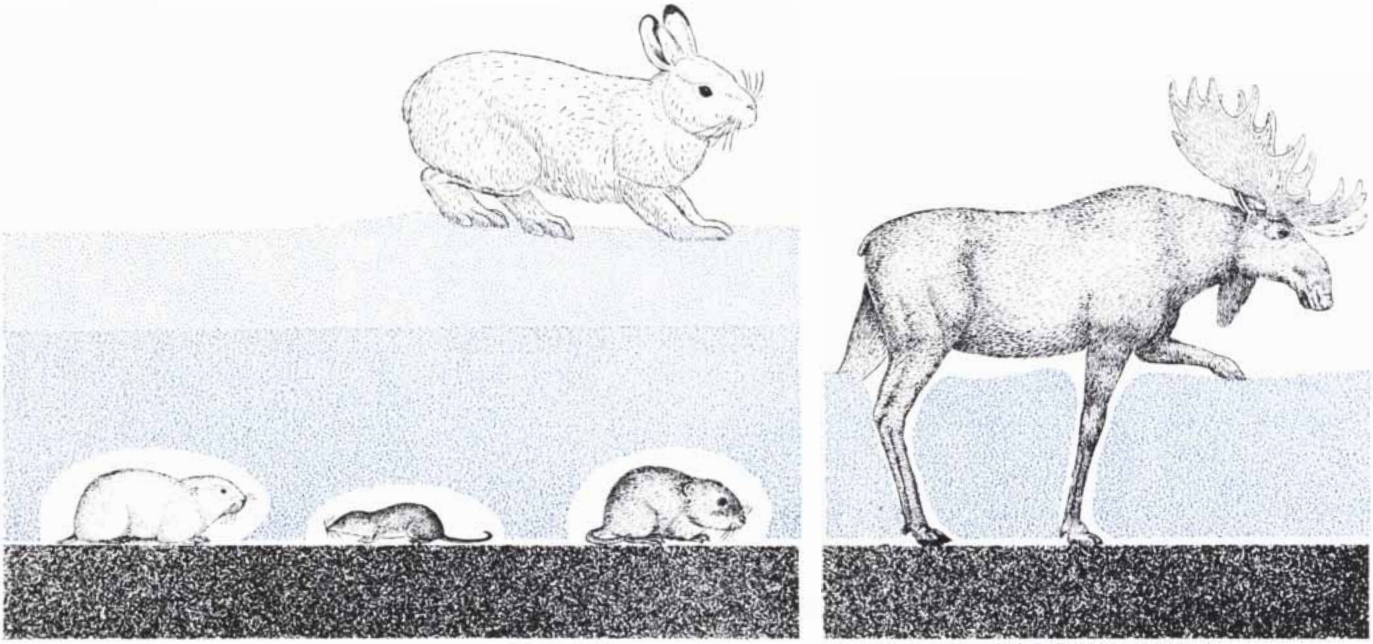


CHARACTER OF SNOW COVER varies with weather as it accumulates. The first snow is compressed by later falls (*shaded layer at left*). Warm, moist winds may thaw the top centimeter (*second from left*) which freezes to a thin, dense crust. Cold, dry winds break up the flakes (*third from left*) and lay down a "wind crust" of more densely packed snow. Trees, catching the snow in their branches, cast a "snow shadow" on the ground. The ground temperature in the shadow is lower than that under the insulating snow cover.

upon runners, and is unsurpassed in lightness, ruggedness and ease of pulling. For the thick, fluffy snows of the subarctic forest, or taiga, where the komatik would bog down, the Indians created the runnerless toboggan. The Eskimos built snug houses quickly and easily from roughly shaped blocks of the hard tundra snow, though many of them have now lost the art. To build a snow house in the soft taiga snow the Dindye or Kutchin Indians of Alaska first heaped up a huge mound, allowed it to harden or "set," and then hollowed out a cavern inside. On the snow-covered tundra the Eskimo can walk almost anywhere without sinking, but in the forest the Indians had to devise snowshoes; small ones with coarse-meshed webbing for relatively dense snow-cover and long, broad ones with fine-meshed webbing and turned-up tips for a thick cover of light snow. The rich lore of snow that underlies such ingenious adaptations is reflected in the



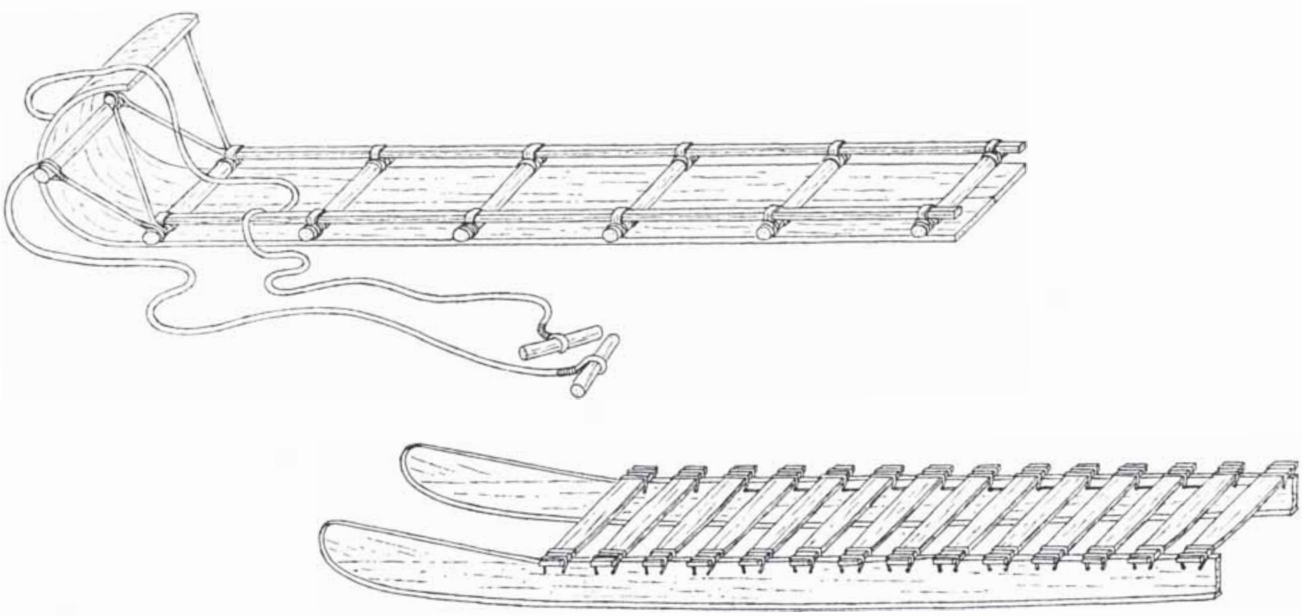
TECHNOLOGICAL ADAPTATION of Indian and Eskimo reflects the different quality of the tundra and taiga snow cover. To walk upon the light, fluffy snow of the taiga country, Indians must use snowshoes: large shoes with fine-mesh webbing for soft, deep



ADAPTATION TO SNOW is achieved by three principal routes. The varying hare has developed "snowshoes" and so travels on top of the snow. The moose is able to manage fairly deep snow on its long "stilts." Smaller animals such as the lemming, shrew and vole (*left to right*) live under the snow, finding there a damp environment with a relatively constant temperature that never falls far below freezing. The heat loss due to the high surface-to-volume ratio of these small animals would cause them to perish above the snow.

languages of the northern peoples. Each of these languages offers concise words to designate particular aspects of snow which in English call for cumbersome descriptive phrases [*see glossary on page 66*]. I have found many of these words more suitable than the "official" meteorological terms for specifying snow conditions in their relationship to the life of animals that inhabit snowy regions.

The variations in snow cover begin with the formation of the snow as it falls. In temperate and cold-temperate climates, as atmospheric moisture sublimes directly from the vapor to the solid state, the snowflake builds up as a six-armed star or hexagonal plate with a thickness of about .1 millimeter and a diameter ranging from one to five millimeters. Through aggregation as they fall, such snowflakes may form extremely complex structures. In the arctic or sub-



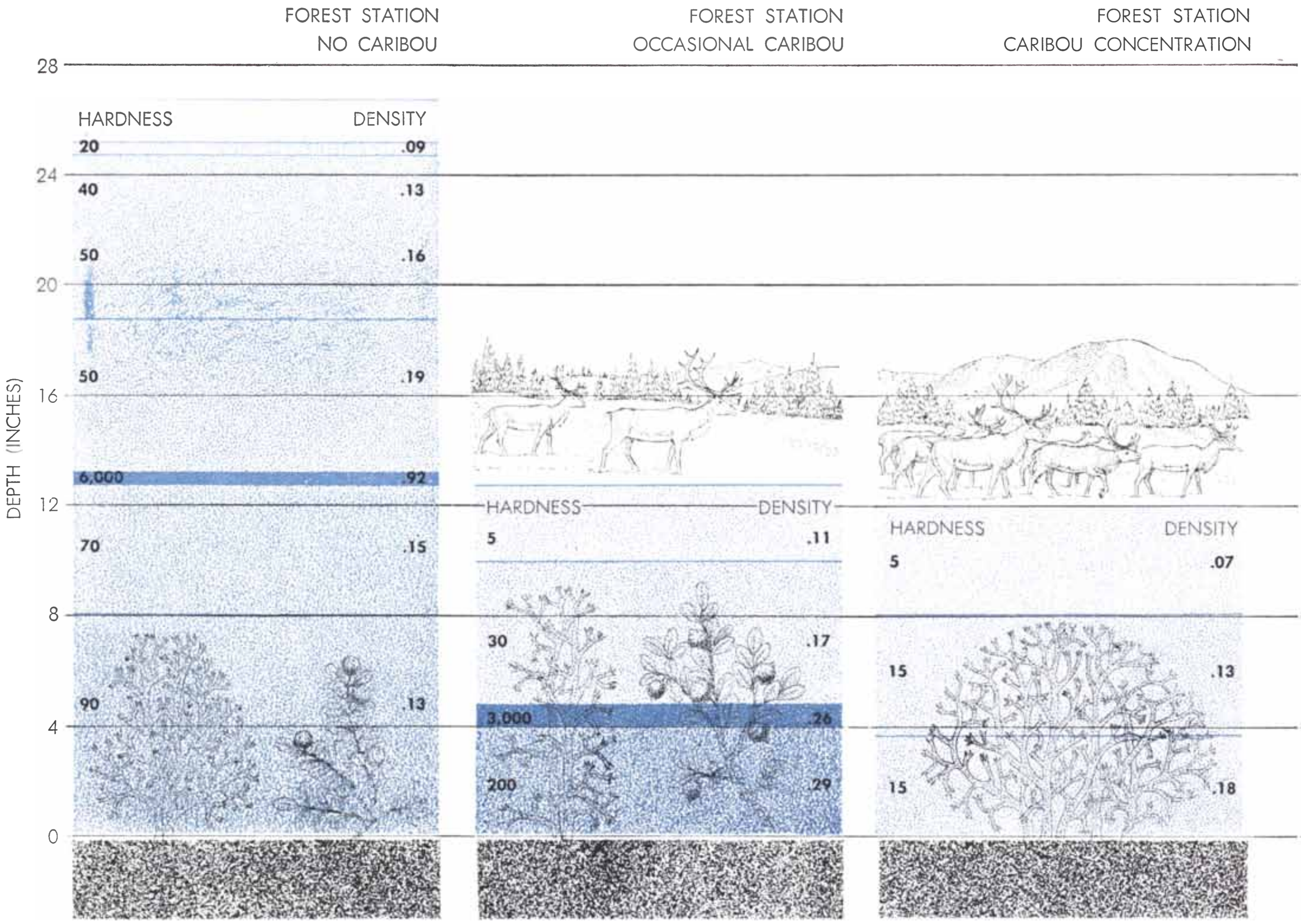
snow; smaller shoes with wide-mesh webbing for denser snow. From roughly carved blocks of hard, dense tundra snow Eskimos build igloos. The Indian toboggan is adapted to the soft taiga snow; the Eskimo "komatik" rides on runners on top of tundra snow.

arctic, snow falls more frequently as needles or tiny prisms, ranging in length from .1 to three millimeters and in diameter from .01 to .2 millimeter. From the moment they come to rest on the earth or upon snowflakes that have preceded them, the delicate stars and flakes change their shape.

The taiga snow, on which my work has centered, may best be visualized as an emulsion of air and ice, with the volume of air far exceeding that of the ice. New-fallen taiga snow may have a specific density only 5 per cent of that of water. Beneath the snow cover, as a rule, the soil is warmer than the air through which the flakes have fallen. Heat and moisture therefore flow upward from the soil through the snow. These temperature and vapor-pressure gradients play a crucial role in the history of the cover. Through sublimation, molecules of water leave the attenuated tips and corners of the flakes below and attach themselves to the tips of flakes above, which are colder because they are farther from the soil. In this process the larger and more massive flakes also grow at the expense of the smaller and more delicate ones. Eventually the bottom layer of the cover assumes a coarse granular structure, the so-called depth hoar—"pukak" in the language of the Kobuk valley Eskimos of Alaska. The snow particles next to the ground may in time be completely eroded away, leaving a vacant space with fragile, lattice-like walls and roof.

As the cover thickens with successive falls, its lower layers are compressed. Each snowfall, originating in a unique sequence of meteorological events, is somewhat different from all others. Thus each layer is made of a different type of flake or grain and has a different thickness, hardness and density. The passage of a warm, moist air-mass, bringing thawing temperatures and perhaps even a light rain, will increase the moisture content and density of the uppermost centimeter or so of snow. The succeeding cold air-mass will freeze the moisture, and the snow cover will now possess a hard, dense top-layer, or even a crust of ice. This layer may be buried by subsequent snowfalls. If it is dense enough, it may be impervious to the passage of air and water vapor and so will cause a change in the steepness of the moisture and heat-flow gradients in the cover. Marked fluctuations in the air temperature during the accumulation of the cover will thus set up complex gradients and a succession of ever changing densities and hardnesses within.

Later in the winter a windstorm may sweep over the snow. Reaching down through the sheltering spruce trees of a taiga the wind picks up the surface flakes and tumbles them about, abrading their delicate points and reducing the flakes to shattered remnants. With their smaller size and simpler outlines, the particles nest more closely together, forming a hard, dense layer. If this reworking of



DISTRIBUTION OF CARIBOU is determined by the character of the snow cover. The hardness of the layers in the cross sections of snow is measured by the weight (in grams) that can be supported by a square centimeter of the snow. The density is relative to water;

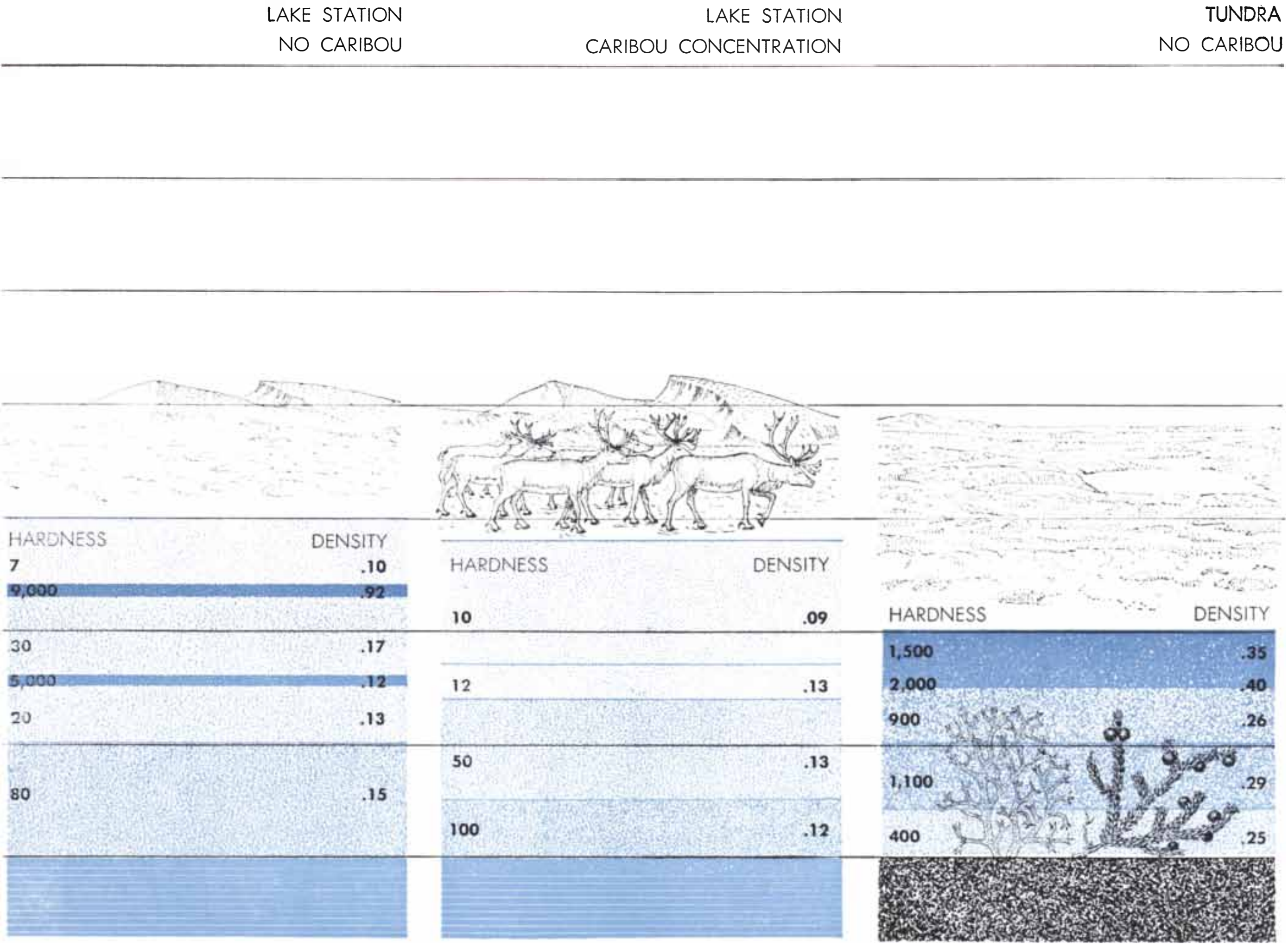
the cover is confined to the surface, it forms a "wind slab." If it involves the entire depth of snow, as happens regularly on the tundra, the cover is transformed into a hard, dense mass ("upsik") capable of supporting the weight of a fox, wolf, caribou or man.

As the snow whispers down through the spruce trees, a significant portion of it remains caught in the branches. The snow that clings to the trees ("qalí") often accumulates in quantities sufficient to bend and break mature spruces. Indeed, there is evidence that in the interior of Alaska breakage by qalí initiates the cycle of forest succession that gives the taiga there its characteristic mosaic of evenly aged stands of spruce interspersed with stands of variously aged willow, alder and aspen. With so much snow caught in the branches of the spruce there develops around the base of each tree a bowl-shaped depression in the cover, called a "qámaniq." The soil may be bare at the trunk, and the snow gradually increases in depth outward from the tree. At the tips of the branches the "snow shadow" ends, and the depth of the snow increases abruptly.

As the days lengthen in the spring, sunlight striking down through the trees melts the top layer. Upon freezing at night, the soggy surface forms a "sun crust," or "siqoqtoaq." In high altitudes and latitudes, where the coming of spring brings lengthening periods of intense sunlight with the air temperature still far below freezing, the surface flakes are transformed into long vertical spicules, called ablation needles or "qulu."

For most birds and several of the larger mammals the snow cover means deprivation of food supply. Their behavioral response to this ecological challenge is to flee the country that is so ideally suited in the spring and summer for their reproductive period, the most vulnerable in their life cycle. Investigation has shown that in most cases these animals can withstand the prevailing winter temperature of the regions they abandon, if they are provided with sufficient food. It must therefore be their inability to procure food from under the snow that induces their mass exodus. Among birds the migratory species are principally insect-eaters and ground-feeders; among mammals the most notable migrators are the elk and the gregarious caribou.

I have found that the winter distribution of caribou is quite precisely regulated by the character of the snow cover. Most of them abandon the tundra and its hard-packed snow-cover in the autumn and migrate to within the tree line. Aerial surveys of wintering bands of caribou, combined with on-the-spot analyses of the snow cover, show that these animals concentrate where the snow is soft, light and thin, permitting them to dig through it easily to uncover the food below. These areas are bounded, as if by a fence, by areas where the snow is hard,



ice has a density of .92. Caribou typically concentrate in the soft snow-cover in and around spruce forests, but they also congregate in similar cover on lakes to rest and chew their cud. The plants across the bottom of this illustration are not drawn to scale.

ENGLISH	KOBUK VALLEY ESKIMO (ALASKA)	DINDYE (FORT YUKON, ALASKA)	CHIPEWYAN (NORTHERN ALBERTA)
SNOW	ANNÍU	ŽA	SIL(CH)
SNOW THAT COLLECTS ON TREES	QALÍ	DÉ-ŽA	DE-CHÉN-KAY-SÍL(CH)
SNOW ON THE GROUND	APÍ	NON-KÓT-ZA	SIL(CH)-DE-TRÁN
DEPTH HOAR	PUKAK	ŽAI-YA	YATH(K)ÓNA
WIND-BEATEN SNOW	UPSIK	SETH(CH)	SIL(CH)-T(CH)RÁN-AL
FLUFFY TAIGA SNOW		THEH-NÍ-ZEE	YATH-THEY-YÉ-REE-LAY
SMOKY SNOW OR DRIFTING SNOW	SĬQÓQ	ZA-HE-ÁH-TREE	NIL(CH)-SEE-NI-(K)OTH
SMOOTH SNOW SURFACE OF VERY FINE PARTICLES	SALUMÁ ROAQ		
ROUGH SNOW SURFACE OF LARGE PARTICLES	NATATGÓNAQ		
SUN CRUST	SIQOQTOAQ	ŽA-ES-(CH)A	NA-HÓ-T(CH)RAN
DRIFT	KIMOAQRUK	ZA-KÉ-AN-É-HAE	YATH-NÉE-ZUS
SPACE FORMED BETWEEN DRIFT AND OBSTRUCTION CAUSING IT	ANMANA		
SHARPLY ETCHED WIND-ERODED SNOW SURFACE (SASTRUGI OR SKAVLER)	KAIOGLAQ		
IRREGULAR SURFACE CAUSED BY DIFFERENTIAL EROSION OF HARD AND SOFT LAYERS	TUMARÍNYIQ		
BOWL-SHAPED DEPRESSION IN SNOW AROUND BASE OF TREES	QÁMANĬQ	(ZH)E-QUIN-ZEE	DAY-CHEN-YATH-DÓ-DEE
SNOW DEEP ENOUGH TO NEED SNOWSHOES		DET-THLO(K)	YATH-THAY-T(R)ÁN-AI(CH)-HÁ
SPOT BLOWN BARE OF SNOW		SI(CH)	OH-BÉH
AREA OF DEEP SNOW THAT PERSISTS PERHAPS ALL SUMMER		ZA-KAY-TAK-KOK	YATH-THAY-(ÁN)

TERMINOLOGY OF SNOW is enriched by precise words from Eskimo and Indian languages. Each word specifies a snow condition that often requires a full phrase in English.

dense or thick. The critical hardness, expressed in terms of capacity to bear weight, seems to be around 60 grams per square centimeter. The corresponding specific density ranges upward from 16 per cent of that of water to that of ice (which of course has a density somewhat less than that of water), and the fence-forming depth of snow is about two feet [*see illustration on preceding two pages*]. In the course of a winter the caribou herds may be seen to move about in accord with the shifting of the fences of unsuitable snow.

In contrast to the caribou, the moose is an exemplar of anatomical adaptation. Its long legs reach down through the snow cover to the firm ground beneath and carry its belly well above the surface. When the snow cover attains a thickness of about three feet, however, stilts no longer suffice. At such times the moose packs the snow in trails or "yards." The alternative to the stilt is the snowshoe, and the classic example of this adaptation is the oversize feet of the varying hare (*Lepus americanus*). But wherever the hardness and density of the snow fall below a critical level, the hare too turns to packing the snow to form regular trails and runways.

Temperature as well as snow cover is an important factor determining the behavior of animals in the northern winter. Only the larger mammals—the hare, fox, wolf, lynx and moose—are metabolically able to withstand the extremes of cold and live above the snow surface. Smaller mammals such as shrews, voles and lemmings have such a small body mass with respect to their heat-dissipating body surface (and such comparatively inefficient fur) that their metabolism cannot maintain normal body temperature. Their survival in the subarctic winter climate is made possible only by the behavioral adaptation that causes them to seek shelter under the taiga snow cover.

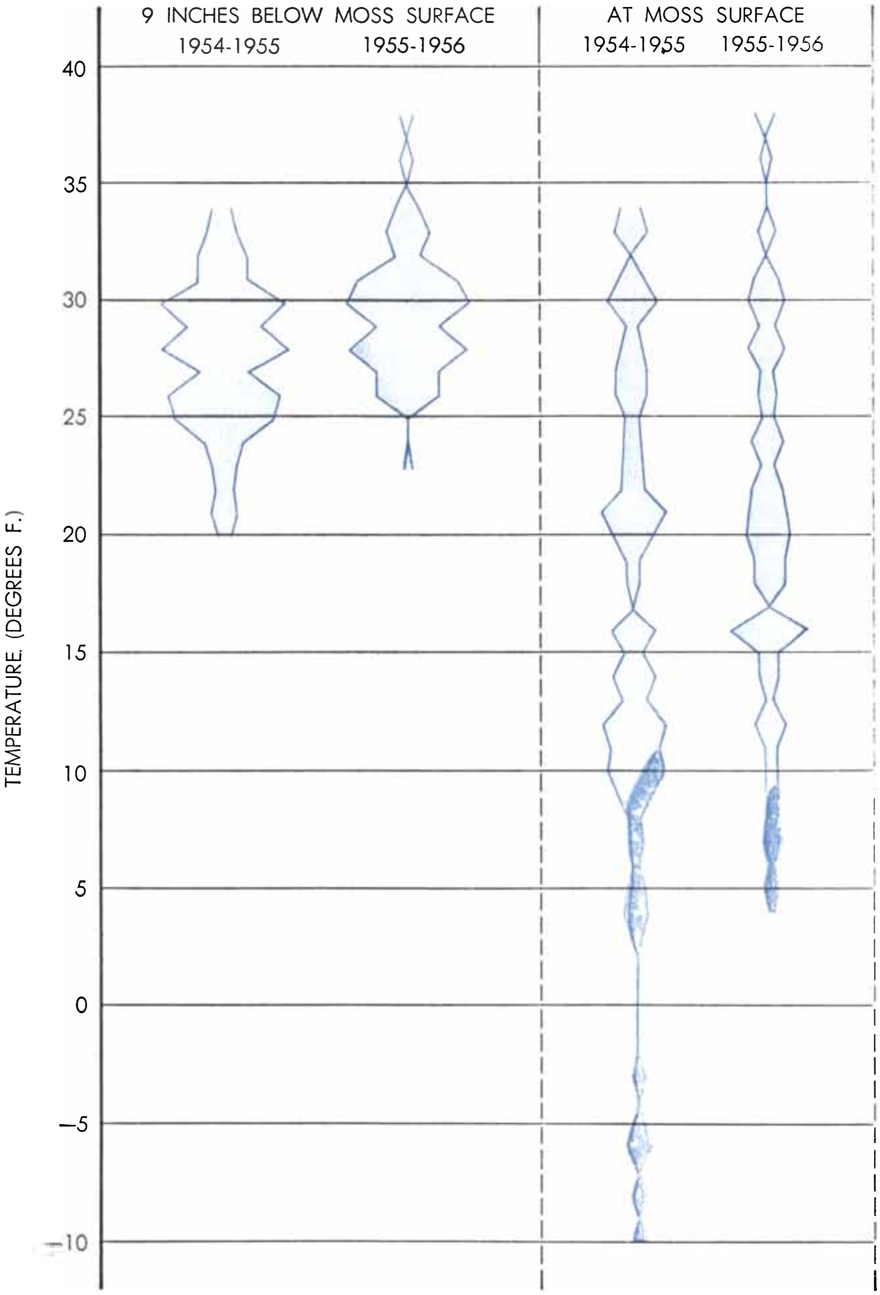
The snow is such an effective insulator that the temperature of the mossy floor of a mature spruce forest seldom drops below 20 degrees Fahrenheit, even though the air above may fall to 50 and 60 degrees below zero F. In the interior of Alaska I was once unable to detect any temperature change during a period of nine days at a spot in the forest floor under a cover of two and a half feet of snow, even though the air temperature above fluctuated between 24 degrees above and 28 degrees below zero F. Freshly fallen fluffy snow has a thermal conductivity of only .0002 calorie per square centimeter per second through a gradient of one degree centigrade. Thus vegetation, small mammals and hibernating or pupating insects are protected from the violent temperature changes that characterize the climate above the snow cover.

Small mammals disappear below the surface in the autumn when the snow cover has built up to a depth of about six inches. The temperature of the moss and the soil at this time ceases to follow the fluctuation of the air temperature. A. N. Formozov, the distinguished Russian naturalist, has observed the same threshold in the activity of small mammals of the taiga in the U.S.S.R. In the cycle of the seasons the period between the onset of subfreezing temperatures and the development of the snow cover to the critical thickness undoubtedly gives shrews, voles and lemmings their severest trials.

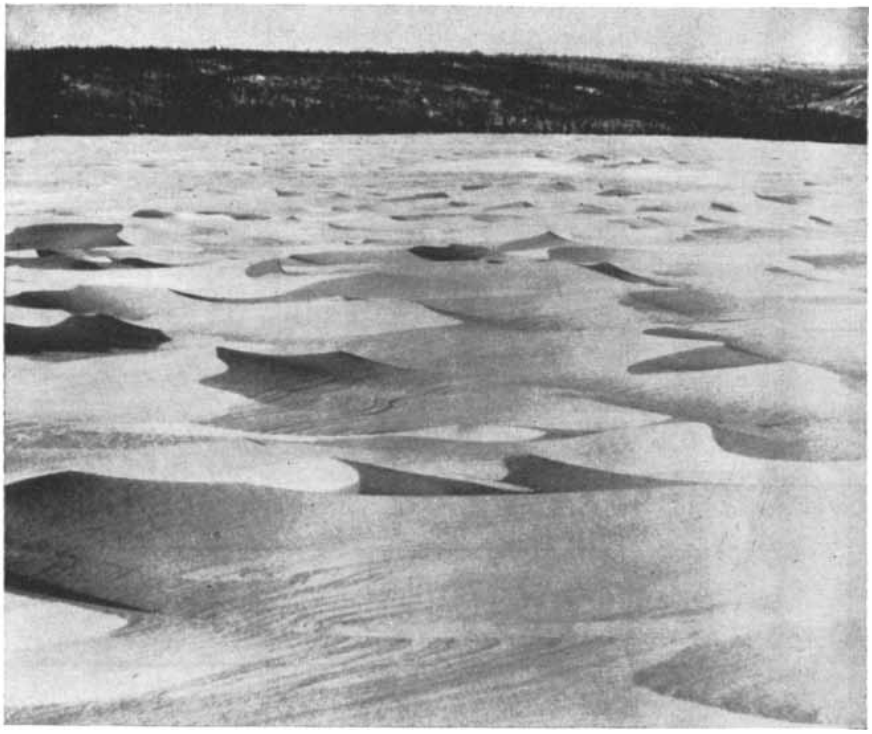
Although the temperature under the snow cover remains stable from day to day, the temperature of the forest floor varies strikingly from place to place. One would expect, for example, that the qámaniq under the snow shadow of the spruce would be cold spots. I have found this to be true: With the air temperature at 25 degrees below zero, the soil temperature one inch below the surface was 2.5 degrees below zero at the base of a tree and 9.5 degrees above zero just beyond the qámaniq. Later in the winter, with the air temperature at 33 degrees below zero, the temperatures were respectively 6.5 below zero and 10.5 degrees above zero. The activity of the small mammals under the snow reflects this pattern of temperature at the forest floor. Sampling of the population by means of live traps under the snow shows that red-backed voles avoid the qámaniq in favor of those parts of the home range under full snow-cover. The Russian worker N. V. Bashenina has recently shown that carbon dioxide gas sometimes accumulates under a taiga snow cover in concentrations sufficient to cause voles to construct "ventilator shafts" up through the snow. At the openings of these shafts the voles are exposed to predation by owls. Formozov believes that it is this habit of the vole that permits certain species of owls to survive the subarctic winter.

Since snow is an excellent insulator against sound, the winter environment of the voles and shrews is silent. It is also dark, because a one-foot snow cover transmits only 8 per cent of the incident light and a two-foot snow cover only 1 per cent. The air beneath the snow is calm and essentially saturated with moisture. Hovering between 15 and 25 degrees above zero for most of the winter, the temperature varies quite slowly. The subnivean environment is thus strangely removed from the subarctic winter above the snow, with its brilliant days and moonlit nights, its relatively sudden and violent temperature changes, its winds and forest noises. By diverse bodily and behavioral adaptations the small mammals of the taiga are able to utilize this environment and survive the northern winter. Without the snow cover the region would be deprived of most of its mammals.

There is one mammal, the familiar red squirrel (*Tamiasciurus hudsonicus*), whose size and weight place it just between the two groups that live respectively above and below the snow. When the deep cold of the subarctic winter settles over the spruce forests of the Alaskan interior, the red squirrels shift the locus of their activity from the trees above the snow to subterranean tunnels below. For weeks at a time no red squir-



UNDER-SNOW TEMPERATURES recorded through two winters at an Alaskan station show the relative stability established by the insulation of the snow. The horizontal dimension of the colored areas indicates the frequency with which each temperature occurred.



LAKE SNOW, contoured like sand dunes by the wind, has a relatively high density due to abrading and breaking up of the snowflakes, which permits them to pack closely together.

TAIGA SNOW, sheltered from the wind, tends to be light and fluffy and clings to the branches of spruce trees. Beneath the trees at left can be seen the snow shadow or "qámaniq."

rels will be seen in the forest. The critical temperature that sends them from the environment of the moose, fox and lynx into the environment of the shrew and red-backed vole seems to lie between 25 and 30 below zero.

We are indebted to Formozov for a scheme that classifies mammals on the basis of their adaptation to snow. Those animals that are unable to adjust to snowy conditions he calls chionophobes, from *chiōn*, the Greek word for snow. In North America the pronghorn antelope, the wild turkey and the opossum belong to this category. Chioneuphores are animals such as the shrew, fox, vole, moose and elk, which can survive in snowy regions. The small, select group of animals such as the varying hare, the North American caribou and the varying or "hoofed" lemming, which possess definite adaptations for snow and are limited to snowy regions, are known as chionophiles. This ecological classification has great possibilities as a tool in zoogeographic studies and should also underlie all wildlife management programs in snowy regions.

In Alaska the distribution of the snow cover very closely follows the known distribution of glacial ice during the Wisconsin age, during which the last extensive glaciation occurred in North America. Formozov has noted a similar relationship between regions of heavy snowfall in the U.S.S.R. and the region occupied by the Dnieper and Don lobes of the glacial ice during the Würm age, which corresponds to the Wisconsin. Undoubtedly the snow-producing conditions that attended the opening of the Pleistocene Epoch contributed considerably to the wholesale extermination of the earlier Pliocene mammals. We may find here an explanation for the disappearance of such mammals as the mammoth, mastodon, antelope, and of certain species of musk ox in North America and the woolly rhinoceros and the "Irish Elk" in Europe and Asia. These animals may have been chionophobes, tied to environments that were cold but had little snow. As their semiarid arctic prairies retreated poleward before the advance of the taiga, with its deep soft snows, the doomed chionophobe species may have been trapped behind such barriers as the glacial Lake Agassiz, which reached across North America from Ontario to eastern Saskatchewan. Or they may have been caught in *cul-de-sacs* of suitable environmental conditions surrounded by ever constricting fences of unsuitable snow.

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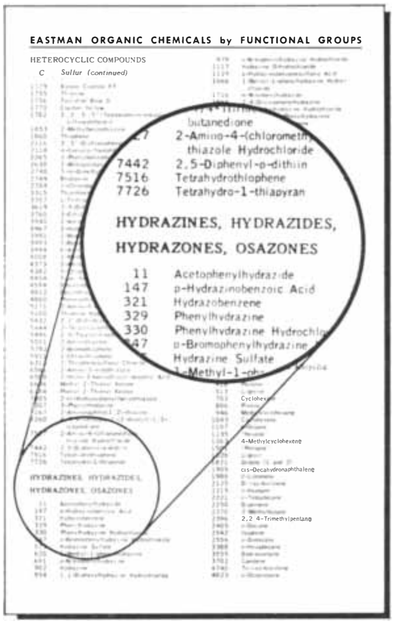

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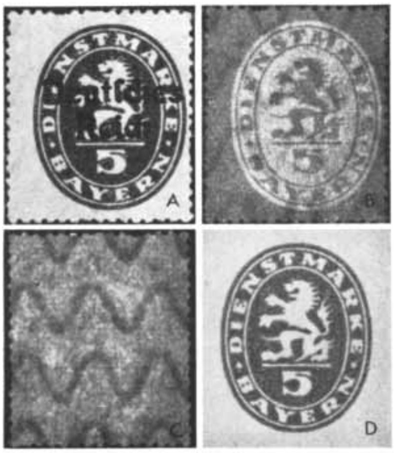

Bavarian stamp of 1920 (Scott No. 052). A. Visible light photograph. The design is green and the "Deutsches Reich" overprint is black. B. Soft x-ray radiograph. Details of both design and paper visible. Design is "negative," indicating absorption of x-rays by the ink. C. Electron radiograph. Only the details of the paper are shown. D. Electron-emission radiograph. The design is "positive," indicating a relatively high electron emission from some heavy element in the ink. The overprint cannot be seen.

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Price quoted is subject to change without notice.

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

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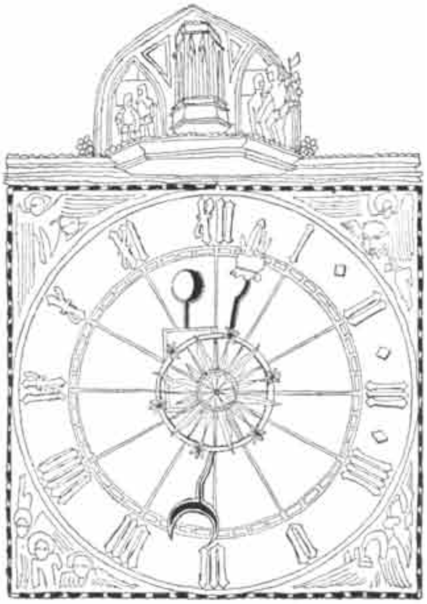
SCIENCE AND



Reserved for Science

The antarctic continent, an area as large as Europe and the U. S. put together, has been removed from the sphere of international wrangling and dedicated to scientific and other peaceful pursuits. Scientific cooperation in the region during the International Geophysical Year has culminated in a treaty, signed by 12 nations, outlawing military activities in Antarctica and on the shelf ice around it at least until 1994. If none of the countries withdraws at that time, the treaty will continue indefinitely.

The agreement declares that "it is in the interest of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord." It therefore bans from the region "any measure of a military nature," including military bases or maneuvers and "the testing of any type of weapon." A separate provision prohibits the setting-off of nuclear explosions in Antarctica or the disposal there of radioactive wastes. To enforce these bans the signatory nations will appoint observers who "shall have complete freedom of access at any time to any or all areas of Antarctica."

Noting "the substantial contributions to scientific knowledge" resulting from international cooperation in the Antarctic during the I.G.Y., the treaty provides for a systematic exchange of scientific plans, personnel and data among the signatories.

The thorny issue of conflicting territorial claims in the region was "frozen" by provisions that neither the treaty nor any activity undertaken while it is in force shall strengthen or weaken existing claims, and that no new claims may be made for the duration of the agreement.

The nations signing the treaty were Argentina, Australia, Belgium, Chile, France, Great Britain, Japan, New Zealand, Norway, the Union of South Africa, the U. S. and the U.S.S.R.

Nuclear-Test Negotiations

Having agreed to join in keeping the Antarctic free of nuclear explosions, Great Britain, the U. S. and the U.S.S.R. last month resumed their efforts to abolish bomb tests over the rest of the earth. After almost a year of debate the U.S.S.R. consented to a review by a committee of experts of the technical problem of identifying underground explosions. It had previously insisted on a 180-station network, proposed in 1958, as the sole basis for negotiation, and had refused to consider U. S. data indicating that the ability of this system to distinguish explosions from earthquakes had been overestimated.

The experts began deliberations in Geneva with instructions to "consider all data and studies relevant to the detection and identification of seismic events" and to "consider possible improvements of the techniques and instrumentation." James B. Fisk, executive vice-president of the Bell Telephone Laboratories, is the leader of the U. S. delegation, which also includes Wolfgang K. H. Panofsky of Stanford University and Carl F. Romney of the Air Force Applications Center. Yevgeni I. Federov heads the Soviet team and Sir William Penney the British.

In a statement to the United Nations the U.S.S.R. reiterated that it would not resume testing unless the Western powers do so. The U. S. had formally agreed to suspend tests through the end of 1959. Henceforth, according to reports from Washington, it will be guided by the progress of the Geneva talks.

As long ago as last May the conferees had framed 17 articles of a treaty to outlaw bomb tests. While the experts were meeting they agreed on an additional measure: to set up a control organization as soon as the treaty is signed, without waiting for its ratification. Under the provisions of the treaty the three nuclear powers will be permanent members of the control commission and four places will rotate among other countries every two years. The U. S. and Great Britain have proposed that the rotating memberships be filled by one "Western" nation, one country of the Soviet bloc and two neutrals. The U.S.S.R. wants two places assigned to Communist countries.

Resolutions adopted by the U. N. General Assembly called upon the Geneva negotiators to "intensify their efforts to reach an agreement" and to continue their voluntary suspension of tests. The U. N. also appealed to other states to desist from tests. The only vote against the latter declaration was cast by France, which is going ahead with its own development of atomic weapons and plans an explosion in the Sahara. Another U. N. resolution expressed "grave concern" over the Sahara test.

Atomic Cooperation

With the dawning recognition by laymen and governments that scientific knowledge is no one's secret, the security that once surrounded atomic-energy research is giving way to cooperation. An agreement concluded last month between the U. S. Atomic Energy Commission and the U.S.S.R. Main Administration for Utilization of Atomic Energy provides for reciprocal visits by scientists and engineers, for possible joint research projects and for sharing unclassified information.

Small groups of researchers in the fields of high-energy physics, power-reactor development and controlled thermonuclear energy will exchange two-week visits during the early part of the program. Possible cooperative projects include "joint facilities and undertakings in controlled thermonuclear reactions; the design and construction of an accelerator of large and novel type; approaches to waste-disposal problems; nuclear-data evaluation and compilation, and the development of nuclear standards." Representatives of the two nations will meet before July to consider which of these enterprises seems the most promising. Information exchanged and developed in the new program will be shared with other nations through the International Atomic Energy Agency in Vienna.

Astounding Science in the U.S.S.R.

The press of the Soviet Union, which has recently had so much to report about the achievements of that country's scientists and engineers, has been further astounding its readers with accounts of a "revolution" in science and a "miracle" of technology. Nikolai A. Kozyrev, an astrophysicist at Pulkovo Observatory, was said to have wrought the revolution, with his hypothesis that the passage of time is the source of cosmic energy. The miracle was the harnessing of a "concentration of energy" in semiconductors that promised to achieve "180 per cent efficiency" and pour "oceans of cheap power . . . torrentially into our machines, devices and installations."

Suddenly the celebration was brought to a halt. Speaking for the Presidium of the U.S.S.R. Academy of Sciences, three distinguished physicists, Lev A. Artsimovitch, Pyotr L. Kapitsa and Igor Y. Tamm, joined in a public rebuke to the press for "cheap sensationalism" and for placing its pages "at the disposal of absolutely incompetent people." "Articles of this kind," they said, "which give publicity to unverified or simply mistaken 'discoveries' misinform the readers and discredit Soviet science."

Taking up the Kozyrev sensation, they declared: "We are not against bold hypotheses, provided they are given substantiation." They could see, however, "no logical sequence in the continual leaps of the thinking, the accumulation of unjustified assumptions, etc." But their indignation was directed not so much to Kozyrev's theory, which is being checked and analyzed by his colleagues at Pulkovo Observatory, as to the way the press reported it. One article that appeared in an important literary magazine was cited as "better suited to advocating a new creed than to expounding a scientific problem."

As for the semiconductor development, they declared: "This is not a case of the concentration of energy, but of the concentration of amazing ignorance." In calculating the 180-per-cent gain achieved by a thermoelectric heat-pump, the science writers had failed to reckon with the heat energy contributed by the water circulating in the system.

"These examples," the physicists concluded, "show that there are serious shortcomings in popularizing the achievements of science and engineering in our country. . . . Surely competent people can be found, say from among the enthusiastic scientific youth, to carry out the important work of popularization."

Terrestrial Relativity-Test

An exquisitely sensitive method for checking one of the central predictions of the general theory of relativity has been proposed by R. V. Pound and G. A. Rebka, Jr., of Harvard University. According to the theory, gravitational force has the same kind of effect on electromagntic waves as it has on material bodies. Thus light moving outward from the sun or another massive body should lose energy, the loss appearing as a decrease in frequency or a "gravitational red-shift." Astronomical observations seem to demonstrate such a shift, but physicists have long wanted a quantitative laboratory test.

One possibility now under consideration is to compare the timekeeping of two identical atomic clocks, one in a satellite and one on the ground. The earth's gravitational field, which should increase the energy (and frequency) of radio waves falling from the satellite to the ground, should also have the effect of making the satellite-borne clock run faster than the one on the ground. The expected effect is very small—about one part in 10,000 billion for each kilometer of height—and requires a very narrow frequency-spread, or band width, if it is to be detected. The band width of atomic clocks is just about narrow enough, but putting them in a satellite involves practical difficulties, and the motion of the vehicle will introduce other frequency shifts.

It would be much more desirable to conduct the experiment between fixed points on the earth's surface, but this would require a fantastically narrow frequency standard. Such a standard, Pound and Rebka suggest in *Physical Review Letters,* can be found in the gamma radiation emitted by radioactive atomic nuclei. Each nucleus has discrete energy-states, and in passing from one to another it sends out gamma rays of sharply defined energy, or frequency. The sharpness is smeared, however, by the recoil of the emitting nuclei, which must acquire an equal and opposite momentum to that of the gamma-ray photons. Depending on the various motions of the nuclei at the time of emission, they absorb more or less energy from the photons, and the latter emerge with slightly different frequencies.

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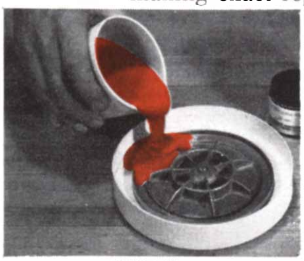

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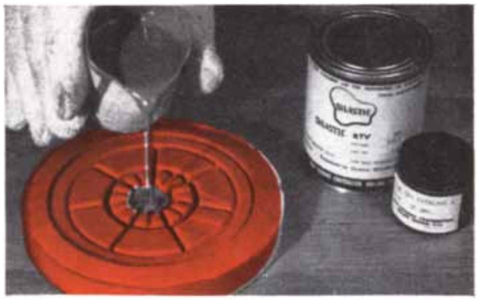

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has been discovered by a German physicist, R. L. Mössbauer. In crystalline solids a certain fraction of the gamma rays transfer momentum not to their individual nuclei but to all the nuclei of the crystal as a coherent whole. This multiplies the recoiling mass enormously, which means that the velocity of recoil, and hence the energy extracted from the photons, is correspondingly reduced. All these photons emerge with essentially their full and identical energy. If the radiation is now sent through a second crystal of the same material, the crystal atoms absorb the gamma rays in the same way. The sharply defined beam has just the right energy to transfer momentum to the whole crystal and is largely absorbed.

An almost unimaginably small change in energy destroys the absorption resonance and allows the beam to pass straight through the second crystal. One way to change the energy is to move the source toward or away from the absorber. In frequency terms, this introduces a Doppler shift in the gamma rays. Pound and Rebka have demonstrated that, for iron-57 nuclei, moving the source at the rate of .017 centimeter per second cuts the absorption by half. In the familiar Doppler-shift example of the whistle on a moving train, this would correspond to detecting a frequency shift in a whistle on a train moving at the rate of an eighth of an inch per year!

Another way to change the gamma rays' energy is to let them fall in a gravitational field. A fall of 2.9 kilometers between the source and the absorber should also reduce the absorption of iron-57 radiation by half. A fall of even a few tens of meters should be easily detectable. The Harvard physicists are now preparing to "drop" gamma rays in a tower.

A recent cryptic announcement from the U.S.S.R. suggests that Soviet physicists may be up to a similar trick. Dmitri Blokhintsev of the Nuclear Research Institute at Dubna said that his laboratory will conduct the first terrestrial experiment to check the general theory of relativity.

Catalyzed Synthetic Diamonds

Investigators at the General Electric Research Laboratories five years ago turned base graphite into precious diamond. The man-made stones are not gems, but the economically more significant industrial diamonds. With the lifting of a U. S. Government secrecy order, the investigators have now revealed how they did it. The crucial factor, they report in *Nature*, is a catalyst that reduces by half the temperatures and pressures needed for the task.

The transformation of graphite into diamonds is a struggle up a thermodynamic hill. Thermodynamics indicates that a pressure of three million pounds per square inch and a temperature of 7,000 degrees Fahrenheit are required to free the carbon atoms from the hexagonal lattice of graphite and force them into the cubic lattice of diamond. This combination of pressure and temperature is unattainable in the laboratory; such high temperature would melt down the pressure-generating apparatus. The catalyst, which can be any of a dozen metals or their metal-yielding salts, reduces the temperature-pressure combination to technologically feasible levels of 800,000 to 1.8 million p.s.i and 2,200 to 4,400 degrees F.

The heart of the diamond-making mechanism is a small cylinder packed with graphite and layers of catalyst metal. Tungsten-carbide pistons converging on the cylinder build the necessary pressures. The intense heat of an electric current melts the catalyst and tears the carbon atoms from the graphite. As the molten catalyst seeps into the graphite, alloying with it, a thin film forms at the leading edge of the melt. Just behind the film the carbon atoms realign themselves and form diamonds.

Temperature determines the shape and affects the color of the synthetic stones. Lower temperatures produce black cubes; intermediate temperatures, green or yellow cubes, cubo-octahedra and dodecahedra; high temperatures, white octahedra. Lower pressure-temperature levels slow the synthesis but yield somewhat larger stones; higher levels, while yielding smaller stones, frequently produce five-pointed stars that are superior to natural diamonds for many industrial uses.

The catalyst film plays a vital but puzzling role in the process. Diamonds will not grow without it, nor will they grow very far from it. Despite the presence of the film, however, the process occasionally yields graphite and no diamonds. The investigators, H. P. Bovenkerk, F. P. Bundy, H. Tracy Hall, H. M. Strong and R. H. Wentorf, Jr., observe that "stubborn mysteries" still surround the transformation.

Spacious Talk

Are intelligent beings on the planets of other suns trying to get in touch with us? Two Cornell University physi-

United Air Lines pilots review flight plan calculated by Bendix G-15 Computer at UAL's Operating Base, Denver, Colorado.

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cists suggest that this may be the case and propose that we start listening.

Writing in *Nature*, Giuseppe Cocconi and Philip Morrison point out that there is no known reason why other stars like the sun should not have planets. If life has evolved on two planets in the solar system (the earth and "very probably" Mars), the chances seem good that it will have sprung up elsewhere. Societies capable, like our own, of "considerable scientific investigation" may well exist, and some may be considerably older and more sophisticated than ours.

To the super-scientists of such civilizations our sun would appear a promising place for life, and scientific investigation, to occur. Very likely they would have long ago established a channel of communication with us and would "look forward patiently" to return signals informing them "that a new society has entered the community of intelligence."

What could they use to signal? So far as we know, only electromagnetic waves. The best frequencies, from the standpoint of low atmospheric absorption and ease of reception, lie between one and 10,000 megacycles per second. It would be almost impossible, however, to scan all of this vast band of wavelengths. Is there some standard celestial frequency that other beings might choose? The best bet is 1,420 megacycles, the frequency of the 21-centimeter line emitted by interstellar hydrogen.

According to the authors' calculations, a detectable beam could be sent to our largest existing radio telescopes from a distance of a few tens of light-years by a transmitter only somewhat more powerful than those we now have. The bigger telescopes now under construction should be able to detect signals even from transmitters like our own. This assumes the transmitter is located out of the galactic plane, away from the region of high 21-centimeter background-noise. As likely starting candidates the authors suggest the stars Tau Ceti, Omicron Eridani II, Eta Eridani and Eta Indi. All have luminosities and lifetimes like those of the sun, and all lie within 15 light-years and out of the high-background region.

Depending on the distance, a two-way communication would be subject to a delay of 10 years or more between Q and A. So the putative message (very likely pulse-coded) may go on for a few years before repeating. As recognition symbols it might contain a sequence of small prime numbers or simple arithmetical sums.

"The reader may seek to consign these speculations wholly to the domain of

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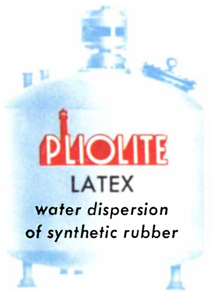

GOODYEAR

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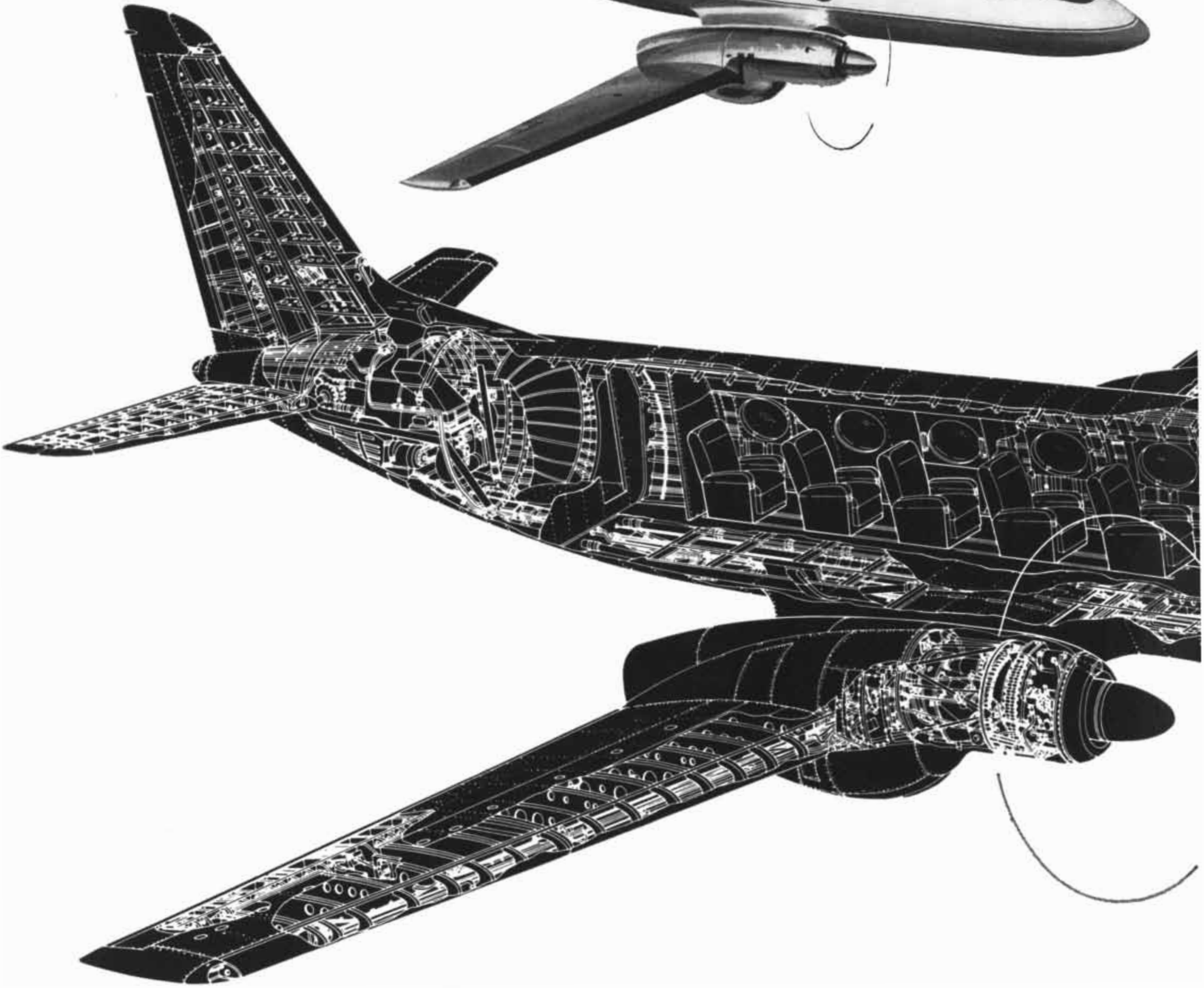
science fiction," Cocconi and Morrison conclude, "but we submit that the . . . presence of interstellar signals is entirely consistent with all we now know. . . . The probability of [finding signals] is difficult to estimate; but if we never search, the chance of success is zero."

One radio astronomer who does not consign such speculation to the domain of science fiction is Frank D. Drake of the National Radio Astronomy Observatory. As director of Project Ozma (after the queen of the fictional land of Oz), he is preparing to turn an 85-foot antenna toward Tau Ceti and Eta Eridani to see whether he can strike up a conversation.

Population Control

Under the pressure of its super-dense population Japan has achieved the most rapid decline of a birth rate in history. A report in *Population Bulletin* states that the rate has dropped from 34.3 births per 1,000 people in 1947 to 18.5 in 1956 and 17.2 in 1957. The annual rate of population growth is now the lowest in Asia: about 1.2 per cent (compared with 1.8 per cent in the U. S.). The Japanese resorted primarily to abortion and sterilization: In 1957 there were 1,170,000 recorded abortions and probably an equal number of unrecorded ones. More than 42,000 women were reported sterilized in 1955, and the actual total may have been 10 times as high. Recent surveys indicate that contraception is now becoming the principal means of birth control, even in rural areas.

In the U. S. birth control for over-populated countries has recently been advocated by two governmental advisory groups. The President's Committee to Study the U. S. Military Assistance Program recommended last July that this country furnish assistance in population control to any nation requesting it lest growing populations make other aid expenditures futile. In a study for the Senate Foreign Relations Committee, the Stanford Research Institute pointed out that while population growth in the Western world followed economic development, "in many underdeveloped countries today a very rapid population growth is preceding economic development," thanks to modern medicine and public-health techniques. Its report called for U. S. help in combatting the "world population explosion." It added: "The traditional means have been disease, famine and war. If other means are to be substituted, conscious national and international policies will be required."



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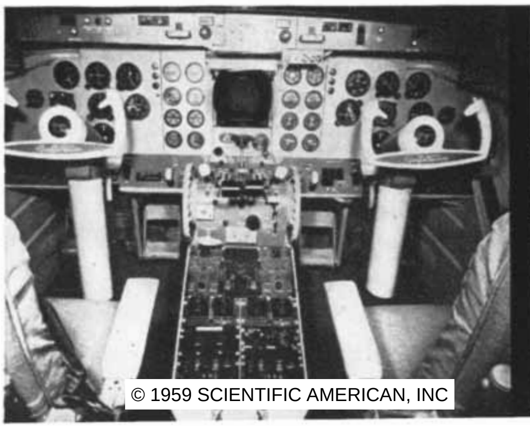


BREEDER REACTORS

Reactors that produce more fuel than they consume make it feasible to "burn the rocks," that is, to utilize the vast supply of uranium and thorium contained not in rich ores but in rocks such as granite

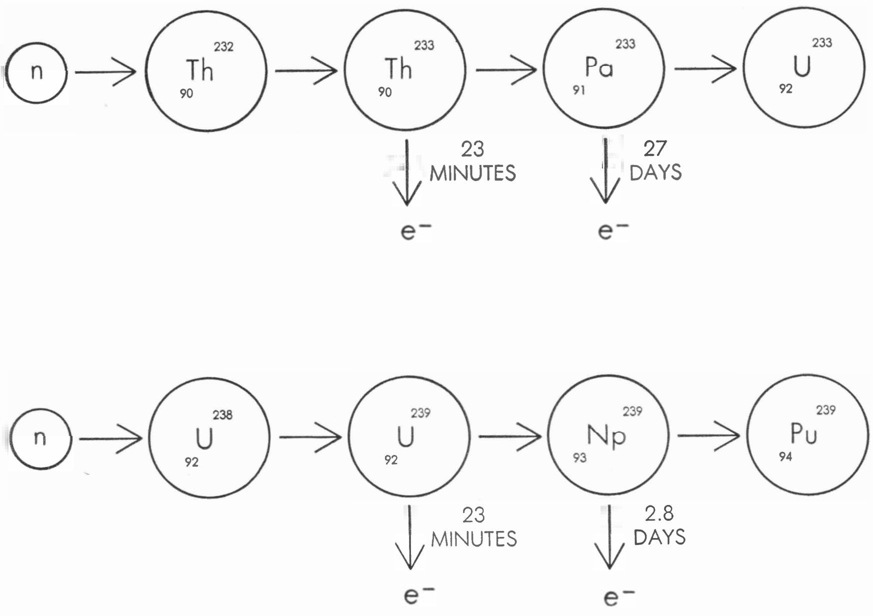
by Alvin M. Weinberg

Even the gloomiest of contemporary Malthusians, projecting an increasingly desolate future for a rising world population, have had to concede that there is one ray of hope. If the controlled fusion of the heavy isotopes of hydrogen can be engineered on a large scale, future generations will have available in the oceans a supply of energy that will last for the lifetime of the solar system. Workers in several nations have been engaged in an effort to learn how to "burn the sea." They have learned a great deal about the behavior of matter at the very high temperatures associated with thermonuclear reactions. But it is not yet possible to assume that a successful thermonuclear reactor can be developed.

Even if such reactors cannot be built, however, mankind will not be condemned to an impasse in the problem of population *v.* resources. Closer at hand is another energy resource about as abundant as that contained in the sea. This resource consists of the enormous quantities of uranium and thorium dispersed in trace amounts throughout the rocky crust of the earth. To extract the energy the rocks contain we can draw upon an existing technology. Nuclear reactors that operate on the controlled fission of the heavy elements are already generating electrical power. We need only to perfect the breeder reactor—the reactor that "breeds" more nuclear fuel than it consumes—and we shall literally be able to "burn the rocks."

The realization that an essentially inexhaustible source of energy lies almost within our grasp has come surprisingly late in the evolution of nuclear power. It was not until 1955, at the first Geneva Conference on the Peaceful Uses of Atomic Energy, that Harrison Brown and L. T. Silver of the California Institute of Technology demonstrated that the trace amounts of radioactive elements present in the granite of the continents could vastly multiply the supply of fissionable material accessible in ores. This conclusion has been supported by Farrington Daniels and his colleagues at the University of Wisconsin.

As a result of these studies and the progress that has been made in development of breeder reactors, there is no longer any doubt that nuclear breeding offers a long-term solution to the energy problem. With the full significance of nuclear breeding now becoming apparent, the Atomic Energy Commission's research program aimed at furthering the development of breeder reactors takes on new significance: If the program is successful, we shall be able to satisfy mankind's hunger for energy, even though we never learn how to burn the sea.



BREEDING CYCLES are based on two sets of nuclear reactions. In the thorium cycle (*top*) an atom of fertile thorium 232 absorbs a neutron and emits a beta particle (e^-) to become protoactinium, which spontaneously emits a beta particle to become fissionable uranium 233. In uranium cycle (*bottom*) fertile uranium 238 absorbs a neutron and emits a beta particle to become neptunium, which then undergoes beta decay to become fissionable plutonium 239.

Breeding Cycles

Breeder reactors have been built or are under construction in the U. S., Great Britain and the U.S.S.R. The first, the Experimental Breeder Reactor No. 1 (EBR-1) at the National Reactor Testing Station in Arco, Idaho, was also the first reactor in the world to generate electricity (on December 20, 1951). Its successor, EBR-2, is now being built at the same site, and a third reactor, the Enrico Fermi Fast Breeder, is under construction near Detroit. The U.S.S.R. has built two breeders at Obninsk, some 100 miles from Moscow. And last November the Dounreay reactor, the first breeder

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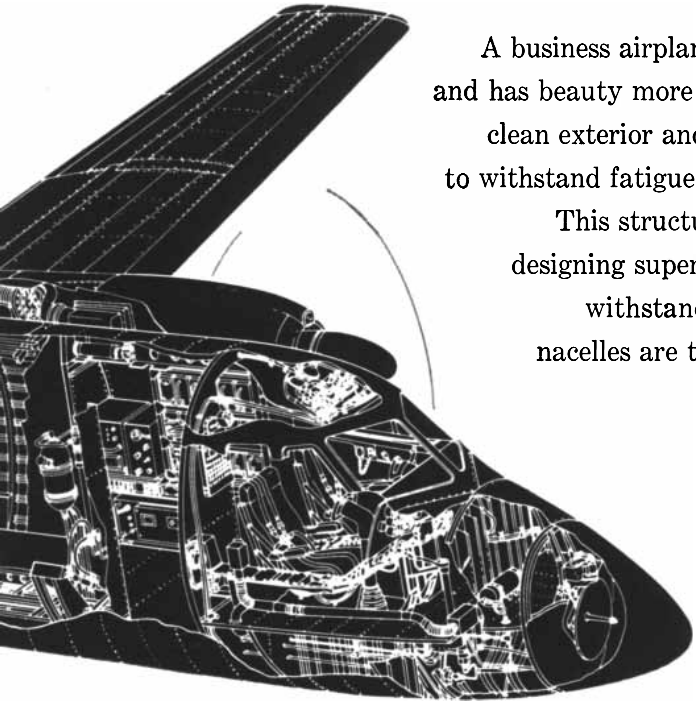

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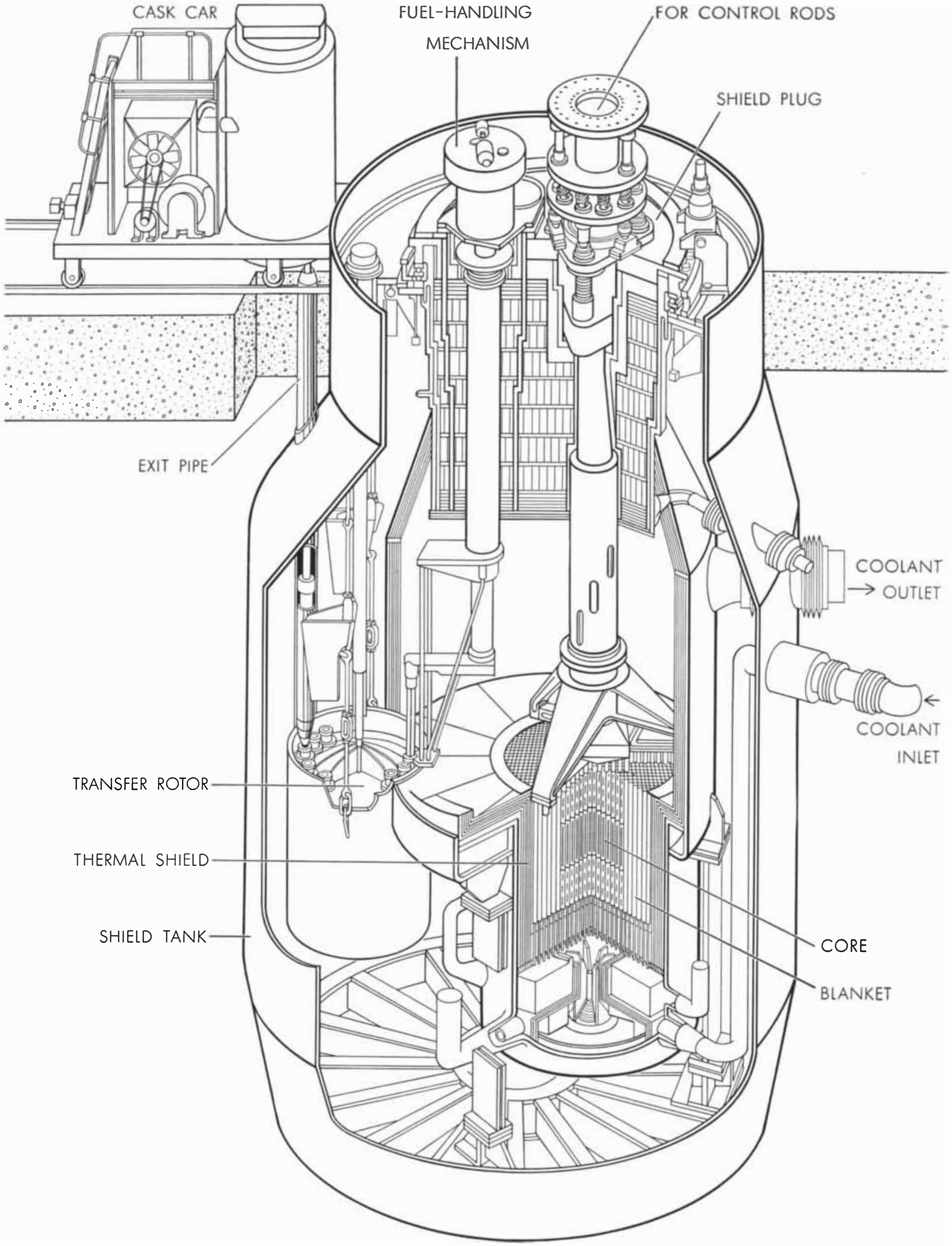
LARGEST BREEDER REACTOR designed to produce electrical power is the Enrico Fermi Atomic Power Plant, now under construction near Detroit. It is expected to produce 300,000 kilowatts of heat and 100,000 kilowatts of electricity. The photograph shows the top edge of the shield tank (*large circle*) and inside it the circular shield plug that caps the reactor vessel. The flanged opening in the right side of the plug is for the reactor control-rods; the fuel-handling mechanism protrudes from the left side of the plug.



CUTAWAY VIEW of Fermi reactor shows the interior of the 40-foot shield tank with the 36-foot reactor vessel inside it. Fuel elements can be removed from the sodium-filled reactor vessel by the fuel-handling mechanism at center, which transfers the elements from the core to the transfer rotor. The elements leave the reactor via the exit pipe and cask car. By reversing the procedure, new fuel and blanket elements can be added to the reactor. Shield plug at top contains cans of neutron-absorbing borated graphite.

in Great Britain, began to operate at low power.

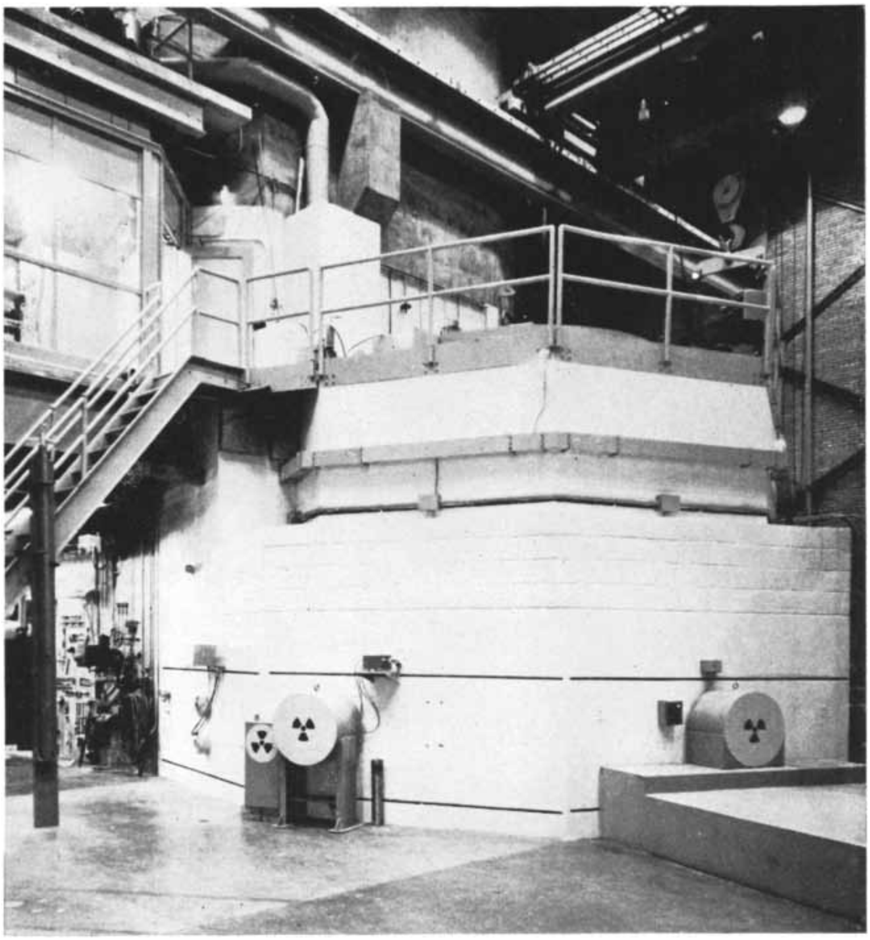
Most breeder reactors are now fueled with uranium 235, but ultimately they will burn the uranium 233 and plutonium 239 they produce. The fission of each atom of these fuels liberates, on the average, two fast (high-energy) neutrons. One of the neutrons must trigger another fission to maintain the nuclear chain-reaction; the other neutron is available to breed a new fissionable atom, that is, to transform a "fertile" isotope of one of the heavy elements into a fissionable isotope. The fertile raw materials for breeder reactions are thorium 232 (which is transmuted into uranium 233) and uranium 238 (which is transmuted into plutonium 239). As the most abundant isotopes of their elements, thorium 232 and uranium 238 are respectively present in an average of about 12 and three parts per million in the various kinds of granite.

In the thorium-uranium cycle an atom of thorium 232 captures a neutron and decays spontaneously in two steps into fissionable uranium 233 [*see top reaction on page* 82]. Similarly, in the uranium-plutonium cycle an atom of uranium 238 captures a neutron and decays in two steps into fissionable plutonium 239 [*see bottom reaction on page* 82].

With a newly bred fissionable atom to replace the one destroyed in the original fission reaction, a breeder can operate with no net loss of fissionable material. One measure of the performance of a breeder reactor is its "breeding ratio": the ratio of fissionable atoms produced to fissionable atoms destroyed. If the ratio is greater than one, the reactor will breed more nuclear fuel than it consumes; if the ratio is less than one, the fissionable fuel must be replenished to keep the reactor going.

Theoretically a breeder reactor can achieve a breeding ratio of one if it produces two neutrons for each fissionable atom destroyed. In practice, however, the neutron economy is always upset by the absorption of neutrons in the control rods and structural materials of the reactor and in the neutron-absorbing isotopes (such as xenon 135 and samarium 149) formed by the fission of uranium or plutonium. Moreover, some newly bred fissionable material is lost in the chemical processing necessary to get rid of fission products and to recover the fissionable and fertile material not yet burned or bred. Because of these losses, it is generally believed that a reactor must produce at least 2.2 neutrons per fissionable atom destroyed in order to

EXTERIOR VIEW shows the Fermi plant with Lake Michigan in the background. The steel dome that houses the reactor is 120 feet high and 72 feet in diameter. The adjoining buildings contain power-plant equipment such as heat exchangers and turbogenerators.

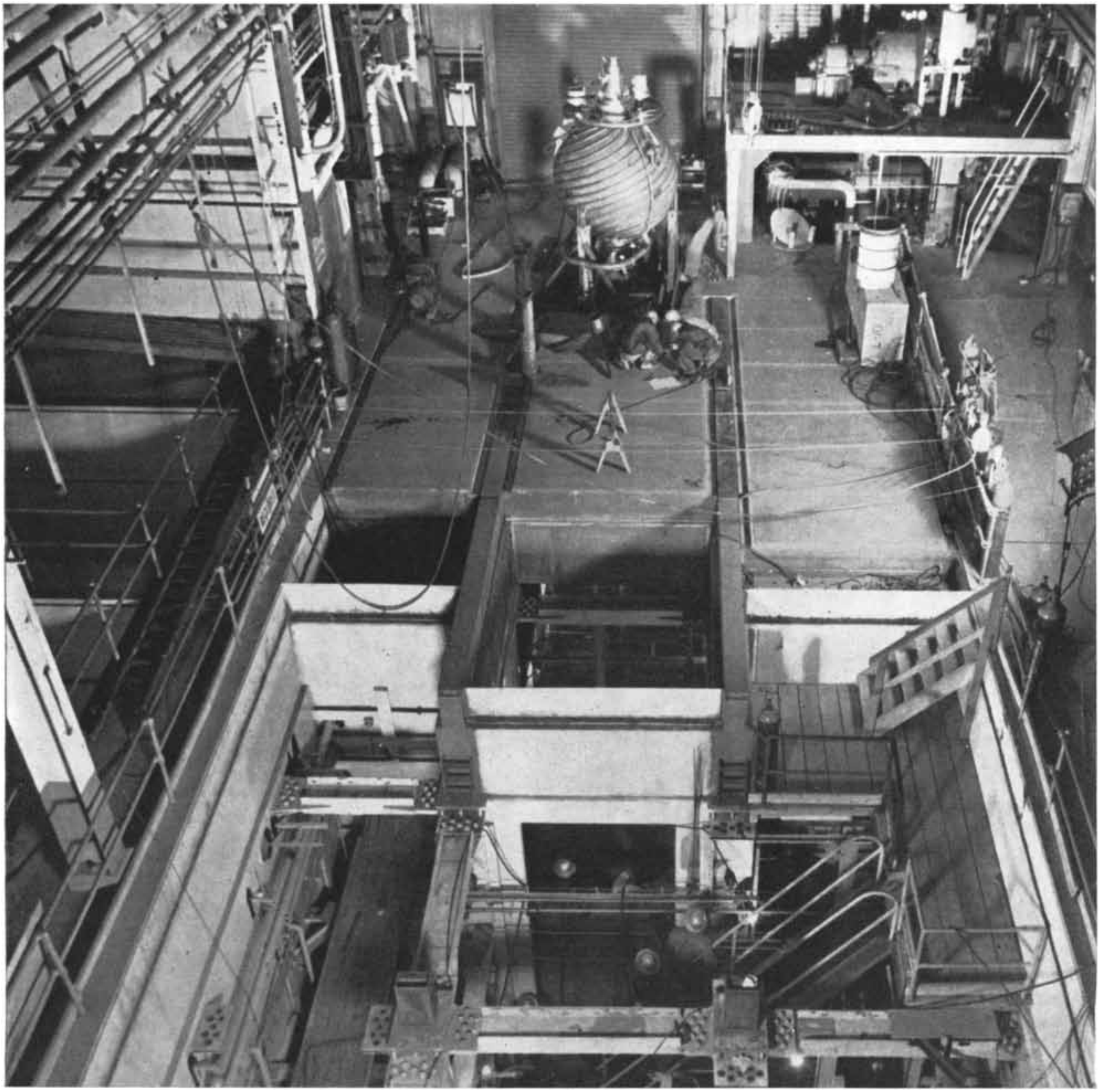


FIRST BREEDER REACTOR, the Experimental Breeder Reactor No. 1 (EBR-1), was built in 1951 by the Argonne National Laboratory. It was the first reactor to produce electrical power, and is still in operation at the National Reactor Testing Station at Arco, Idaho.

achieve a breeding ratio of one or better.

Many workers have seriously doubted the possibility of achieving a breeding ratio well above one, especially in the thorium-uranium cycle, because fissionable atoms do not always fission when they absorb a neutron. As Boyce D. McDaniel discovered during the wartime development of the atomic bomb at the Los Alamos Scientific Laboratory, both uranium 233 and plutonium 239 participate in so-called radiative-capture reactions, in which they absorb a neutron and emit a gamma ray to become the nonfissionable isotopes uranium 234 and plutonium 240. In addition to destroying fuel, radiative-capture reactions use up neutrons and so reduce the reactor's ability to breed.

In general the competition between fission and capture reactions tends to favor fission as the energy of the neutron that triggers the reaction increases. This consideration carries more weight in the uranium-plutonium cycle than it does in the thorium-uranium cycle. When a nucleus of plutonium 239 absorbs a thermal (low-energy) neutron, it fissions and liberates an average of only 2.09 neutrons; when it absorbs a fairly fast neutron (one with an energy of about 500,000 electron volts), it liberates an average of 2.7 neutrons—well above the 2.2-neutron minimum necessary to achieve a breeding ratio of one. In the thorium-uranium cycle, on the other hand, a thermal neutron produces an average of about 2.3 neutrons when it is absorbed by a uranium-233 nucleus, but a fast neutron increases the yield only to 2.4. The values in the thorium-uranium cycle are so close to the 2.2-



LIQUID-FUEL REACTOR, the Homogeneous Reactor Experiment No. 2 (HRE-2) was originally designed as a prototype of a liquid-fuel breeder. The core of the reactor is inside the 74-inch spherical blast shield which is visible at top center. The pipes on the shield are cooling coils. The fuel burned in the reactor consists of uranyl sulfate dissolved in heavy water. In the later stages of construction the reactor sphere was lowered into the pit directly in front of it; the reactor and the pit were then covered by slabs of shielding.

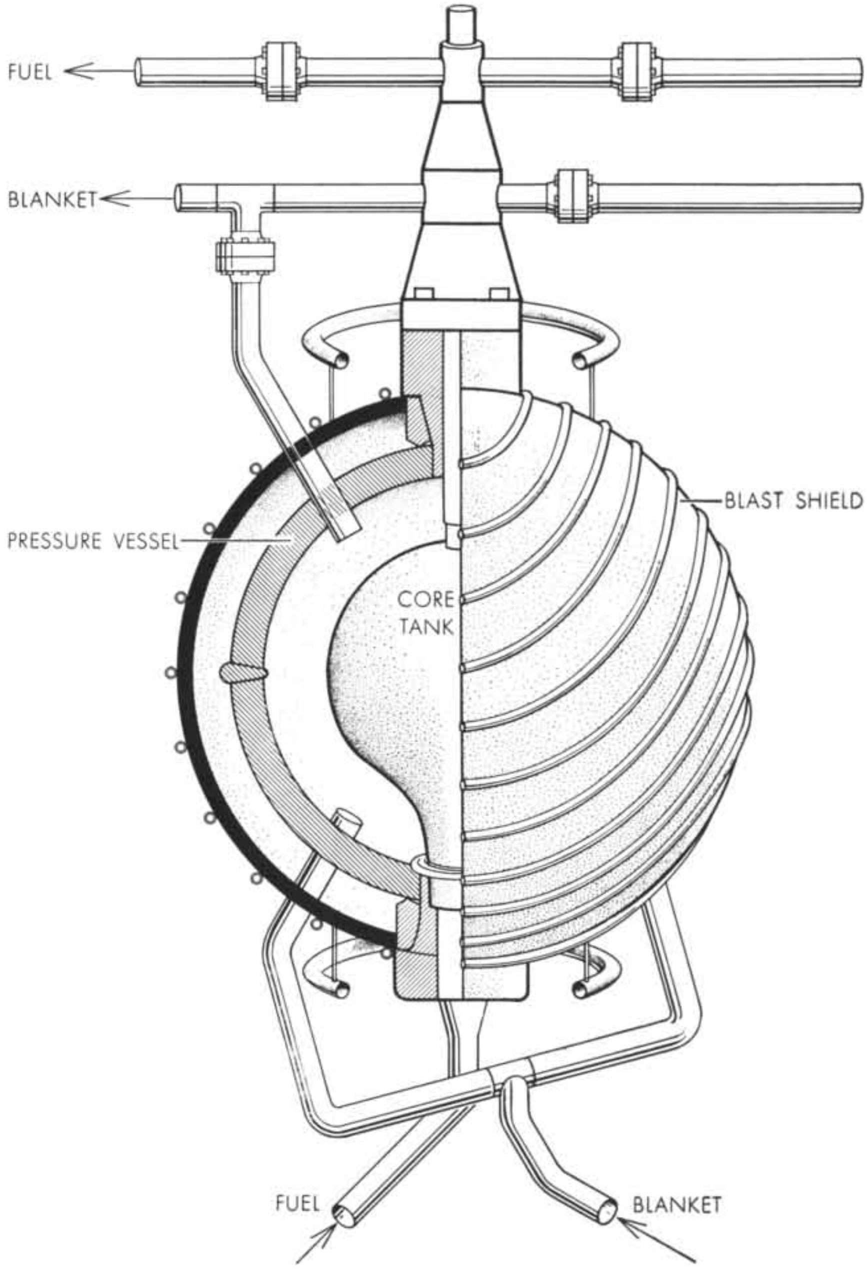
neutron minimum that a great deal of work has been done at the Oak Ridge National Laboratory and elsewhere to determine precisely how many neutrons are emitted (the so-called eta value) when a uranium-233 nucleus is fissioned by a thermal neutron. The thermal-neutron eta value of uranium 233 is now firmly established as 2.28. It is one of the most accurately measured of all nuclear constants.

The eta values for the uranium-plutonium and thorium-uranium cycles have determined the whole strategy of breeder-reactor design. Because there is obviously little to be gained by using fast neutrons to trigger the chain reaction in thorium breeders, these reactors are designed to breed with thermal neutrons, and are often called thermal breeders. Uranium-plutonium breeders, on the other hand, are designed to take advantage of the abundance of neutrons produced in fast-neutron fission; these reactors are accordingly known as fast breeders.

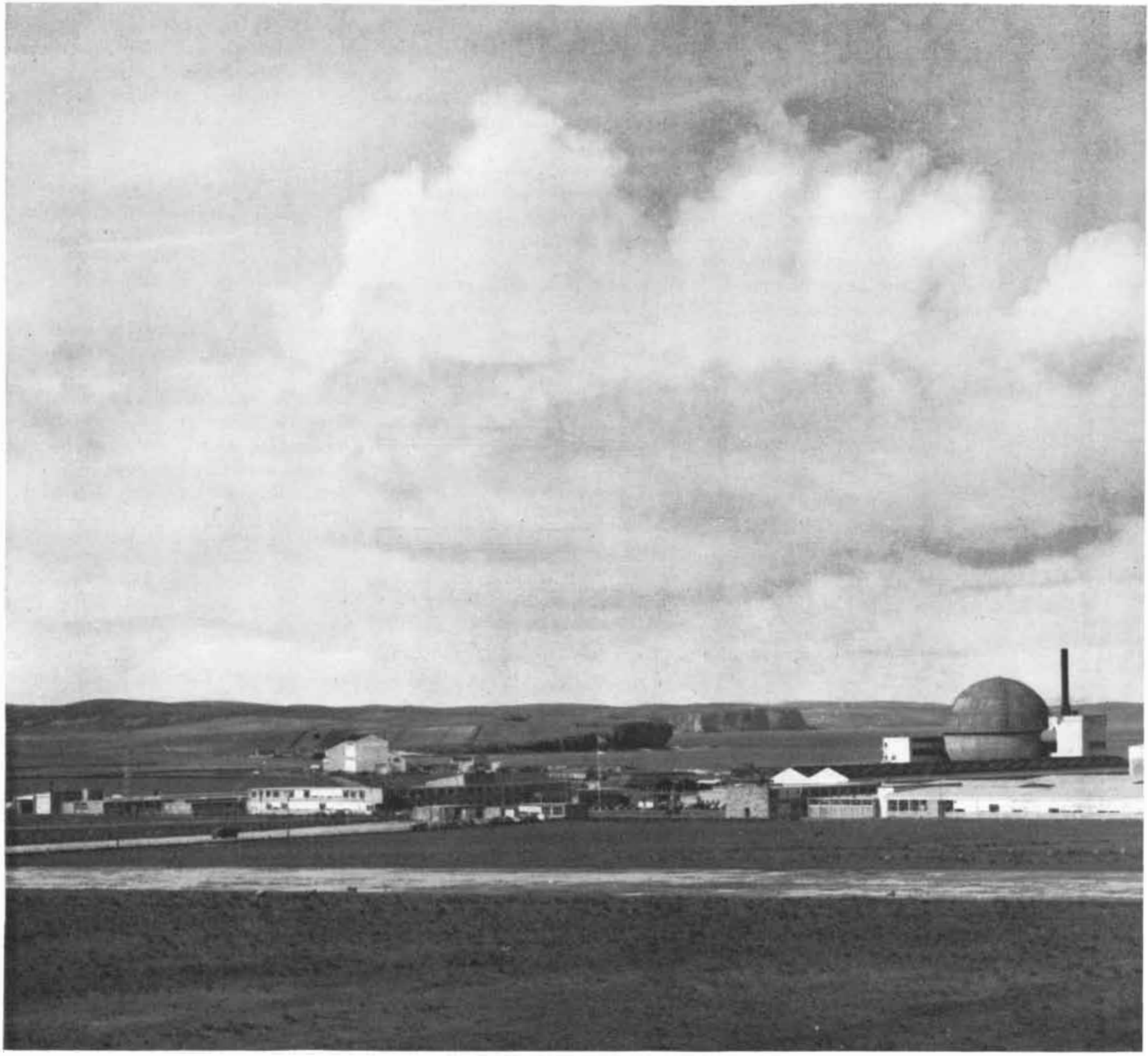
On the basis of breeding ratio alone, the fast breeder would appear to have a decisive superiority over the thermal breeder. As the respective eta values of the two breeding cycles suggest, the fast breeder has a theoretical breeding ratio of 1.6, and the thermal breeder has a ratio of only 1.1. There is, however, another important consideration. This is the "doubling time": the time it takes a reactor to double its original inventory of fissionable material. The doubling time is determined by two factors. One of them is of course the breeding ratio. The other is the specific power of the reactor, that is, its output in kilowatts per kilogram of fissionable material tied up in the reactor and in the chemical plant that processes its fuel. Specific power is thus a measure of the rate at which fuel is burned in the reactor. Since the burning of each fissionable atom results in a certain fractional gain (determined by the breeding ratio) in the over-all inventory of fuel, the higher the rate of burning—that is, the higher the specific power—the shorter the doubling time. The ideal reactor must therefore have a high specific power as well as a high breeding-ratio.

Unfortunately this ideal can only be approximated. The fast reactor has a high breeding-ratio, as nuclear physics shows. But engineering considerations give it an inherently low specific power. If a fast reactor is to breed at all, the fuel in its core must not be greatly diluted by coolants or structural materials; these decrease the energy of fast neutrons to the point where many are lost in useless radiative-capture reactions. The only way to prevent such losses is to design a more compact core containing more concentrated fuel. But this raises serious obstacles to the extraction of heat from the reactor, an operation necessary both to obtain power and to keep the core from melting. For efficient heat-transfer the fuel should be as dilute as possible, a requirement that can be met only by the sacrifice of fast neutrons. Thus the fast breeder is faced with the dilemma of "unusable compactness" *v.* "unworkable diluteness."

In contrast, thermal breeders are inherently dilute systems and so have excellent heat-transfer properties. The fuel in the core is always mixed with large quantities of coolant as well as with a moderator (such as graphite, beryllium or heavy water) and slows fast neutrons down to thermal energies. The thermal breeder thus has a relatively high specific power, perhaps five times as high as the fast breeder. This is enough to offset the lower breeding-ratio of the thermal system. On the basis of present data both types of reactor should have a dou-



CORE OF HRE-2 is a pear-shaped tank 32 inches in diameter. It is surrounded by a steel pressure-vessel and a blast shield. Liquid fuel is pumped into the core from below and leaves at the top. The blanket, a slurry of thorium oxide suspended in heavy water, was to fill the space between core tank and pressure vessel, but a hole in the core prevented this.



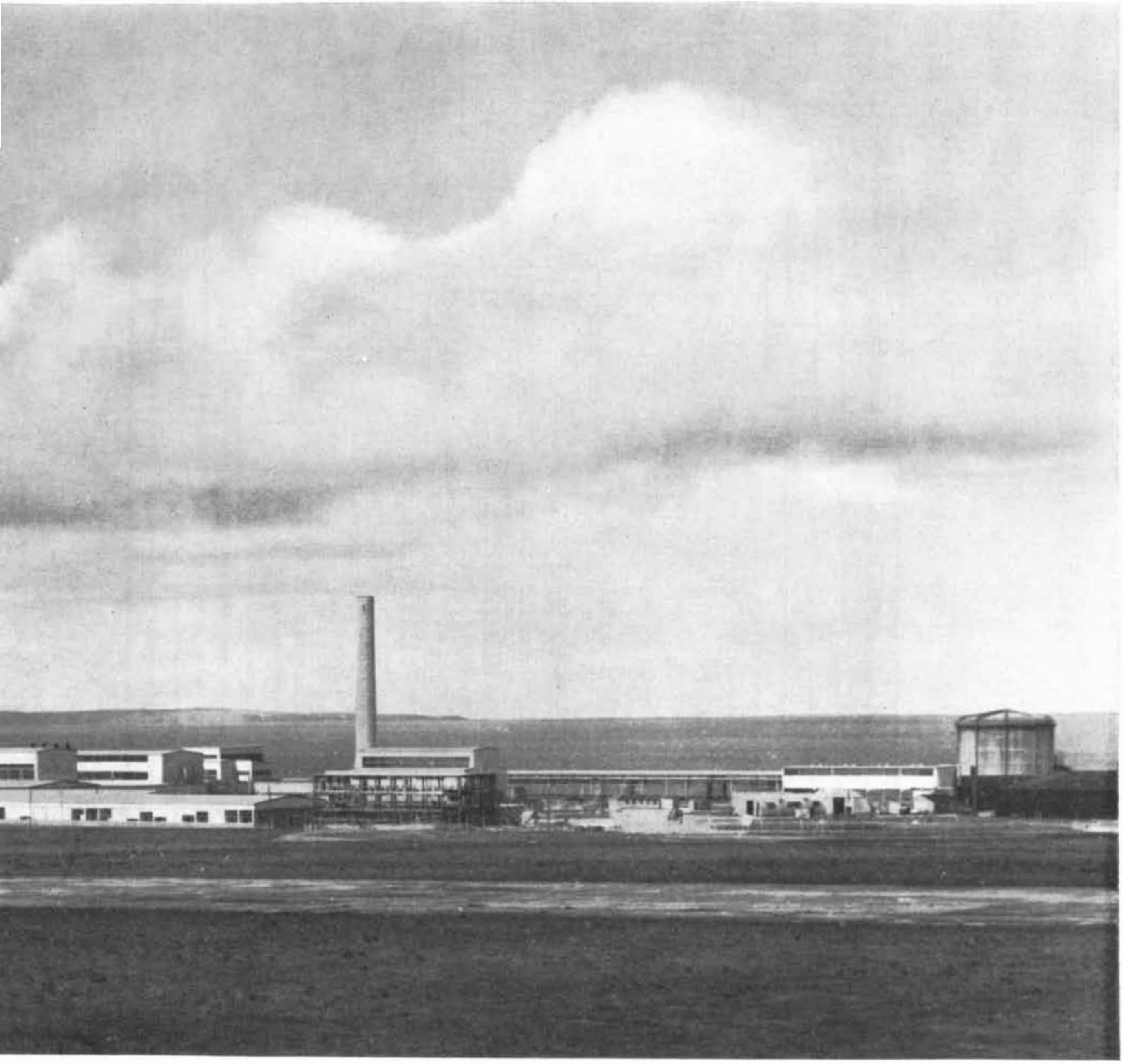
NEW BRITISH BREEDER was recently completed at Dounreay, on the coast of Scotland. The reactor is housed in a steel sphere 135 feet in diameter (*center*); the surrounding buildings contain electrical generating equipment. The reactor is expected to produce

bling time of 10 to 20 years. It should be emphasized that the fast breeder gets its name from the fast neutrons that do its breeding and not from the speed at which it breeds.

Fast Breeders

The compromises that must go into the design of a fast breeder are well demonstrated in the Fermi reactor, an engineering tour de force. Like all breeders, the Fermi reactor has a blanket of fertile material that surrounds a core of fissionable fuel [*see illustrations on pages 84 and 94*]. Both core and blanket are submerged in a pool of liquid sodium, the favorite coolant for fast breeders because it does not sharply decrease the energy of fast neutrons as most other coolants do. The fuel in the core is a mixture of metallic uranium 238 and uranium 235, alloyed with a small amount of molybdenum to improve resistance to radiation. The alloy is fabricated into thin zirconium-clad fuel pins, which are arrayed side by side and far enough apart to permit coolant to flow upward between them. When the molten sodium leaves the core (at a temperature of about 400 degrees centigrade), it is pumped to specially designed heat exchangers, where it converts water into high-pressure steam. The steam drives a series of turbogenerators that produce 100,000 kilowatts of electricity, and the cooled sodium is cycled back through the core.

The conflict of compactness *v.* diluteness is evident in the design of the reactor core. Most of the reactor's 300,000 kilowatts of heat are produced in a cylinder not much bigger than a large garbage can; the cylinder is about a meter high, a meter in diameter and has a total volume of about 600 liters. The thermal-power density in the core thus reaches a level of about 500 watts per cubic cen-



60,000 kilowatts of heat and 15,000 kilowatts of electricity. It began to operate at low power last November and will be gradually worked up to full power over a period of months. The Dounreay reactor is a solid-fuel breeder that will produce plutonium 239.

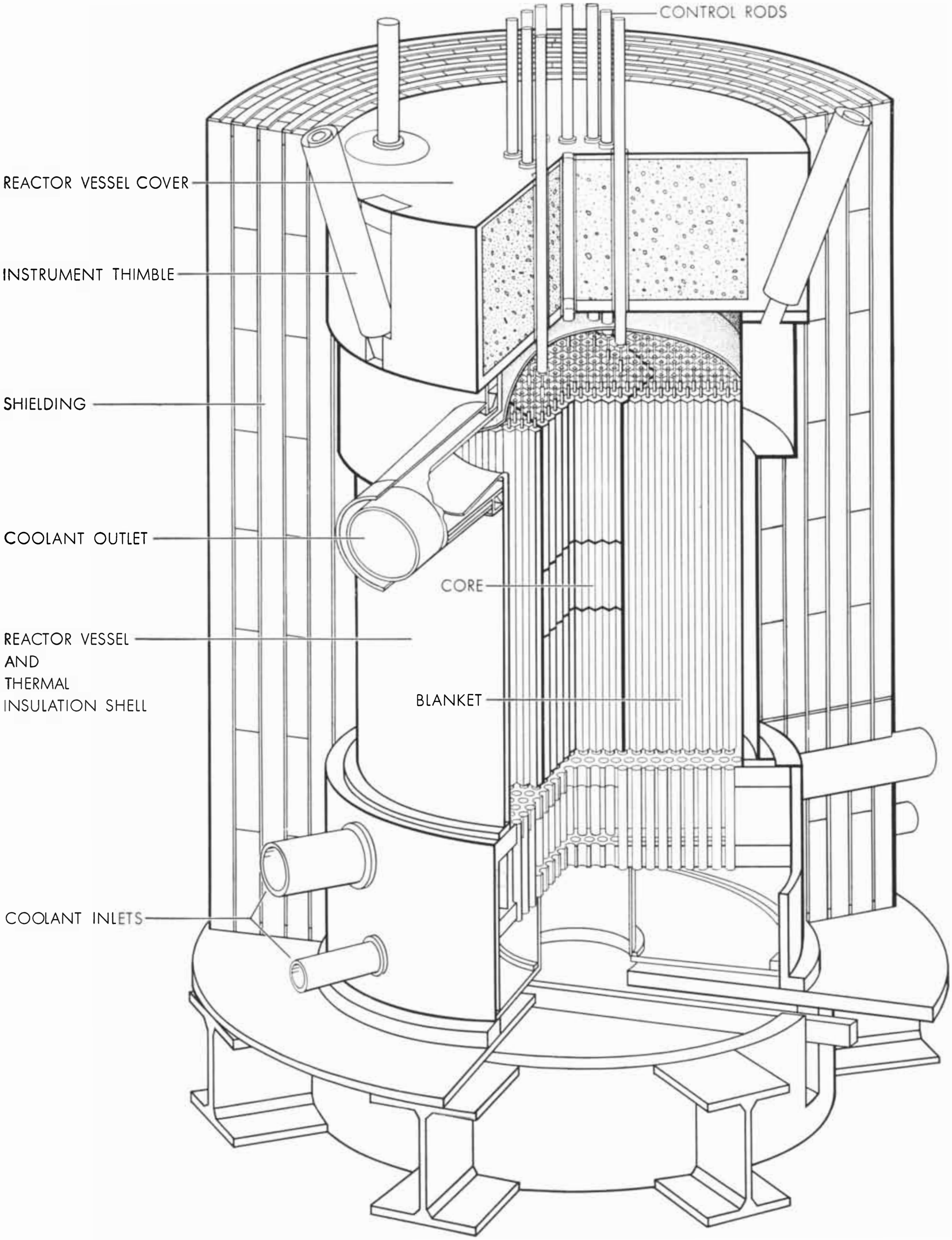
timeter—one of the highest values for any reactor in the world. But considering the amount of fuel in the core (485 kilograms of uranium 235), the specific power is actually quite low. It is expected that the reactor will yield only about 650 kilowatts per kilogram of fissionable material. A full-scale thermal breeder, by contrast, would deliver about 2,000 to 3,000 kilowatts per kilogram.

The specific power of fast breeders would be even lower if the designers did not take advantage of the fact that fast neutrons can trigger the fission of uranium 238, a reaction that produces additional neutrons. By mixing uranium 238 with the fissionable material in the core, the breeding ratio can be increased by as much as .3. The resulting dilution of the fuel also serves to improve the heat-transfer characteristics of the core, increasing the reactor's thermal efficiency and easing the strain that the high power-density places on the fuel elements.

Despite these inherent engineering difficulties, fast breeders have attracted the major portion of the world's research effort. This is only natural, because the breeding ratio in the uranium-plutonium cycle is so large that there can be no question that fast-neutron breeding is possible. Almost every nation that has a reactor-development program has given serious consideration to building a fast breeder.

The first fast breeder, EBR-1 (designed and built by a group headed by Walter H. Zinn, then director of the Argonne National Laboratory), is rated at 1,400 kilowatts of heat and about 200 kilowatts of electricity [*see illustration at bottom of page 85*]. Several years ago, during experiments designed to test its response to temporary overheating, the core of the EBR-1 melted. But the reactor has since been rebuilt and has operated routinely since 1957.

As its thermal rating suggests, the



CUTAWAY OF EBR-2 shows the interior of the 13-foot reactor vessel. Sodium coolant enters at the bottom of the reactor and is pumped upward through the core (*inner hexagonal area*) and the surrounding blanket. The drive shafts of the control rods can be seen protruding through the concrete-filled reactor vessel cover. The shielding on the sides of the reactor is canned borated graphite.

EBR-1 is much smaller than the Fermi reactor. Its core is about as large as a football and is fueled with stainless-steel-clad rods of almost pure uranium 235, about .3 inch in diameter. The blanket contains rods of uranium 238 about an inch in diameter, also clad with stainless steel. Because EBR-1 is fueled with uranium 235 instead of plutonium 239, it achieved a breeding ratio of only about one (instead of the theoretically possible 1.6). Nevertheless, the fact that the reactor operated reliably at reasonable temperature and power while achieving a significant breeding ratio was a major milestone in nuclear-energy development.

Encouraged by the success of EBR-1, several groups are now constructing much larger fast breeders. The Fermi reactor is being built by Atomic Power Development Associates, Inc., a consortium of public utilities and manufacturers, and the Argonne National Laboratory is currently completing the construction of EBR-2 [*see illustration on opposite page*]. Designed to yield 62,500 kilowatts of heat and 15,000 kilowatts of electricity, EBR-2 resembles the newly completed Dounreay reactor in Scotland, which is rated at 60,000 kilowatts of heat and 15,000 kilowatts of electricity [*see illustration on pages 88 and 89*]. Of the two breeders in the U.S.S.R., the smaller, rated at 100 kilowatts of heat, has been dismantled; the other, the BR-5, has a thermal rating of 5,000 kilowatts. All of these reactors are basically similar. They are sodium-cooled and are loaded initially with uranium 235 in the expectation that they will be fueled with plutonium when they have been thoroughly tested. The single exception is the 5,000-kilowatt Soviet reactor, which has begun operation using ceramic plutonium-oxide fuel.

So far there have been no completely satisfactory estimates of the cost of producing electrical power in these early experimental breeders. It is generally conceded, however, that the cost will be hopelessly high in comparison with that of conventional power. Much of the cost of nuclear power can be dismissed as being due to the inevitable expense of developing a new technology; we can expect these costs to fall as we gain more experience. Fast breeders are nonetheless beset by two technical problems which are inherent in their design and which must be solved before they can produce economical power. One is "high holdup": the fact that their low specific power ties up large quantities of fissionable and fertile material. The other is "low burnup," that is, their consumption of only a small percentage of the fissionable material contained in each loading.

Fast reactors must contend with low burnup so long as their fast-neutron economy requires the use of solid metallic fuel. Only about 15 per cent of the fissionable material in a solid-fuel reactor can be burned before the fuel rods become so swollen, warped and weakened by radiation and poisoned by fission products that they must be replaced and reprocessed [see "Reactor Fuel Elements," by James F. Schumar; SCIENTIFIC AMERICAN, February, 1959]. This means that each gram of fuel must go through seven cycles of reprocessing before it is at last consumed. At an initial cost of $15 per gram and a cost of $3 per gram for each reprocessing, the cost of burning one gram of uranium 235 comes to $35. The fast reactor thus runs up a fuel cost of about seven mills per kilowatt hour, perhaps two to three times the energy cost of conventional fuel.

Of course the cost of reprocessing can be charged against the value of the new plutonium fuel bred in the reactor, but this is not enough. Fast breeding will not be economical until fuel elements can be made to withstand much longer burnup, or the cost of reprocessing is reduced, or both. Work in both of these directions is proceeding at the Argonne National Laboratory. Fuel elements made of "fissium," an alloy of uranium and rare earths, seem to be less susceptible to radiation damage than uranium-molybdenum alloy. Greatly simplified fuel-recovering processes and new techniques for refabricating fuel elements, particularly the substitution of casting for machining, promise to reduce costs. Radiation-resistant plutonium-oxide ceramic fuel elements, similar to those in the Soviet BR-5 reactor, are also being tested.

The high holdup of fissionable and fertile material is a problem that stems even more directly from the essential nature of the fast-breeder cycle. In addition to the 485 kilograms of fissionable material in its core, the Fermi reactor will tie up some 40,000 kilograms of fertile material in its blanket. Such large inventories of material will represent an even heavier capital requirement when present high-grade uranium ores have been exhausted. In the Age of Granite envisioned by Harrison Brown, the cost of extracting fertile uranium 238 from rocks will force its price far above the present $5 per pound. With an inventory of half a ton of uranium 238 in the blanket for each 1,000 kilowatts of electrical output, the total capital cost of the blanket of the Fermi reactor is now $2.50 per kilowatt. The cost of extracting uranium in trace amounts from granite is likely to multiply this figure to a prohibitive value, perhaps to $500 per kilowatt of capacity. To the high fixed charge imposed by this capital burden must be added the high operating cost attributable to low burnup.

Undoubtedly future improvements in technology will reduce the inventory. But present circumstances offer a neat way around the difficulty that can reduce at least the start-up costs of nuclear breeding. The reactor can be stocked initially with cheap uranium from high-grade ores, and then be kept burning indefinitely with more costly uranium from low-grade sources to replace the minute amounts of material consumed in each burnup cycle. I can even foresee a situation in which the cheap uranium tied up as inventory in nonbreeding reactors will be transferred to breeders; this may occur when the cost of uranium goes so high that it is no longer economical to burn it in nonbreeders.

Thermal Breeders

The high specific power of the thermal breeders sets up a considerably more modest capital requirement for inventory of fuel and fertile material. Thermal breeders also circumvent the burnup problem by "homogenizing" the fuel and coolant, that is, by mixing them together in a fuel solution or by suspending finely divided fuel in a slurry. With the fuel in fluid rather than solid form, radiation damage no longer limits the burnup that can be achieved before the fuel must be reprocessed. The burnup limit is imposed by the much less stringent requirement of keeping the concentration of neutron-absorbing fission products down to an acceptable level.

Two high-power thermal reactors—the Homogeneous Reactor Experiments No. 1 and No. 2 (HRE-1 and HRE-2) have been built at Oak Ridge. The HRE-2 was originally intended to be a small-scale prototype of a thermal thorium breeder [*see illustration on page 86*]. The core is a pear-shaped zirconium-alloy tank 32 inches in diameter, through which a uranium-235 solution (uranyl sulfate in heavy water) is pumped at a pressure of 2,000 pounds per square inch. The shape of the tank allows a critical mass of fuel to accumulate, starting a nuclear chain-reaction. The heat generated by the reaction is carried away by the fluid fuel, which leaves the core at a maximum temperature of 300 degrees C. and delivers the heat to a 5,000-kilowatt heat exchanger. A small steam turbogenerator converts 300 kilowatts of the heat to electricity, and the rest is dumped into the atmosphere.

The core tank is surrounded by a heavy steel pressure-vessel. The vessel is four feet in diameter, leaving a space between it and the core. Through this space was eventually to be pumped a slurry of thorium oxide in heavy water, constituting a blanket in which uranium 233 was to be bred. Unfortunately local overheating during early power-runs melted a small hole in the core tank, allowing the uranyl sulfate fuel to mix with the blanket. For this reason HRE-2 has operated since April, 1958, as a one-region reactor with fuel in both core and blanket.

Because the radioactive fuel contaminates the entire circulating system, the HRE-2 reactor and all its cooling equipment, including the pumps and heat exchanger, are enclosed in a completely shielded steel box. During the past year and a half the reactor has been run at power levels up to 5,000 kilowatts for months at a time; during these runs it has never been necessary to enter the box for maintenance. Although this suggests that the circulating-fuel technology has been developed to the point where larger reactors are feasible, a number of engineering problems must be solved before it will be prudent to build a full-scale homogeneous thorium breeder. For example, the slurry must be well stirred throughout the system to keep it from settling out and forming cakes of fuel and fission products. Damage to the zirconium core tank by the corrosive fuel-solution is also something of a problem, although corrosion in the greater part of the system that is made of stainless steel is gratifyingly low. Still another problem is represented by the fact that the homogeneous fuel-and-coolant mixture tends to separate into two solutions under intense radiation: one rich in uranyl sulfate and the other rich in heavy water. The higher concentration of fuel in the uranium-rich solution accelerates the fission reaction, leading to local overheating and possible melting of reactor components.

None of these difficulties is unsolvable, however, and all are being vigorously attacked. The experience now being gained with HRE-2 should prove directly useful to the designers of liquid-fuel thermal breeders. Moreover, because HRE-2 is the first reactor in which the entire circulating system is contaminated with radioactivity, experience gained with it should be indirectly useful in the development of other reactors with contaminated cooling systems. Among these are the advanced gas-cooled, solid-fuel thermal breeders now being studied in Great Britain and the U. S.

The gas-cooled, solid-fuel thermal breeder is the product of an entirely different approach to the achievement of nuclear breeding. Up to this point we have been discussing what might be called the "egghead" approach. This involves starting from scratch and designing a completely new reactor patterned after the physicists' concept of how a breeder should look. The opposite, or "hardheaded," school argues that breeders should be developed by starting with existing, well-engineered nonbreeder designs (such as that of the gas-cooled British Calder Hall reactors) and improving the performance in increments, saving a tenth of a neutron here and there until the reactor has been converted into a breeder. As might be expected, the two strategies tend to overlap. All the breeders built so far, however, can be considered to be primarily egghead reactors. In the next 10 years we can expect to see a number of hardheaded reactors transformed into breeders or at least near-breeders.

Energy Economics

It seems obvious that in the long run the world will be able to use breeder energy only if it is cheaper, more abundant or more accessible than any other energy source. One of the most serious potential competitors is solar energy. But the diluteness and unpredictability of sunlight argue against it as a primary energy-source in large power stations, especially because such a station would involve a formidable capital investment. It is estimated that solar energy will require an initial investment of from \$1,000 to \$2,000 per kilowatt. To compete successfully, an alternative energy system should cost less than, say, \$1,500 per kilowatt. Here breeder reactors have a marked advantage, for their capital cost should be no more than \$750 per kilowatt even if their fertile material comes from low-grade sources such as

EBR-2, the successor to EBR-1, is now under construction at the National Reactor Testing Station in Idaho. The reactor is housed in the steel dome at left; adjoining it is a power plant that will use the reactor's heat to produce 15,000 kilowatts of electricity.

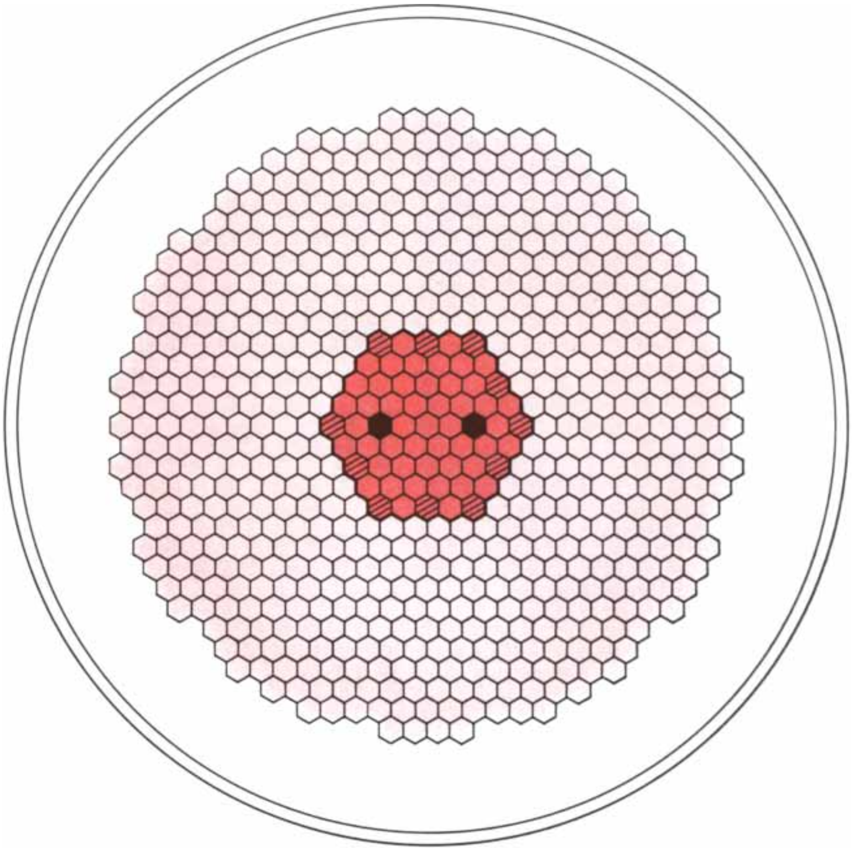
granite. This estimate drops to about $200 to $300 per kilowatt if the reactor is started with cheap uranium from high-grade ores and kept burning with the relatively expensive materials from low-grade sources.

Controlled fusion, if it is ever achieved, will also be a strong competitor. The raw material for fusion is relatively easy to recover from the sea, the present cost of deuterium being 30 cents per gram. Burned in a fusion reactor at 25 per cent thermal efficiency, this amount of deuterium would yield about 24,000 kilowatt-hours of electricity. The burnup charge works out to about .015 mill per kilowatt-hour. This is a negligible figure, and one that should always remain negligible, because the extraction of deuterium from the sea will not significantly reduce its concentration for eons to come. Assuming, as Harrison Brown does in his book *The Next Hundred Years*, that the world will finally settle down to an energy consumption of 40 billion kilowatts per year (20 times the present rate), the energy reservoir in either the rocks or the sea will last for more than 10 billion years.

The long-term raw-material costs for breeder power are almost as clearly defined as the costs for fusion power. Because the breeder operates with no net loss of fissionable fuel, the raw materials that are actually consumed are the abundant fertile isotopes, thorium 232 or uranium 238, rather than the much rarer and far more expensive uranium 235 by which the reactions are first ignited. According to Brown, a ton of granite could be processed for $1 to $2.25, and this would lead to a cost of 30 to 80 cents per gram for fertile material. Other estimates suggest that $1 per gram is more realistic. Even at this price, however, the burnup cost would be only .18 mill per kilowatt-hour. Although such a cost is not quite negligible, it is a small fraction of the total cost of generating a kilowatt-hour of electricity.

It is conceivable that the burnup cost could go still higher, because relatively little of the earth's crust is accessible to mining: we should not count the sea bottom, nor rocks more than three kilometers below the surface, nor those heavily overlaid with thorium- and uranium-poor sediments. Yet even a 10-fold increase in fuel cost (to $10 per gram) would still leave the burnup cost at 1.8 mills per kilowatt-hour, a figure comparable to the present energy-cost of coal.

The scale of the necessary mining (or quarrying) operation would also be comparable to our present coal-mining ef-



CORE AND BLANKET OF EBR-2 are typical of those in fast breeders. The core (*darker color*) consists of hexagonal fuel elements containing uranium 235; the surrounding blanket elements (*lighter color*) contain uranium 238. The small hatched hexagons represent the control rods that govern the rate of the nuclear reaction; black hexagons are safety rods.

forts. To support an energy economy 20 times larger than our present one, we would have to obtain 40 tons or so of fertile material a day. This would require mining about 10 million tons of rock, not much more than the world's daily coal and lignite production (in 1953) of approximately six million tons.

Perhaps the strongest argument for burning the sea instead of the rocks is that fusion is a "cleaner" process than fission. Admittedly the most troublesome aspect of rock-burning is the question of what to do with the huge quantities of radioactive wastes produced by fission reactors. The methods of waste disposal now being studied involve using the earth, whence the unburned fissionable materials came, as a grave for radioactive wastes. Salt domes, deep natural wells and artificially created cracks in the earth's crust have all been suggested as possible disposal sites, but it is premature to say that any of them will prove entirely satisfactory. Nevertheless it is encouraging to note that a committee recently established by the American Petroleum Institute to examine geologic methods of waste disposal has endorsed the feasibility of the proposed deep-well and salt-dome disposal schemes.

With fusion reactors the waste problem would be considerably less severe. But to compare fission and fusion reactors is a highly speculative pastime, for we have yet to show that we can develop a fusion reactor to burn any fraction of the deuterium in the sea. Burning uranium, on the other hand, is a rather routine process. It has become so routine, in fact, that the solution of mankind's long-term energy problem by breeding, instead of by thermonuclear fission, seems almost inelegant. We need only the solutions to certain tedious engineering difficulties rather than brilliant flashes of scientific insight. As academician N. N. Bolgolyubov, head of the Institute of Theoretical Physics at the Soviet Joint Nuclear Center, said to me recently, "breeding constitutes a trivial solution to man's ultimate energy problem." Perhaps it is because of the simplicity implied by the word "trivial" that those of us who are interested in breeding find it such an exciting technological development.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Radiation-Imitating Chemicals

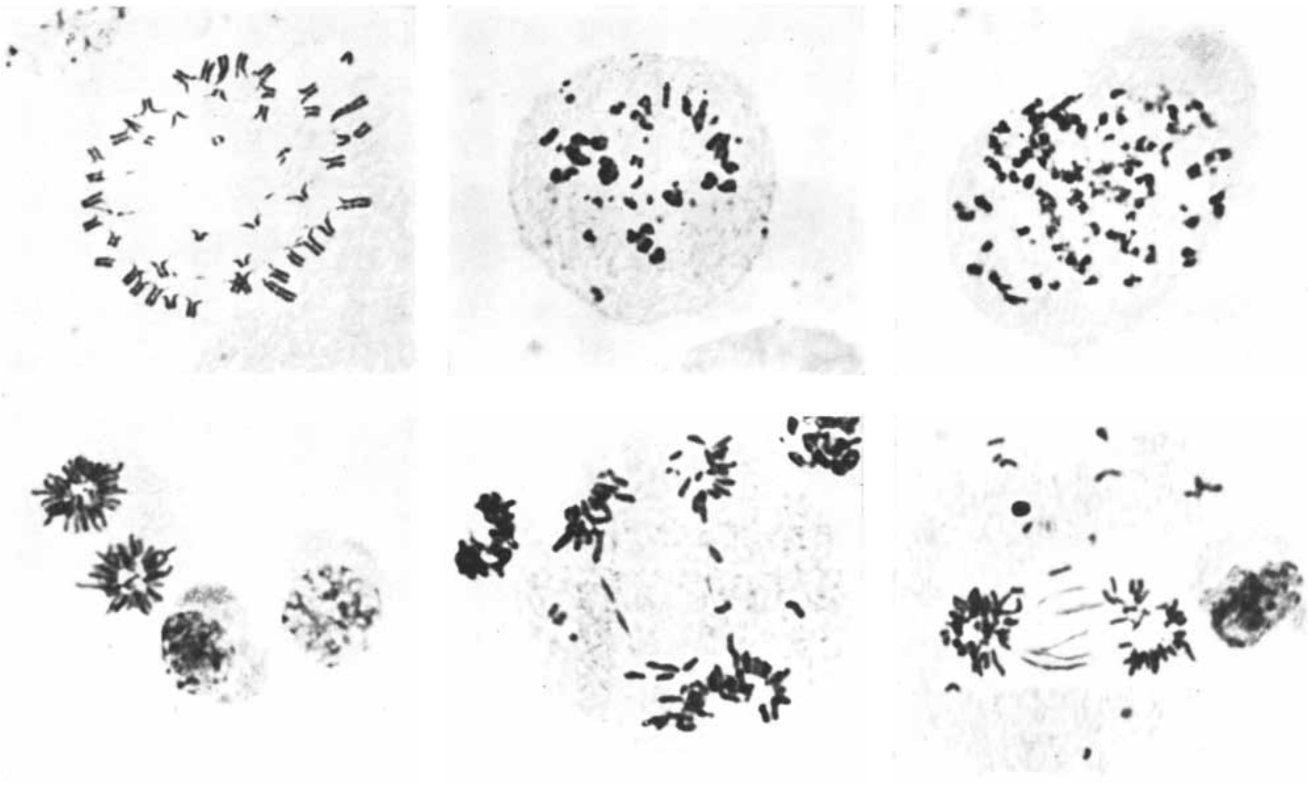
Nitrogen mustards and certain other compounds produce the same apparent biological effects as high-energy radiation. These chemicals have some use in cancer therapy and great value in basic research

by Peter Alexander

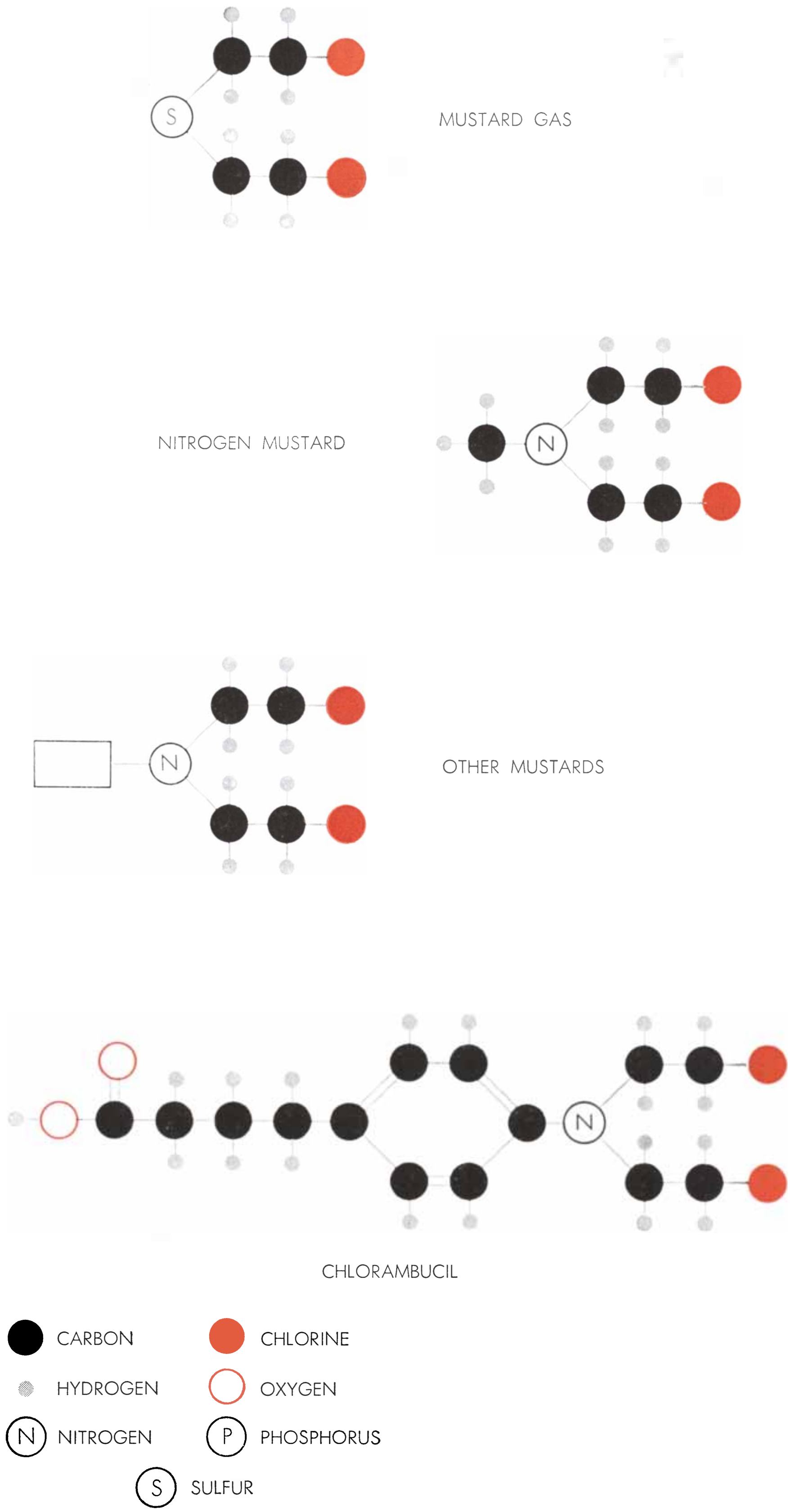
As a result of the development of atomic energy it is now widely appreciated that radiation causes profound changes in living matter. The changes have been studied for 50 years, but they are many and varied and still far from completely understood. Taken together they make up the well-defined group of radiation effects whose potential for good and ill has now become the subject of such wide concern. What is not generally realized is that these effects are not unique to radiation. There is a considerable number of chemicals that produce, so far as we can tell, the same biological results.

The knowledge that substances can be "radiomimetic" is largely a product of World War II research in poison gases. For a few years after the war these substances were expected to open the way to a cure for cancer. Today it is clear that they are no cure, but they are therapeutically useful in many types of malignant disease. More important, however, is their role in fundamental research, where studies of their mode of action are throwing new light on cell biology. Although the radiomimetic chemicals are themselves not the answer to cancer, they are helping to achieve the fundamental knowledge in which the answer lies.

What are the characteristic effects of radiation? On the cellular level they can be divided into four categories. First,



CHROMOSOME ABNORMALITIES are seen in cells treated with nitrogen mustard (*center and right*). At metaphase (*top*), when the chromosomes are about to separate, the treated ones show fragmentation. At anaphase (*bottom*) treated cells have bridges between chromosome halves. These photographs were made by P. C. Koller of the Chester Beatty Research Institute in London.



MUSTARD MOLECULES are diagrammed schematically. Common to all are two chains containing two carbon atoms and a chlorine. In mustard gas (*top*) the chains are attached to a sulfur atom. In original nitrogen mustard (*second from top*) sulfur is replaced by nitrogen. Other nitrogen mustards (*third from top*) are formed by attaching any of various chemical groups (*rectangle*) to nitrogen atom. One such mustard is chlorambucil (*bottom*).

radiation can cause genetic affects: gene mutations and permanent changes in the structure of chromosomes. Second, it interferes with some of the processes of cell division; this interference may lead eventually to the death of the affected cells, although they usually multiply a few times after the exposure. Third, it kills certain types of cell outright; radiation-sensitive cells include white blood cells, mammalian egg-cells and certain pigment-producing cells. Fourth, it induces cancer and leukemia, the disease usually appearing years after the exposure. An additional strange effect on the whole organism is a nonspecific shortening of life-span. Animals that have been exposed to radiation and have apparently recovered completely from the immediate damage live less long, on the average, than unexposed animals even if they do not develop malignant diseases.

Substances have been known for many years that produce some of the effects of radiation. In this article I shall deal with chemicals that are radiomimetic in the strictest sense, that is, chemicals that produce all the effects listed above.

The story begins with two separate lines of research, started under wartime secrecy, that converged only after security restrictions were lifted. Among the chemical-warfare agents being studied in a number of laboratories was mustard gas, a substance that produces blisters on human skin (but curiously not on the skin of most other animals). It was discovered that a relatively minor change in the mustard-gas molecule—the substitution of a nitrogen atom for a sulfur—greatly enhanced the effectiveness of the gas. The new agent was called nitrogen mustard [*see illustration at left*]. Subsequently a number of different compounds, the molecules of which incorporated the chloroethylamine group ($-NHCH_3CH_2Cl$), were found to have the same activity, and these compounds are now called nitrogen mustards also. While investigating their pharmacology, Alfred Gilman at the Yale University Medical School was impressed by the fact that they destroyed lymphoid tissue and organs containing rapidly dividing cells. This suggested that the nitrogen mustards might be useful for controlling cancer and leukemia. A group at Yale pursued the idea from 1943 onward, though they could not publish their results until after the war ended.

Meanwhile in Britain, Alexander Haddow and his colleagues at the Chester

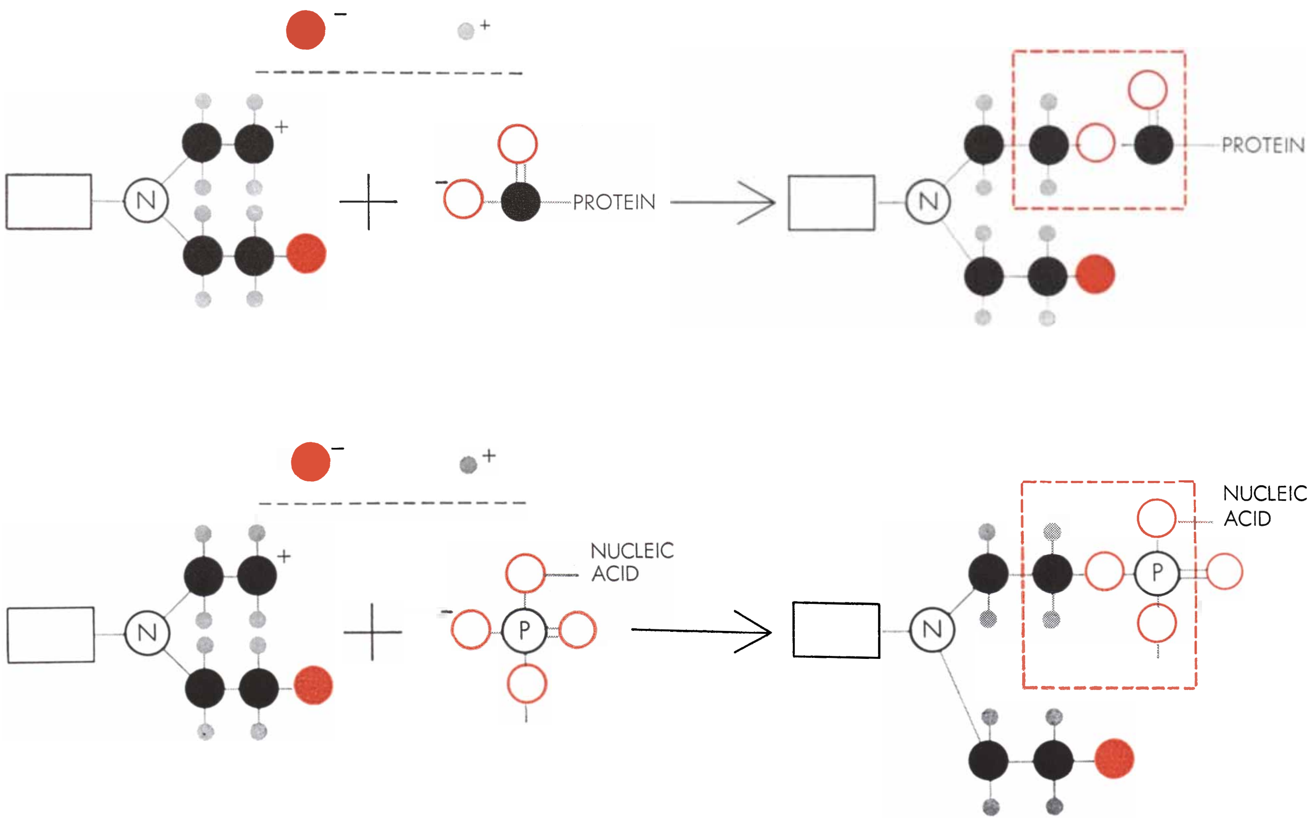
Beatty Research Institute of the Royal Cancer Hospital in London had been experimenting with entirely different chemicals for the control of cancer. Learning of the U. S. work, they attempted to combine the active groups in one of their substances with the active group of the nitrogen mustards. The biological activity of these new compounds turned out to be dominated by the nitrogen-mustard groups. Therefore they undertook an intensive program to prepare new derivatives that might show improved biological properties. Clinically their efforts have had a limited success. Many different compounds are now used in treatment, but the advantages over the parent compound are relatively small. Scientifically, however, the research by Haddow's group was extremely valuable, because it revealed the two key properties of the nitrogen mustards that account for their growth-inhibiting activity.

First, the reactivity of the chlorine atom proved all-important. When nitrogen mustard is dissolved in body fluids, the chlorine atom splits off, leaving a reactive intermediate that readily combines with many of the molecules of the cells [*see illustration below*]. The result is the attachment to these molecules of a straight-chain group, a reaction known as alkylation. On the theory that alkylation was responsible for the capacity to kill cells, Haddow's group tested other compounds, chemically quite different from the nitrogen mustards but capable of the same type of reaction. These substances included epoxides, ethylene imines and methane sulfonates [*see illustration on next page*]. All were growth inhibitors. Having no other feature in common, their activity seems inescapably to be due to their alkylating ability under physiological conditions.

As so often happens in science, these discoveries were subsequently found to have been partially anticipated many years earlier. In 1898 Paul Ehrlich, the father of chemotherapy, had recognized the unusual pharmacological properties of ethylene imine and of the simplest of the epoxides: ethylene oxide. He noted that they differed from all the hundreds of other substances he had studied in causing intense cell destruction in tissues containing rapidly dividing cells. However, his report came to the general attention of scientific workers only in 1956, with the publication of his collected papers. Had it not been overlooked in the wealth of Ehrlich's researches, we should not have had to wait for a world war to focus attention on the potentialities of alkylating agents.

The second critical property of the growth-inhibiting chemicals to emerge from the studies of Haddow and his colleagues was the presence of two alkylating centers in each molecule. The original mustards—nitrogen or sulfur—have two such groups. Of all the other derivatives tested, only those with two reactive chlorine atoms proved effective in arresting the development of tumors in experimental animals. (Single-group, or "one-armed," compounds do inhibit growth in experiments on single cells, but only in concentrations too high to be tolerated by an animal.) The same condition applied, in general, to the other biological alkylating agents; for example, a compound having two epoxy groups is very much more effective than a mono-epoxide.

We shall presently consider the significance of these findings, but first let us turn to a second radiation-like feature of the alkylating agents: their genetic effects. In 1928 H. J. Muller showed that X-rays produce mutations in genes, the hypothetical units of heredity that are strung out along the chromo-



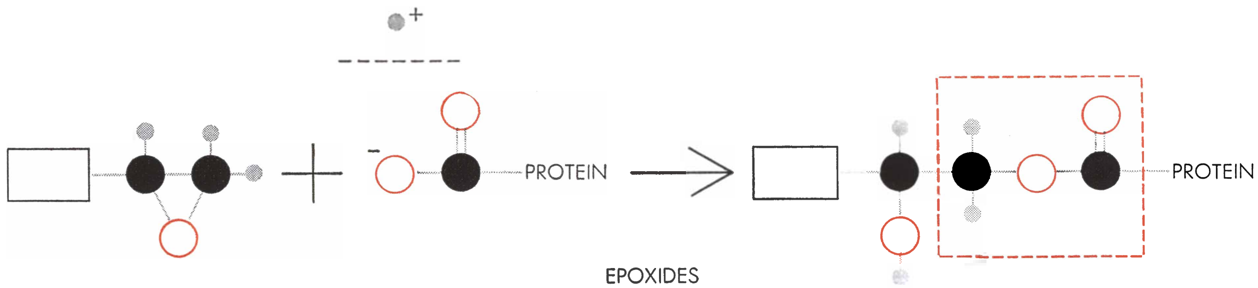
ALKYLATION REACTIONS involve attachment of active group on mustard molecule to a receptor such as an acid group on a protein (*top*) or a phosphate group on a nucleic acid (*bottom*). Broken rectangles enclose region where reaction has taken place.

somes and passed down from generation to generation. Subsequently it was found that all types of high-energy radiation cause mutations in all forms of life that have been tested. These radiations can also damage the structure of chromosomes, the changes becoming apparent when cells divide. For many years geneticists looked for chemicals that would have the same actions, but none was found. Radiation seemed to be unique in these respects.

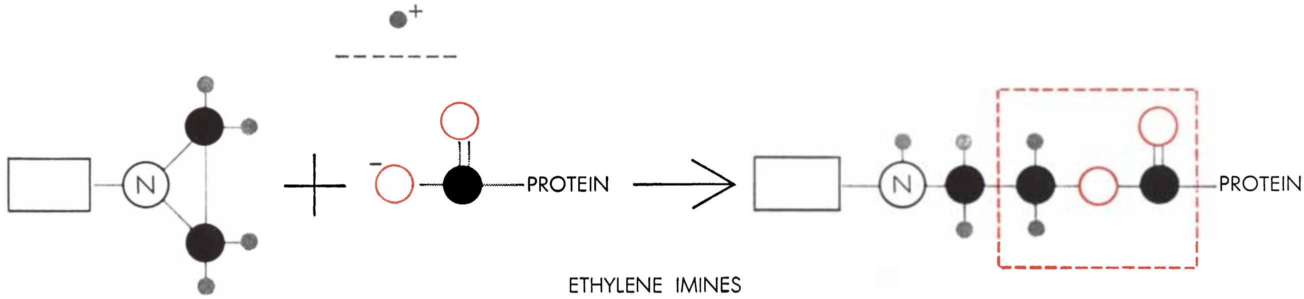
Then during the war P. C. Koller, working at the University of Edinburgh, observed that mustard gas produces permanent chromosome abnormalities that are indistinguishable from those induced by X-rays. Charlotte Auerbach and William Robson, also at the University of Edinburgh, had set out to test whether this compound would also cause mutations in the fruit fly. It did; they had found the first chemical mutagen. Quite independently of the British work, the publication of which was again delayed by security requirements, I. A. Rapoport, a geneticist in the U.S.S.R., also discovered the mutagenic action of an alkylating agent: diethyl sulfate. He published his results in 1947, though his studies had not been stimulated by military research.

It soon developed that the ability to cause mutation and chromosome damage, like the ability to inhibit tumors, is shared by all the biological alkylating agents. Mutagenic action, however, requires only one alkylating center per molecule and is not, in general, greatly enhanced by the presence of a second reactive group. On the other hand, compounds with two centers are much more active than one-armed substances in producing abnormalities in chromosomes.

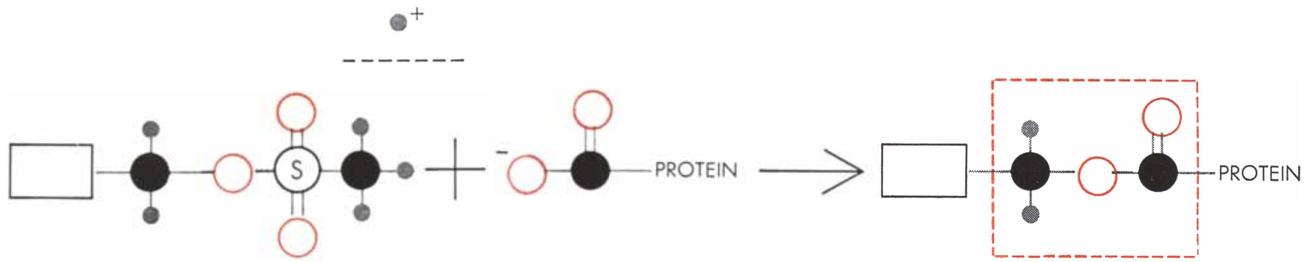
Like X-rays, the alkylating agents cause mutations in the genetic systems of organisms ranging from bacterial viruses to mammals. Many other types of



EPOXIDES



ETHYLENE IMINES



ESTERS OF METHANE SULFONIC ACID

OTHER ALKYLATING AGENTS are diagrammed schematically at left. Although they are chemically unlike the mustard molecule, they react with cell molecules such as proteins in the same way. All these substances produce the detectable effects of radiation.

chemical substance have since been found that cause mutations and chromosome damage in certain cells, but none of these seems to be so universal in its action. Apparently genetic changes can be induced by a variety of different mechanisms, some of which work rather indirectly, possibly by altering metabolism. The fact that the alkylating agents affect the genetic system wherever it is found indicates that they directly attack the fundamental genetic material, common to all forms of life. It is this that makes them true radiomimetics.

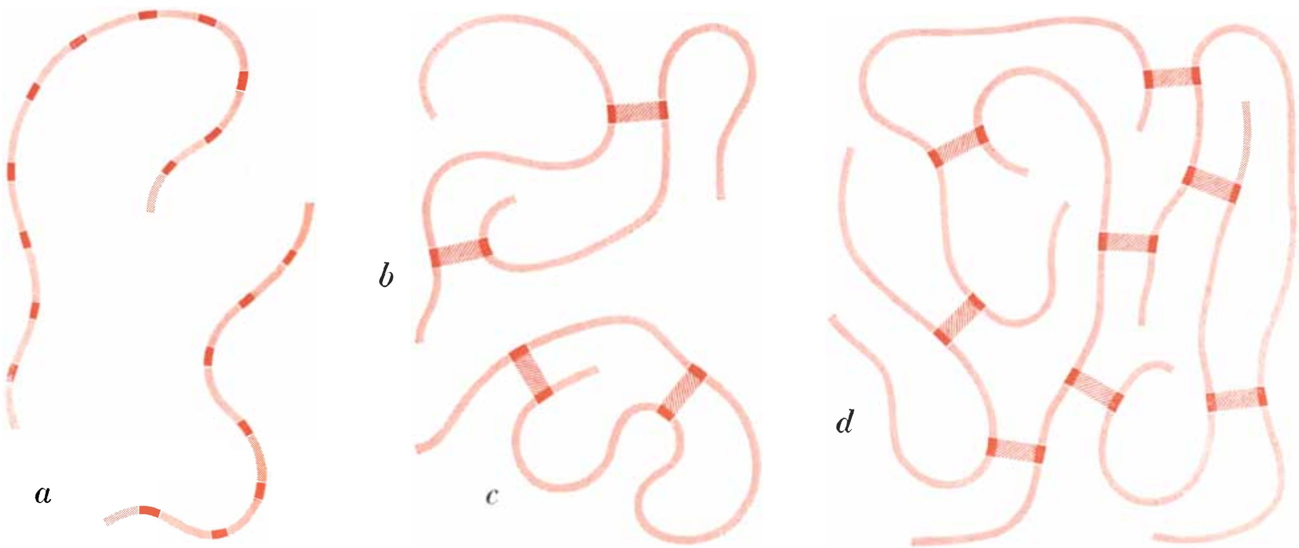
One of the many unsolved problems in cancer research is the connection between these genetic effects and the ability of alkylating agents to kill cells, which is the basis of the agents' therapeutic use. Undoubtedly chromosome abnormalities can be fatal to isolated cells, although the effect is delayed for some generations. The cells usually pass through a few divisions after sustaining this damage. Eventually unequal sharing of genetic material between daughter cells, or mechanical interference with the division process, will bring reproduction to a halt. This type of destruction may be called mitotic death, since it is bound up with the process of cell division, or mitosis.

The role that mitotic death plays in the whole animal is not certain. It may contribute to damage in organs containing rapidly dividing cells, such as the bone marrow, which turns out a continuous supply of blood cells. But what is called interphase death is more important in the treatment of many types of tumor. Here the cells die some hours after exposure without an intervening division (*i.e.*, during interphase), so that there seems to be no role for chromosome damage. Some cells are very resistant to direct killing, by radiation or chemicals, while others, notably the mammalian egg, the mature sperm and the white blood cells known as lymphocytes, are extremely sensitive. In any case the influence, if any, of genetic effects in this type of cell destruction is obscure.

Let us turn now to the question of how the radiomimetic chemicals produce their effects. Knowing the chemical reaction responsible for their biological activity, one might expect that the rest of the problem would be relatively easy to solve. Unfortunately alkylating agents react with nearly all the important components of cells. Every protein has many points to which they can attach. So do nucleic acids; so do nearly all the different vitamins. Thus when alkylating agents enter a cell, they are dissipated in a large number of different reactions. Many of these reactions, if they involved a significant proportion of the available molecules, would no doubt lead to the death of the cell. But the concentrations necessary to produce radiation-like effects are so low that most of the possible receptor molecules must be left untouched. The problem, then, is not to find the kinds of molecule that are alkylated, but to eliminate the trivial reactions and to determine those vital sites where a few alkylations can cause deep-seated and permanent damage.

The chief chemical groups with which alkylating agents react in living material are the sulfhydryl group (SH), the amino group (NH_2) and the acid group (COOH). Many other substances also combine with sulfhydryl and amino groups, but none exhibits true radiomimetic properties. Hence the process of elimination points to acid groups as the important sites. Every chemical that can alkylate an acid group under conditions existing in living cells has proved to be radiomimetic. The reasoning is by no means conclusive, and if we accept it we are still left with a bewildering number of possibilities. Every protein and every nucleic acid contains many eligible acid groups. Furthermore, the different biological end-effects are not necessarily initiated by the same primary chemical reaction.

Our next guidepost is the fact that compounds having two or more alkylating groups per molecule are very much more effective than one-armed compounds in inhibiting growth and damaging chromosomes. This suggests that such injuries may be produced when the chemical agent reacts with two of the cell molecules, joining them together. Specifically, if the two threads of a chromosome were cross-linked before a cell divided, the two could not separate properly during division and abnormalities would result. Although there is little evidence for cross-linking of chromosome threads, the general notion of cross-linking has proved most fruitful. This reaction is quite plausible. Cross-linking will almost surely put a giant



CROSS-LINKING OF DNA molecules (*colored strands*) occurs when an alkylating agent with two active groups per molecule attaches to receptors on DNA chains (*dark segments*). Linking may be between different molecules (*b*) or between parts of the same molecule (*c*). When enough different molecules are joined together (*d*), this portion of the DNA is not soluble but gel-like.

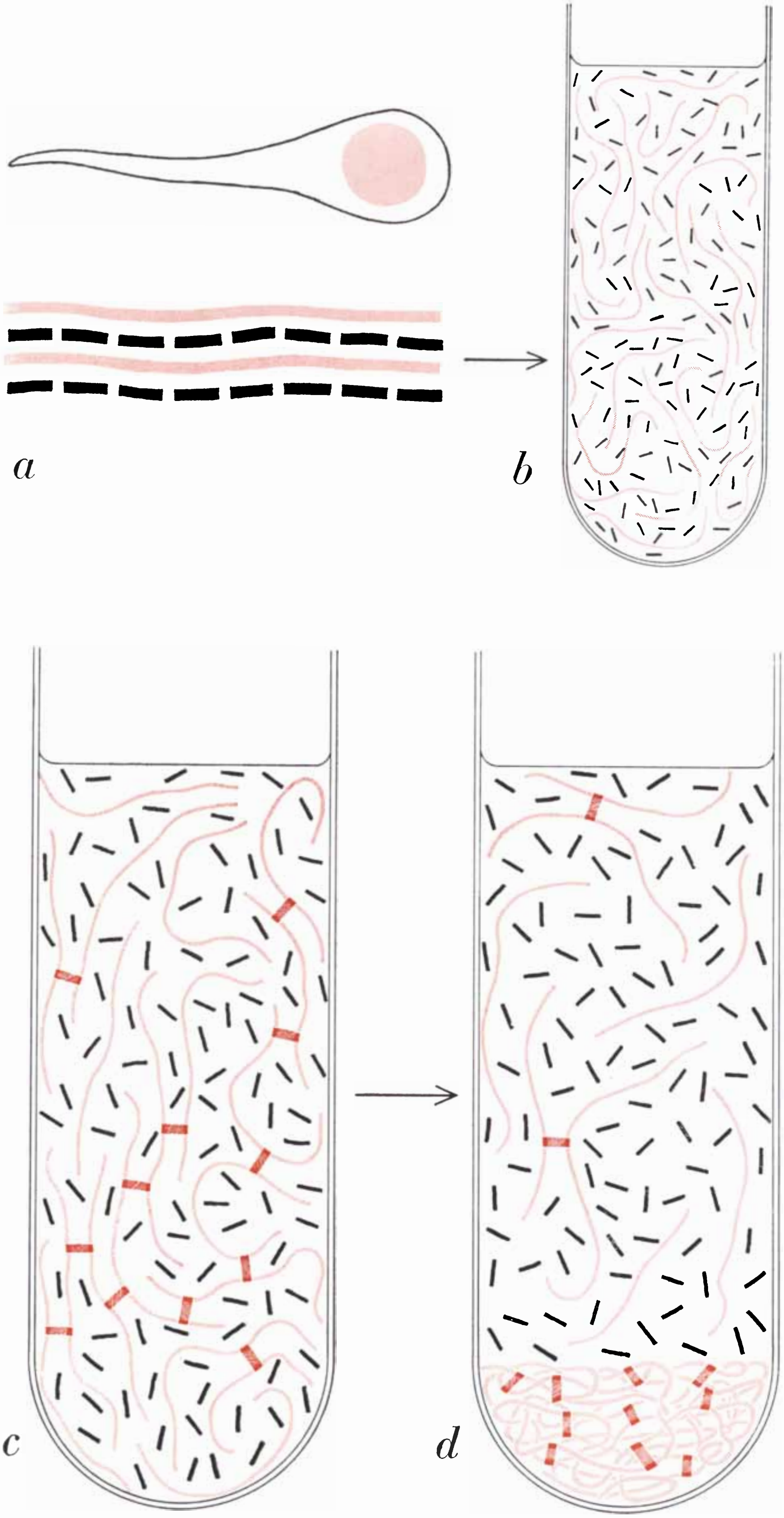
molecule out of action, no matter where the linking takes place. The simple attachment of a small side-group will have no effect if it takes place at a biologically unimportant site. For example, many enzymes, which are proteins, can be extensively alkylated without losing their activity.

Assume, then, that radiomimetic chemicals cross-link the giant molecules of cells by attaching themselves to groups that can be alkylated. The question remains: What molecules are involved? We know that the chemicals do cross-link proteins. However, the universality of their genetic effects suggests that, in this case, they act directly on the genetic material: deoxyribonucleic acid (DNA). Another reason for choosing DNA is that many substances cross-link proteins under physiological conditions, but do not show radiomimetic properties. These biologically inactive cross-linking agents do not combine readily with isolated DNA, while the biological alkylating agents do. Moreover, the ability of the alkylating chemicals to cross-link DNA has been demonstrated directly [*see illustration at right*].

Does cross-linking explain both types of cell-killing? It is certainly not hard to see how it applies to mitotic death. Joining DNA molecules together in an unnatural configuration must lead to trouble during cell division, when the DNA has to be shared between the daughter cells. Once the genetic material has been altered, the change will be perpetuated and eventually give rise to nonviable cells.

As to interphase cell-death, the picture is less clear. The cells most sensitive to death without intervening division are the lymphocytes, which have a large nucleus and very little of the surrounding cytoplasm. There are indications that damage to the nucleus kills them, but we do not know whether cross-linking of DNA has anything to do with it.

In the case of mutation it is obvious that the cross-linking mechanism is not involved, because one-armed molecules are just as effective as those with double groups. As readers of this magazine are well aware, current genetic theory holds that hereditary information is stored in the DNA molecules in the form of a code. DNA is composed of four (sometimes five) basic units called nucleotides, and the order in which they are strung together determines the information in the molecule. In reproduction the dividing cell makes identical copies of its DNA which it transmits to its



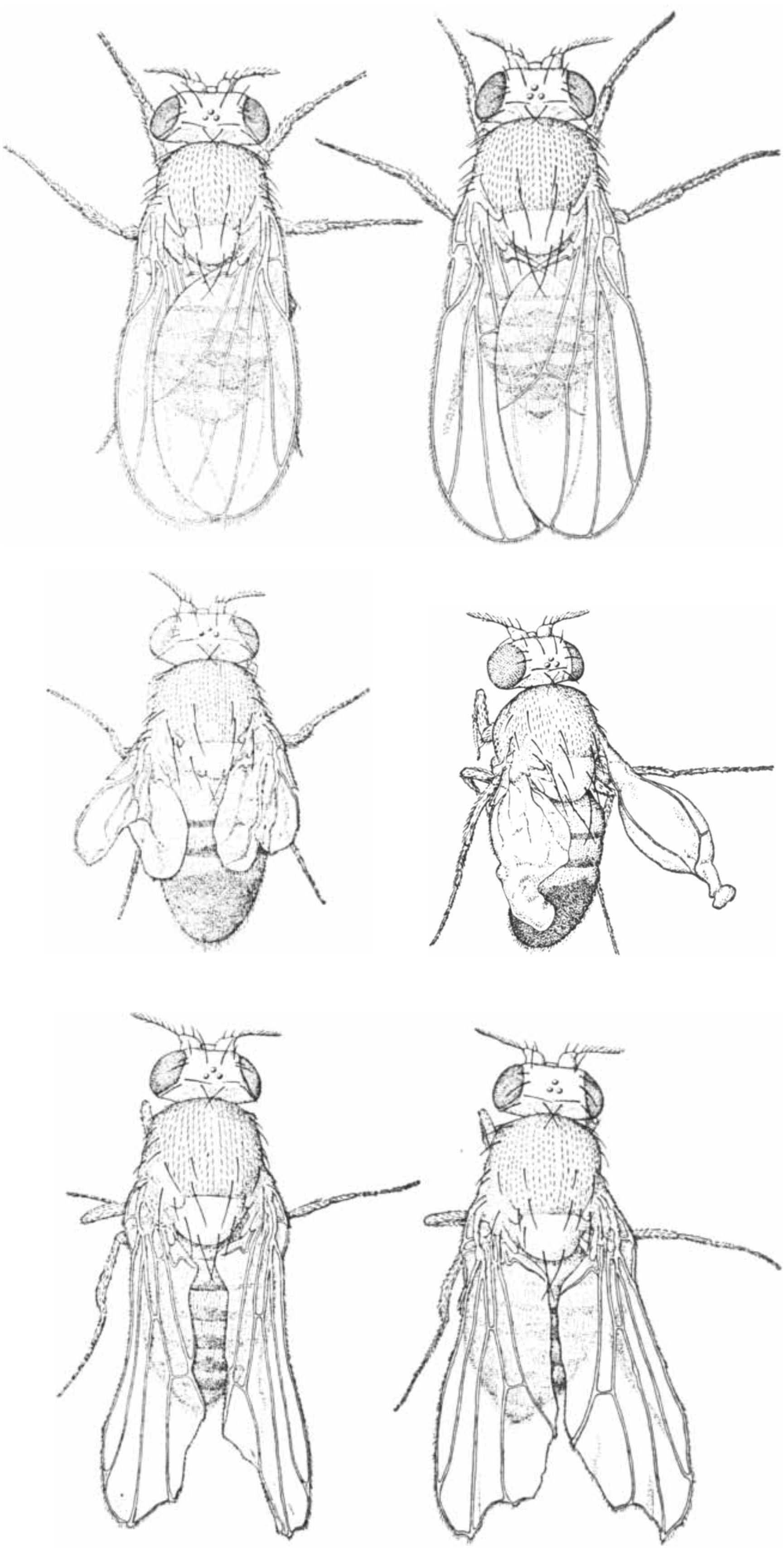
SALMON-SPERM DNA is cross-linked by alkylating agents in experiment diagrammed here. Intact nucleus contains an aggregate (*a*) of DNA (*colored strands*) and protein (*black segments*). When nuclei are dissolved in strong salt solution (*b*), the DNA and protein separate. If cells have been treated, part of the DNA is cross-linked (*c*). Upon centrifugation (*d*) the part of the DNA that is most heavily cross-linked separates in form of a gel.

descendants. Occasionally there is an error in copying, the sequence of a few nucleotides is changed, and a spontaneous mutation has occurred.

How can the alkylating agents increase the number of mutations? Since they do this in the genetic system of organisms ranging from the bacterial virus to the mouse, it is most probable that they work by direct reaction with DNA. Apparently they interfere in some way with the replication process, increasing the chance of copying-errors. It seems likely that the alkylation of one of the many reactive groups in the DNA molecule would have such an effect. The alkylated DNA is not itself the "mutant," since it is a structure that cannot be copied by the normal metabolic processes. We suggest that alkylation of an isolated group slightly complicates the synthetic process, thereby increasing the likelihood of a copying-error.

The final radiation-like property of the alkylating agents is their capacity to cause malignant growths years after the organism is exposed to them. All the different classes of chemicals we have mentioned have been found to be carcinogenic in animals. Whether their cell-killing or their mutagenic properties or both are responsible is not clear. According to one school, the cancer results from a mutation that robs a cell and its descendants of the ability to respond to the restraining influence of the host in which they grow. If so, we should expect a close correlation between the mutagenic and cancer-producing properties of a compound. An alternative view is that the carcinogenic agent damages tissue, making it possible for the occasional cancer cell that arises by chance mutation in this tissue to establish itself and develop into a malignant growth. On the latter theory the important reaction is not with the parent cancer cell but with the neighboring cells. The two ideas are not mutually exclusive. Some cancers are almost surely produced by the indirect mechanism and others seem to result from mutation, though this has never been unambiguously proved. Since radiation causes both tissue damage and mutations, it does not provide a means of deciding between the two possibilities. As we have seen, some of the alkylating agents produce mutations, but do not, in general, damage tissues by killing cells. Thus we have high hopes that research with these chemicals may furnish valuable information about the nature of the cancer-inducing process.

The remarkable similarity between



WING MUTATIONS in fruit flies are produced by injecting alkylating agents into the testes. At top are the normal male (*left*) and female (*right*). The drawings of male (*center*) and female (*bottom*) progeny of treated fruit flies illustrate four of the wing mutations produced. This study was done by O. Fahmy of the Chester Beatty Research Institute.

the detectable effects of radiation and of alkylating agents naturally raises the question of whether the ends are reached by the same biochemical route. We know that several stages intervene between the primary action of radiation—damage to an important center in a molecule of the cell—and the appearance of biochemical disturbances [see "Radiation and the Cell," by Alexander Hollaender and George E. Stapleton; SCIENTIFIC AMERICAN, September, 1959]. Metabolism develops the injury just as a developer brings out an image on a photographic plate. Is the initial reaction of the alkylating agent comparable to the primary chemical lesion of radiation? It is tempting to think so, and to suppose that the biological pathway from then on is the same. But the evidence is not clear.

Radiation can, under certain conditions, cross-link the DNA in the nucleus of the cell. Unfortunately, however, there are many reasons for believing that this reaction is not the starting point for radiation injury of cells (though it may well be responsible for the inactivation of viruses by atomic radiations). Thus the train of events set in motion by alkylating agents and by radiation may meet only at the stage of the detectable biochemical disturbances. It seems unlikely, however, that there is no common pathway at all, and that the many identical end-effects are reached in quite different ways.

Ten years of intensive research on alkylating agents has failed to produce a cure for cancer. Thousands of compounds have been synthesized and tested, but none shows any fundamental advantage over the original nitrogen mustards. Some of the newer substances do have fewer toxic side-effects, making them more useful in therapy. All share the basic defect that they do not specifically seek out the malignant cell, but attack all rapidly dividing cells. For example, they destroy the normal cells in bone marrow as readily as the cells that give rise to leukemia. A dose large enough to kill all the leukemic cells would therefore be fatal to the patient. So the chemicals produce remissions, but not cures. Because their action is not localized they cannot be used to eradicate a local tumor, as radiation often can.

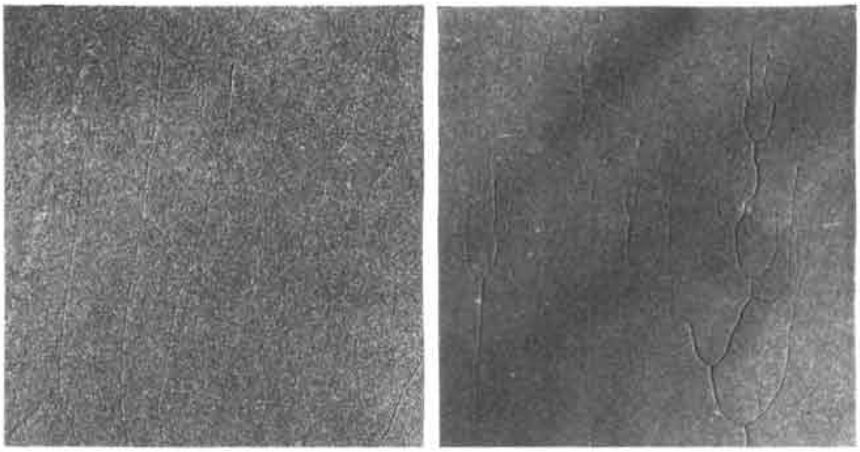
Probably the greatest benefit that has been, and will be, derived from the radiomimetic substances is the increase in basic knowledge. Interfering as they do with the most fundamental cellular processes, they offer one of the best

INHIBITION OF TUMOR GROWTH was produced by injecting an alkylating agent. Pictures show 14 days' tumor growth in a treated animal (*top*) and an untreated one (*bottom*). Photographs were furnished by Alexander Haddow of the University of London.

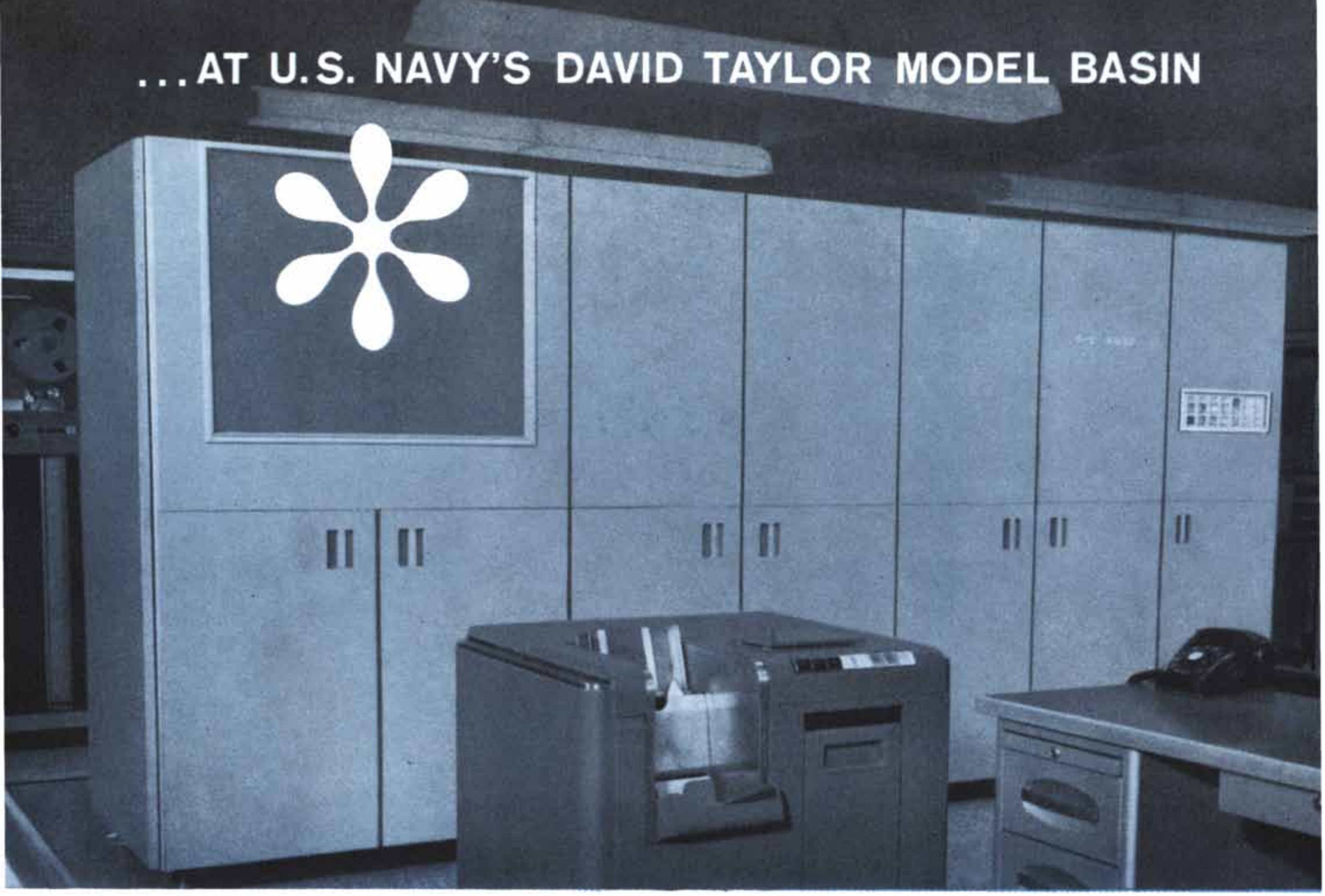
ways of learning more about these processes.

Finally it seems worthwhile to consider these agents from another point of view. The dangers of atomic radiations continue to be a matter of lively public concern, and rightly so. What about the chemicals that so faithfully imitate radiation? They may well represent a greater danger. We add chemicals to food, spread them widely in pest control, inject them into the air we breathe. In setting standards of safety it is usual to consider only the quantities necessary to cause acute toxic effects. If the level of exposure is well below these limits, it is considered safe. We test not at all for genetic effects, and for cancer risk only in the case of food additives.

The facts reviewed in this article ought to put us on our guard. We are trying very hard to assess the subtle and long-term risks of radiation. Should we not pay equal attention to the chemicals, new and not so new, that we encounter in our everyday lives? The effort might pay a great dividend.



DNA MOLECULES show visible alterations when treated with nitrogen mustard. Normal molecules (*left*) are long and flexible. They are stretched straight by surface tension in being prepared for the electron microscope. Treated molecules (*right*) have a different form. They are not similarly straightened but remain more coiled. These electron micrographs were made by M. S. C. Birbeck and K. A. Stacey of the Chester Beatty Institute.



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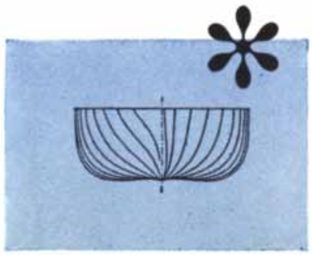

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THE GREEN FLASH

When the sun's disk is disappearing at sunset, or appearing at sunrise, its top sometimes momentarily turns a brilliant green. The flash results from dispersion of sunlight in air

by D. J. K. O'Connell, S. J.

Some clear evening as the sun is sinking below the horizon you may, if you are fortunate, witness one of nature's most unusual and beautiful displays. Just as the last of the solar disk is about to disappear, it may momentarily turn a brilliant green.

The green flash, as the phenomenon is called, is not easy to see from most places. People who have heard of it but looked for it in vain tend to dismiss it as a fantasy. Many who have seen it, including astronomers and physicists, have considered it an optical illusion. But, as color photographs such as the one on the cover of this issue of SCIENTIFIC AMERICAN demonstrate, the green flash is in fact purely objective and perfectly real. We shall see that it has a straightforward physical explanation.

Appropriately enough, widespread interest in the strange effect began not with scientific observation but with a work of science fiction. *Le Rayon vert,* a novel by Jules Verne published in 1882, describes a long search for the mysterious green ray of the title. (The word "ray" is used in both French and German to describe the effect, but "flash" is a better description.) It would be interesting to know what drew Verne's attention to the matter, because one can find hardly any mention of it before that time.

Since then many observers have seen the green flash and speculated about its cause. Most commonly they have described a thin green band, visible for a fraction of a second at or just above the top edge of the sun as it sinks out of sight. But the flash can take other forms. Sometimes it is blue, or turns from green to blue; sometimes it is even violet. On rare occasions it appears while the whole disk of the sun is still above the horizon, and then there may be a red flash at the bottom of the disk as well as a green or blue one at the top. The flash is about as common at sunrise as at sunset. Here too it may be blue or violet as well as green. If it changes color, it does so in the reverse order, passing from blue to green.

Normally the flash is extremely narrow. From top to bottom it covers only about 10 seconds of arc, which gives it the same apparent width as a one-inch ribbon at a distance of 570 yards.

To see the flash with the naked eye requires a sharp horizon and a sky free from haze—conditions most likely to be found in deserts or on mountains, or over water. The clear desert air of Egypt affords an exceptionally favorable setting, and the flash appears very frequently there. In fact, there is evidence that the ancient Egyptians were familiar with it. A stone pillar dating from about 2500 B.C. shows the rising (or setting) sun as a semicircle colored blue above and green below. Furthermore the people of the time seem to have believed that the sun is green during its nocturnal passage beneath the earth, an idea they might have got from seeing the green flash at sunset and sunrise.

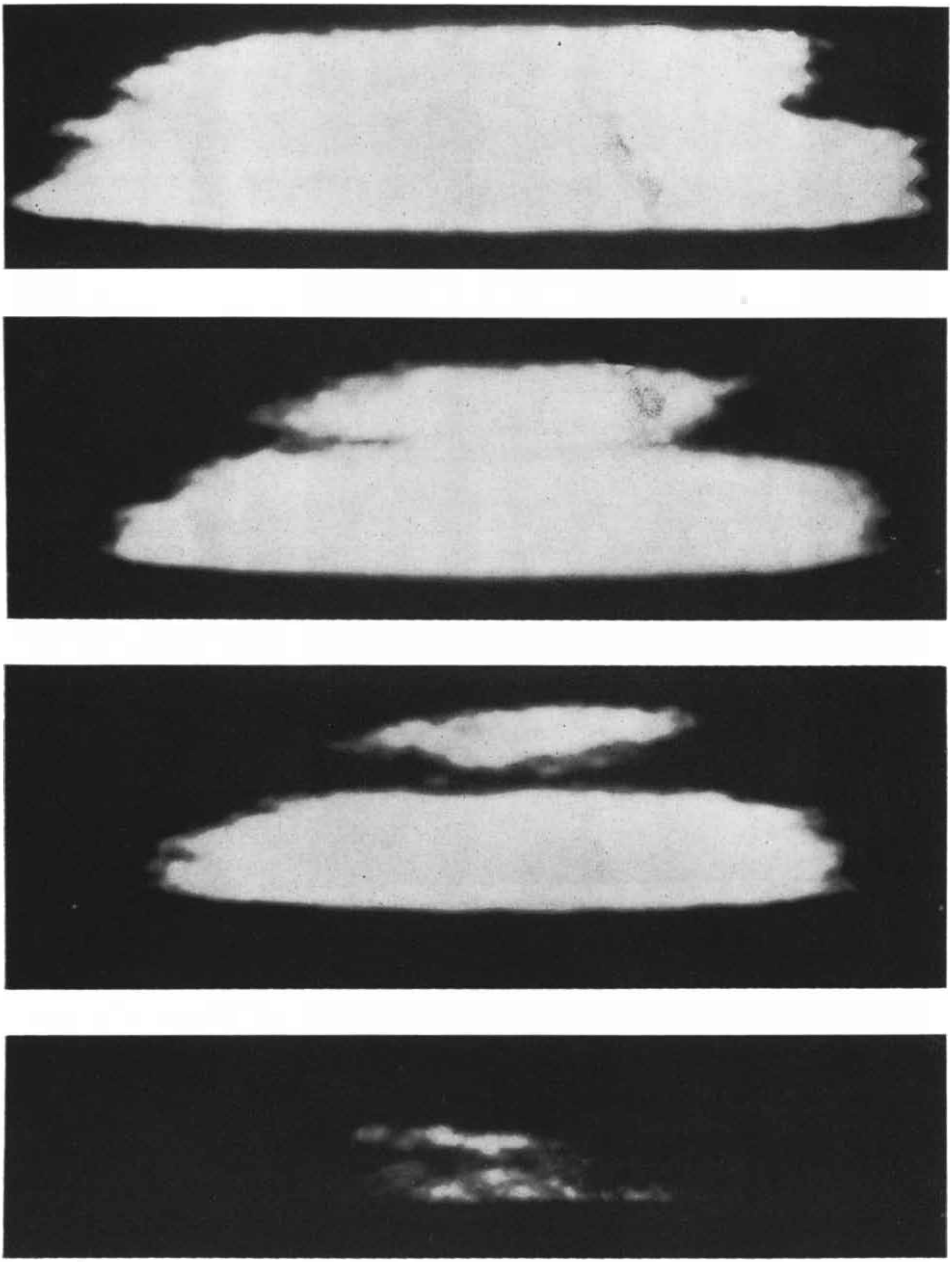
Some modern attempts to account for the phenomenon are scarcely less naive. According to one theory the horizontal rays of the sun become green by passing through water waves. The fact that the flash can be seen over land disposes of that fancy. A medical man has suggested that biliousness of the observer is responsible!

A more plausible physiological explanation, which has had and still has many supporters, attributes the effect to retinal fatigue. It is a well-known fact that, after looking into a bright-colored light, our eyes become fatigued. Upon looking away we now see the complementary color. So, the theory says, in looking at the red sunset our eyes are dazzled and we see, immediately afterward, the complement of red, which is green. In other words, the green flash is all in the eye, and is purely subjective.

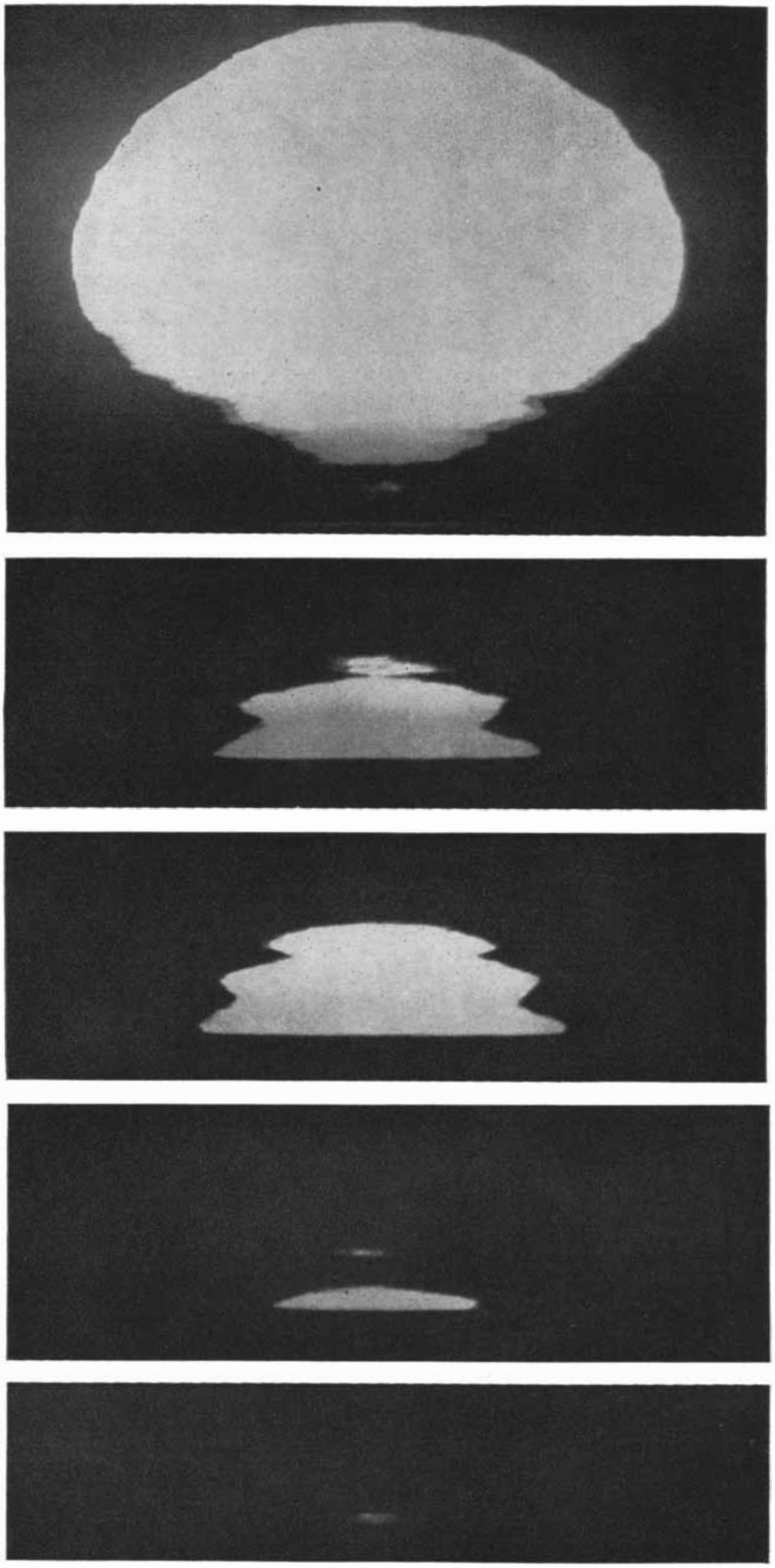
Although a number of distinguished workers have espoused this theory, it is patently wrong. The flash can also be seen at sunrise, *before* the sun's disk appears in the sky.

As long ago as 1899, in a letter to *Nature,* Lord Kelvin described a sunrise blue flash. He had seen the green flash at sunset some six years previously and wanted to see what happened at sunrise. A trip to the Alps, he wrote, "promised me an opportunity for which I had been waiting five or six years, to see the earliest instantaneous light through very clear air, and find whether it was perceptibly blue. I therefore resolved to watch an hour till sunrise, and was amply rewarded by all the splendours I saw. . . . In an instant I saw a blue light against the sky on the southern profile of Mont Blanc; which, in less than the one twentieth of a second became dazzlingly white."

One might think that this statement, from one of the greatest physicists of the time, published in a widely read journal, would have disposed of the subjective theory once and for all. But it still keeps cropping up. Paradoxically the advent of color photography has given it a new lease of life. Attempts to photograph the flash on color film with an ordinary camera are always futile, even when it is quite apparent to the eye. This has led unsuccessful photographers to conclude that the color they saw was merely subjective. The real trouble is simply that the focal length of their camera lens is too short to form a visible image of the



DEVELOPMENT OF A GREEN FLASH is seen in these black-and-white reproductions of color photographs. At top the sun has almost set, and the upper rim of the segment is green. In the next two pictures a green flash is splitting off from the solar disk. At bottom sun has disappeared and a green flash remains suspended above horizon. Time between top and bottom views was 8.4 seconds.



DISTORTION in the sun's disk is caused by discontinuities in the atmosphere. In top photograph the color print shows a green rim at the top of the disk and a red rim at the bottom, together with a red flash below. At bottom the green flash remains after sun has set.

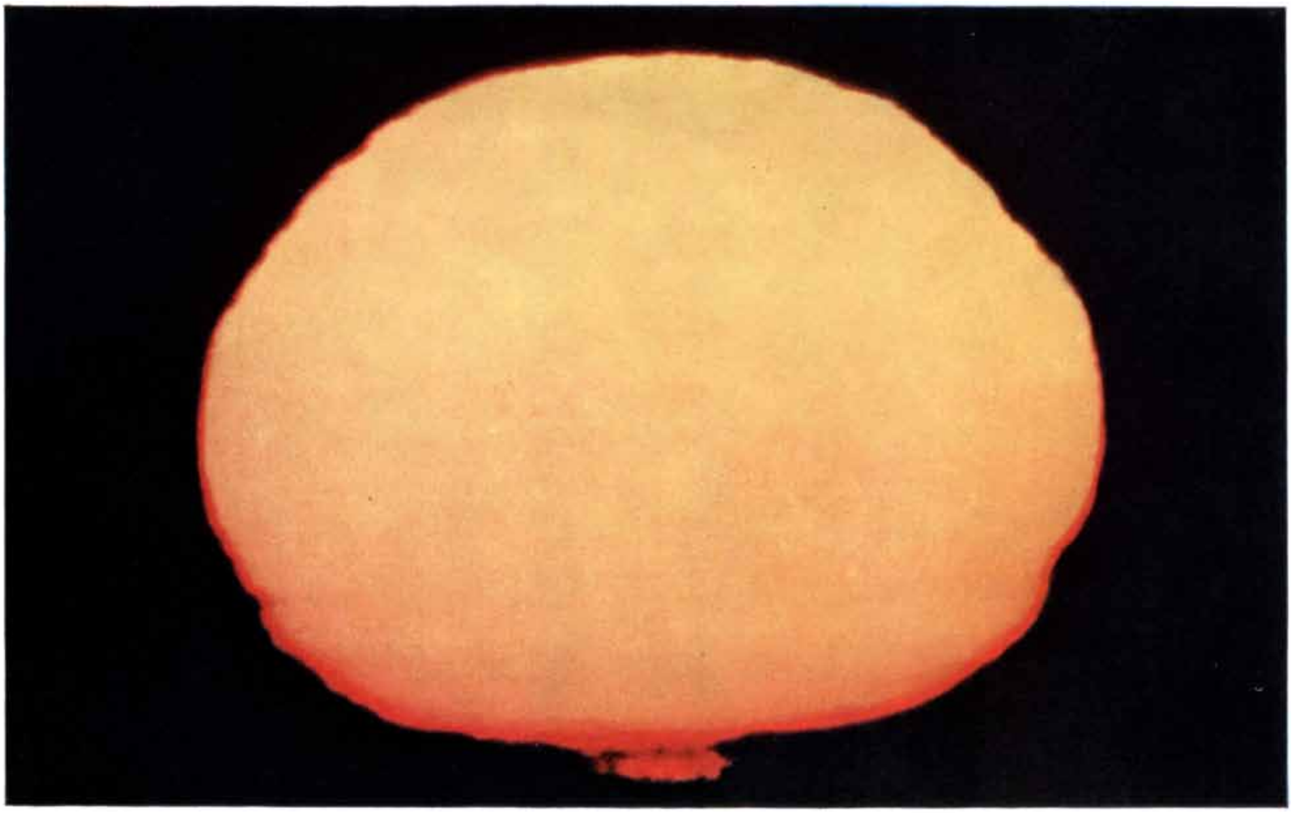
narrow band of color. For example, in a 35-millimeter camera with a lens five centimeters in focal length the image of a normal green flash would be only .005 millimeter wide, much too narrow to be recorded on the film.

For years I had looked in vain for the green flash—at sea, on mountains, in many parts of the world. Then, a few years ago, I saw it very clearly at sunset over the Mediterranean from the Vatican Observatory at Castel Gandolfo. (The Observatory, at an altitude of 1,500 feet, provides an unobstructed view across the Roman Campagna to the sea horizon, 50 miles away.) I soon began to wonder whether it might be possible to photograph the flash on color film with one of our telescopes. With a focal length of several feet, they should magnify the image sufficiently to make it visible. At any rate it seemed worthwhile to try. If we succeeded, we would be able to administer the quietus to the subjective theory of the flash.

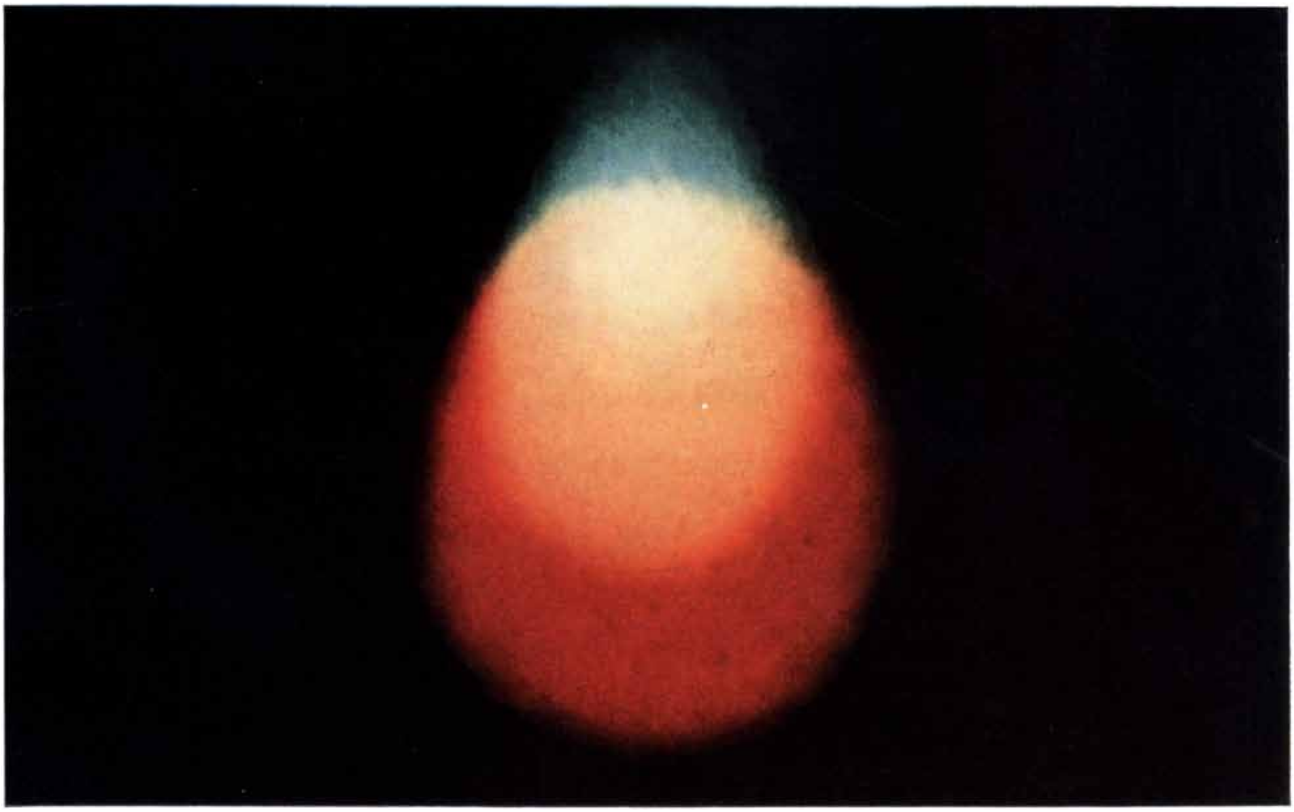
In 1954, after a long series of experiments, C. Treusch, S.J., instrument-maker and photographer of the Observatory, took our first color photographs of the green flash. Developing a successful technique was no easy task. For any such fleeting phenomenon it is very difficult to find the exposure that will give a faithful reproduction on film of what is seen. Moreover, the intensity of the light changes very rapidly during the last moments of sunset, and the exposure must be continually adjusted to compensate. Many trials were required before we learned how to do it. A further complication is that, while the sun is still above the horizon, the light from the disk is much brighter than that from a green flash. Thus if the exposure is right for the flash, the rest of the sun will be overexposed. With the help of the Kodak Research Laboratories we made extensive studies of the effects of over- and under-exposure on the colors in film.

All these difficulties were compounded in the beginning by the necessity of sending the Kodachrome film we were using to France or to the U. S. for development. This meant waiting several weeks to see the results of each test run. As soon as Kodak Ektachrome film became available, we began to use it almost exclusively. It can be developed right at the Observatory.

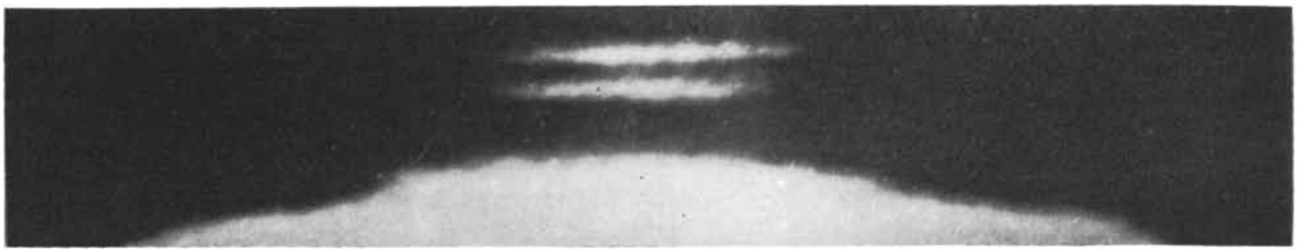
Our earlier photographs were taken with a 24-inch Zeiss reflector, the focal length of which is 95 inches. We used a reflector rather than a refractor



RED FLASH appearing about one degree above the sea horizon was photographed from Castel Gandolfo. This picture was made on Kodachrome film using a reflecting telescope with a focal length of eight feet. To record finer details requires a longer focal length.



SETTING OF VENUS was photographed on Ektachrome daylight film with a refracting telescope 20 feet in focal length. The planet appears as a series of separate but overlapping images ranging from blue-green at the top to red at the bottom. The blue image as seen visually was at least twice as elongated as the image recorded on the film. The colors are the result of atmospheric dispersion.



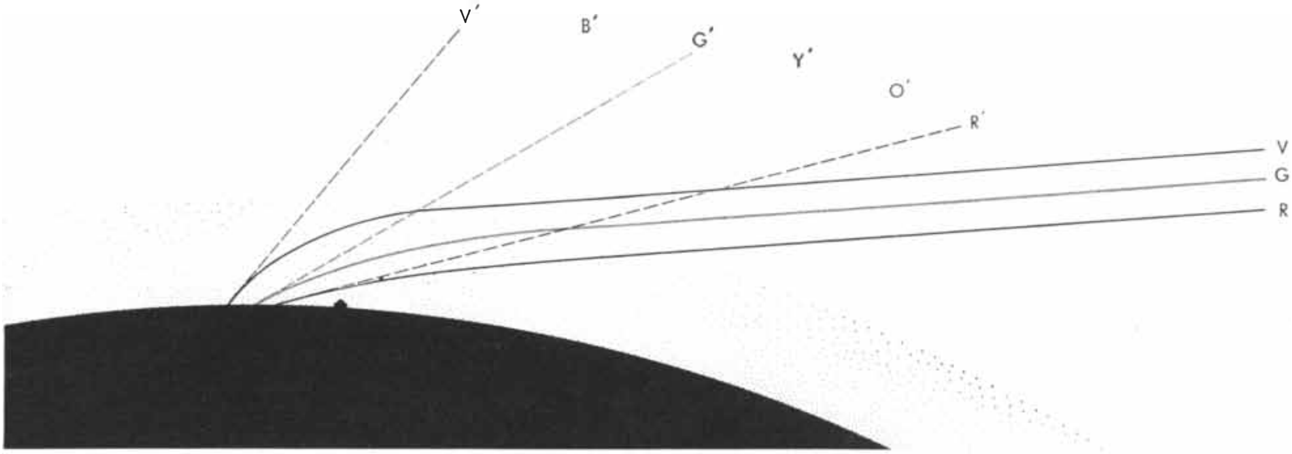
MULTIPLE FLASHES are sometimes seen. Those pictured here were a brilliant blue-green in color and floated for about two seconds above the last tip of the setting sun. There was also a third strip below the two shown here, but it was too faint to be recorded.

to ensure that the instrument introduced no spurious color effects, as a lens might have done. Later on we tried our Zeiss 16-inch refractor (focal length 20 feet). Its lens is an exceptionally good one, very well corrected in the visual region. It turned out to give no spurious color effects and its pictures are in no wise inferior to those obtained with the reflector. The longer focal length makes it possible to photograph very fine details that are lost with the shorter focus. Most of the later photographs were taken with this telescope.

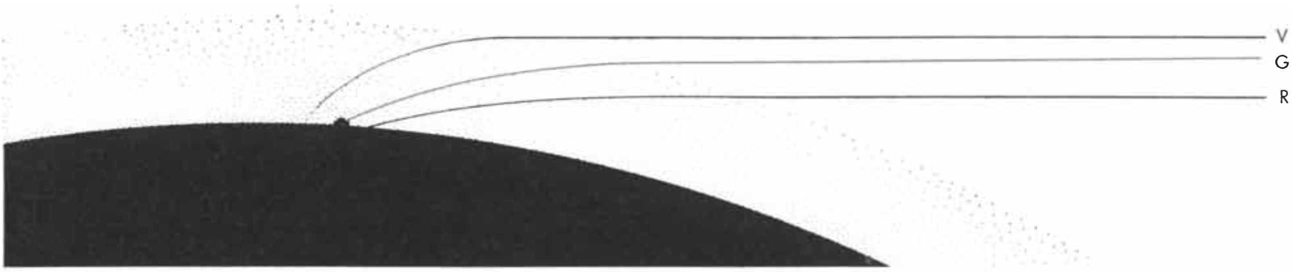
Thanks to Treusch's skill and patience we now have pictures showing the diverse forms the green flash can take, the ways in which it develops, the influence of various atmospheric conditions and the strange forms that the setting sun can assume as it is seen through different layers of the atmosphere. There are also photographs of the red flash which sometimes appears below the sun, as well as of various phenomena seen at the setting of the moon and of Venus.

The green flash is even more difficult to photograph at sunrise than at sunset. One has to judge the exact point of the horizon where the sun will rise and the precise moment when a flash may appear, as well as the correct exposure. At Castel Gandolfo conditions are particularly bad because the eastern horizon, running along the crest of the Alban Hills, is mostly covered with forest. Only at one point is the horizon clear of trees, but through this gap we have made some color photographs of the green flash at sunrise.

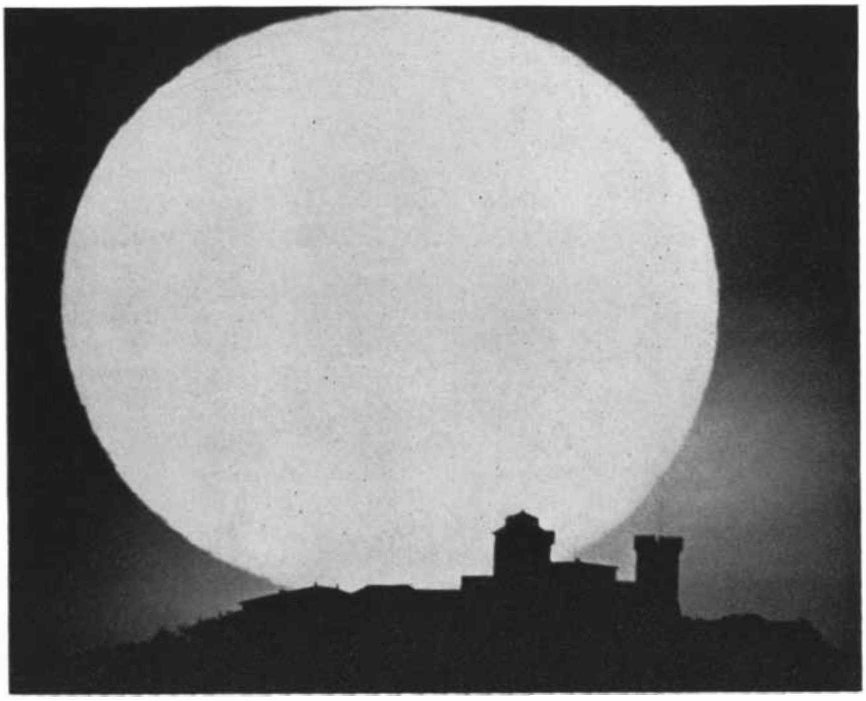
A much wider selection of the Castel Gandolfo photographs than can be included in this article are reproduced in a recent book by the writer: *The Green Flash and Other Low Sun Phenomena* [see "Bibliography"]. The ones shown here and on the cover, however, are quite enough to demonstrate the reality



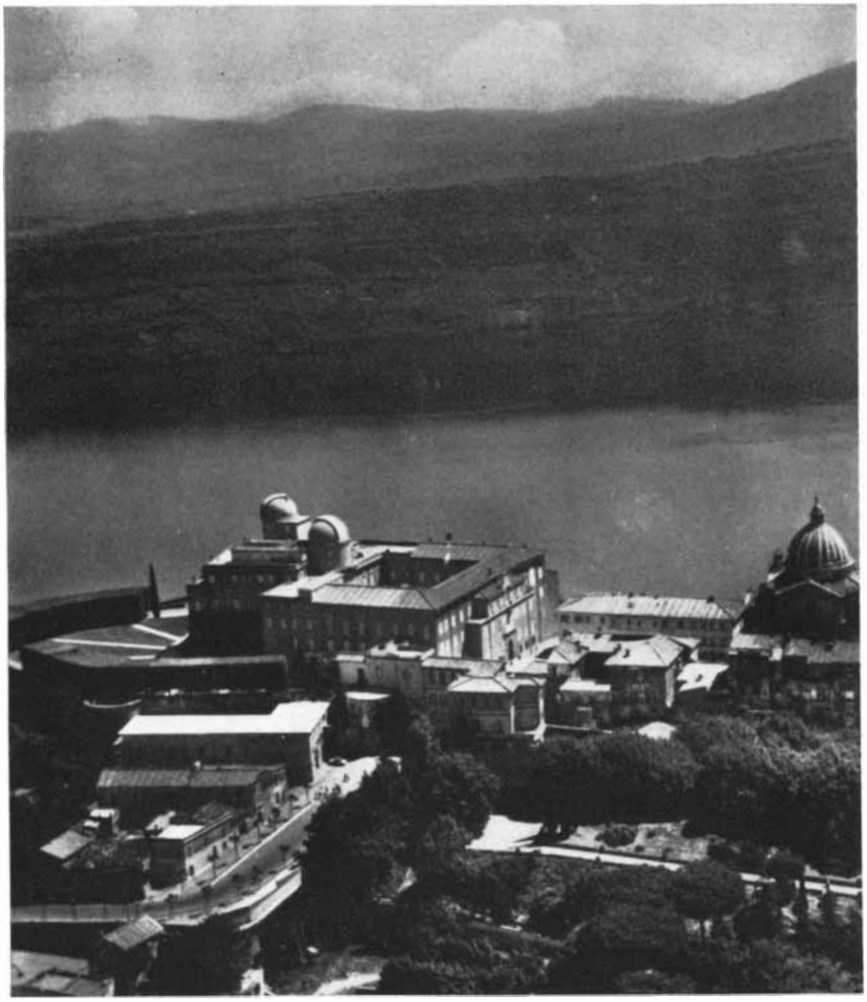
CAUSES OF THE GREEN FLASH are dispersion, scattering and absorption of sunlight by the earth's atmosphere (*black-dotted area*). Solid lines show the paths of three spectral colors, violet (V), green (G) and red (R), in the light coming in at a small angle to the earth's surface from a low-lying sun. The broken lines show the directions from which the rays appear to be coming toward observers on the ground as a result of bending of their paths in the air. They have been dispersed into a spectrum. Between the three rays shown in the drawing fall the other colors of the spectrum, blue (B), yellow (Y) and orange (O), in normal order.



GREEN FLASH APPEARS ABRUPTLY when the lower, red rays have sunk below the observer's horizon. Orange and yellow are largely absorbed by the atmosphere. Blue and violet rays are scattered by particles in the air, leaving green as the color seen.



RISING SUN is seen from Castel Gandolfo behind castle at Rocca Priora, 6.5 miles away. The green flash appears at sunrise, but is harder to photograph at that time.



CASTEL GANDOLFO, the site of the Vatican Observatory, is seen from the west, looking across Lake Albano toward the eastern horizon. Two observatory domes are at left center.

of the green flash. What does produce the phenomenon? The answer can be found in the laws of physics.

When light from the sun enters the earth's atmosphere it is slowed down, and therefore bent or refracted, just as when it passes through a glass prism. The amount of refraction depends on the wavelength of the light, the shorter waves being bent more than the longer ones. Thus the white sunlight is spread out or dispersed into a spectrum, with the longest (red) wavelengths at one end and the shortest (violet) at the other. The lower the sun, the greater the thickness of air through which its light must pass before reaching the eye of an observer. Hence the dispersion is greatest at sunset and sunrise.

Because the short waves are bent more sharply, they strike the eye at a steeper angle and appear to be coming from a point higher in the sky than the longer ones [*see middle illustration on preceding page*]. Thus the spectrum extends from violet at the top to red at the bottom. As long as a fair portion of the sun's disk is visible, light rays from its various parts overlap, and one cannot see the spectrum. (Sometimes a green or blue rim does appear at the top of the disk and a red rim at the bottom.) When the sun sinks below the horizon, the colors of its spectrum disappear one by one, the lowest red rays first, then the orange, yellow, green and so on.

Why, then, do we not see an orderly change of color instead of an abrupt flash of green? The reason is that the atmosphere filters out the other colors. In addition to dispersing light the air also absorbs and scatters it. Absorption, due mainly to water vapor, oxygen and ozone, affects chiefly the orange and yellow light. Scattering is stronger for short wavelengths. (Preferential scattering of blue light accounts for the color of the sky.) Thus when the red rays have sunk below the horizon, the orange and yellow are attenuated by the thick layer of air through which they are traveling toward our eyes. The blue and violet light is largely scattered away. The color least affected is green, and this is what reaches us. At high altitudes, and when the air is very clear, the shorter waves may still come through, and the flash can be blue or violet.

The same processes that operate on sunlight affect the light from stars or planets. Since the images of these objects are so much smaller than that of the sun, the dispersion of their light is apparent when they are near the horizon. Because of absorption and scatter-

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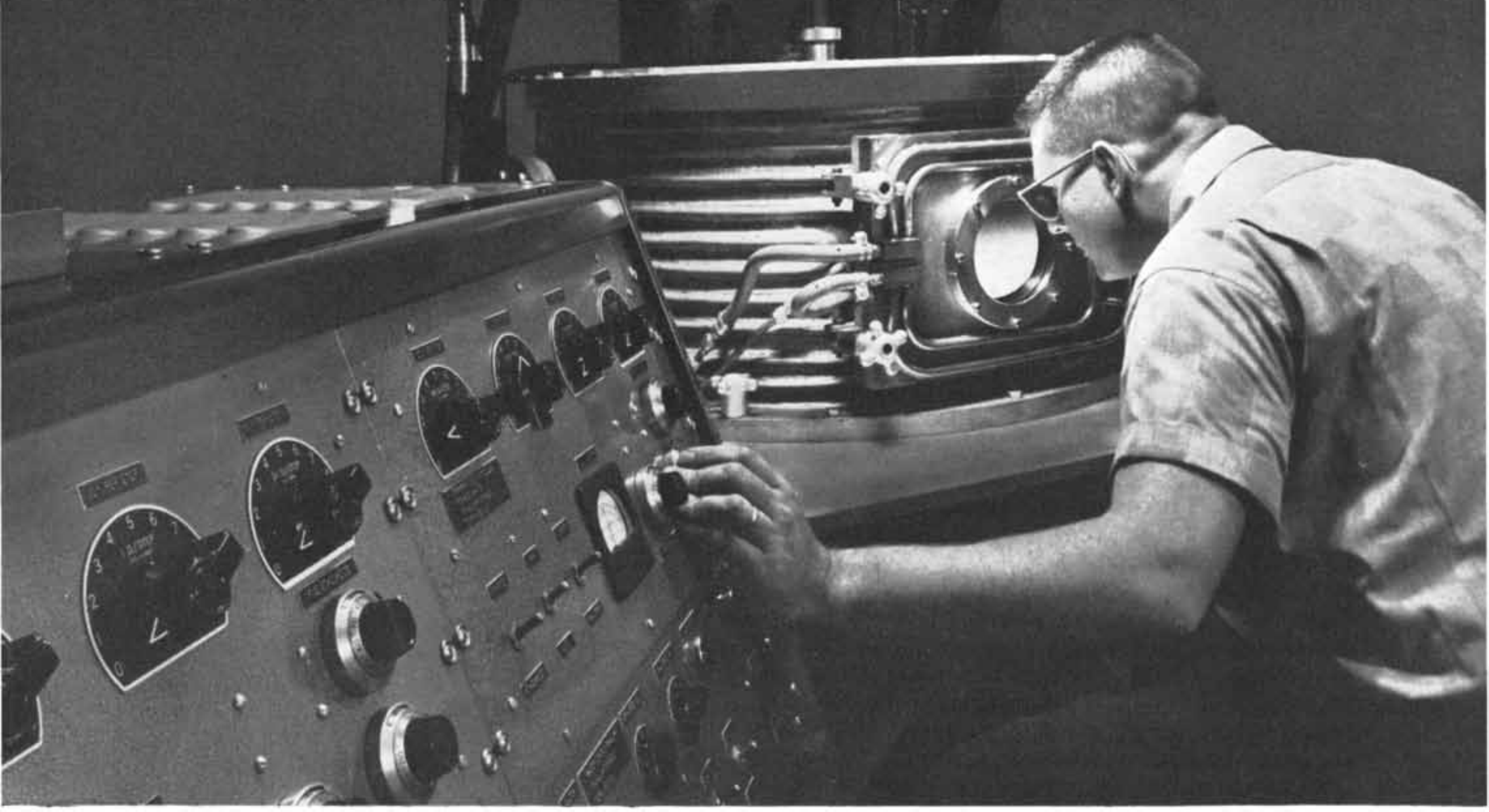
Systems, Packages and Components for: AIRCRAFT, MISSILE, ELECTRONIC, NUCLEAR AND INDUSTRIAL APPLICATIONS ing, the spectra are not continuous. Instead we see a set of overlapping images in different colors. The brighter the object, the clearer the effect; the setting of Venus provides a vivid example [*see bottom photograph on page 115*].

While dispersion, selective absorption and scattering are chiefly responsible for the green flash, other factors favor or hinder its appearance. Dust or haze in the air absorbs light and makes it less likely that a flash will be seen. On the other hand, abrupt variations in the density and temperature of different layers of the atmosphere may act to increase the intensity and duration of the effect. The English astronomer J. Evershed, while traveling by sea from Australia to Java, saw a brilliant green flash at sunset every evening and noted that on each occasion there was also a mirage. This was caused by a thin inversion layer—a region where the temperature of the air increases with height—near the surface of the ocean. When the sun was near the horizon, two images of it could be seen—the direct one and a mirage reflected upward from the inversion layer. As the sun sank further, the reflected image moved up to meet the direct one, and the green flash appeared when they coalesced. Evershed observed a similar effect at the setting of Venus.

The duration of the flash depends on the rate at which the sun is sinking below the horizon, and at any one place this rate varies with the time of year. Moreover, the sun sinks more slowly, and the green flash lasts longer, as one moves from the Equator toward the poles. For example, at Hammerfest in Norway (latitude 79 degrees north) the flash at midsummer may last as long as 14 minutes, seven minutes during the slow sunset and another seven at sunrise, which follows immediately. The longest display on record was reported by Admiral Byrd's expedition to Little America (78 degrees south) in 1929. The sun grazed the irregular horizon of the barrier ice and the green flash was seen, on and off, for about 35 minutes.

Refraction, in addition to producing the flash, extends its duration. The downward bending of light rays makes the sun appear higher than it really is, and keeps it visible for an appreciable time after it has actually sunk below the horizon. At Castel Gandolfo, under normal conditions, refraction raises the sun about 1.3 degrees, or about two and a half times its diameter. Depending on atmospheric conditions the effect may sometimes be much greater, delaying sunset still more and lengthening the life of the flash proportionately. Some

TEXAS INSTRUMENTS SEMICONDUCTOR REPORT • NUMBER SIX



Giant crystal puller grows, casts 10-inch silicon crystals at TI

Silicon crystal chalice, produced by combining growing and casting techniques, illustrates capabilities of TI giant crystal puller that grows 10-in. silicon crystals and casts ½-in. plates to 12-in. diameters.

Anticipating and keeping pace with advanced infrared materials requirements, TI engineers designed and built a giant crystal puller capable of growing semiconductor crystals to 10-inch diameters. Designed for engineering and development studies, it can grow a wide variety of crystal configurations, and add further variations to the TI developed cast silicon dome process. The latter method economically casts silicon domes such as those used on infrared guided missiles. This casting of thin silicon shells instead of growing entire crystals substantially reduces material costs and saves considerable grinding and polishing time. Combinations of the growing and casting techniques can be used advantageously to produce many unusual results such as the chalice shown at left.

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remarkable instances of abnormally great refraction have been recorded. In 1597 some Dutch sailors in the Arctic Circle saw the sun for 14 days when it should have been entirely below the horizon. It had been raised no less than four degrees by abnormal refraction.

With so many factors involved it is small wonder that the appearance of the green flash is quite capricious. As has been mentioned, the chances of seeing it, at least with the naked eye, are much better in high mountains, tropical seas or deserts. I should add that it is much easier to see if you already have a good idea of what to look for. People who have often tried and failed to find the green flash have been able to see it without difficulty after studying our color photographs.

If you decide to make a serious attempt to look for the green flash, you will find the search much facilitated by a modest optical aid such as low-power binoculars or a small telescope. It is not light-gathering power that is needed, but simply magnification of the extremely narrow band of color. Of course you must be very careful to avoid damaging your eyes. Binoculars should be turned on the sun only at the last moment, when the disk has almost disappeared. With a telescope you might use a neutral filter or a solar eyepiece to reduce the intensity without altering the color of the light.

Even if you succeed in seeing the green flash, you will not be able to photograph it in color with an ordinary camera of short focal length. At the Vatican Observatory we have obtained good pictures using a focal length of eight feet, but the finest details can be recorded only with the refractor of 20-foot focal length. Amateurs should not be discouraged, however; there are many interesting sunset phenomena that can be photographed with much more modest equipment. It is not so difficult, for instance, to record the changing, and often very curious, shape of the sun's disk as it nears the horizon.

Beyond its interest as an odd and often beautiful sight the green flash may help increase our understanding of the earth's environment. As we have seen, it is a wholly atmospheric phenomenon, and its appearance is influenced not only by the lower layers of air, but also by conditions at very high levels. It is possible that studies of the green flash and related effects will augment the information about the upper atmosphere now being gathered by rockets and artificial satellites.

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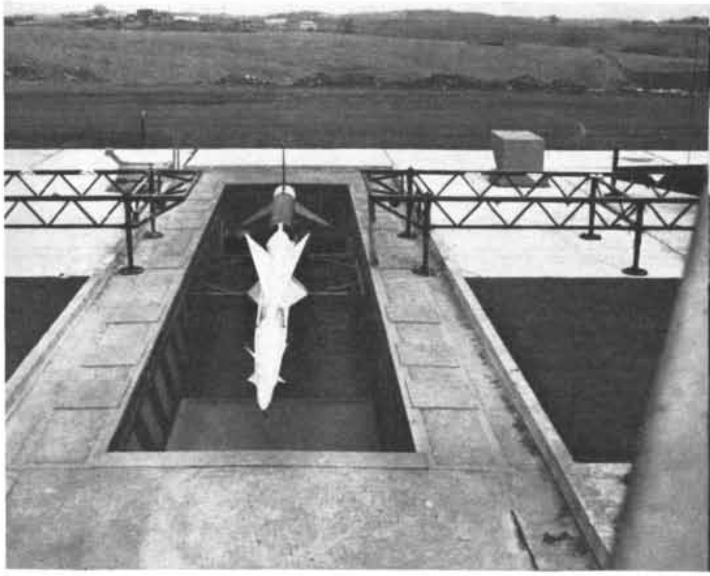
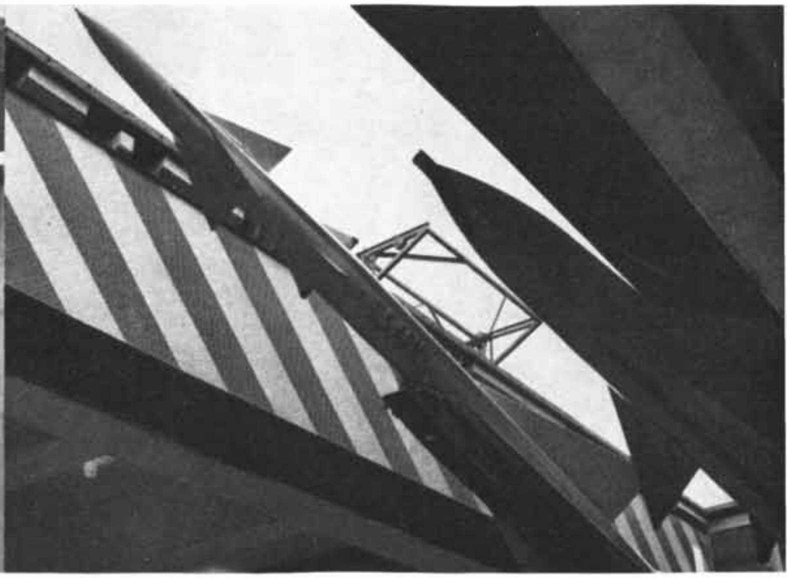
About the earthly side of the Nike Ajax.

The U. S. Army's Nike Ajax is a strange but potent bird. Graceful, tough, packed with delicate instruments. He will fly only once in his lifetime—only in the event of an enemy attack. To launch him with split-second timing and accuracy, the Army puts most of its manpower and most of its materials into ground equipment. And virtually all the steels used in missiles and launching sites can be purchased from one firm—United States Steel. Whether you're talking about carbon steel, high-strength low-alloy, or ultra high-strength alloy steels, Stainless Steel, steel fence,



The Nike Ajax spends his days in a concrete and steel nest like this one. ICBM's will also live this way, but in nests that will take *thousands* of tons of concrete and steel. U.S. Steel specialists work continually with designers and construction engineers to find ways to use steel to its full advantage on such projects to build stronger with less materials . . . to build them faster.



It takes miles of wire and cable to rig a Nike nest. It will take *hundreds* of miles when bigger birds are put to roost. The Army uses many types of steel and steel products in a Nike nest. U.S. Steel conducts research and knows how to cut costs for any steel product used in ground support equipment.

electrical cable, cement or wire rope, United States Steel maintains the technical services to provide the proper assistance to cope with any problem on materials for ground equipment. When a ground support program goes to the drawing board, consult with

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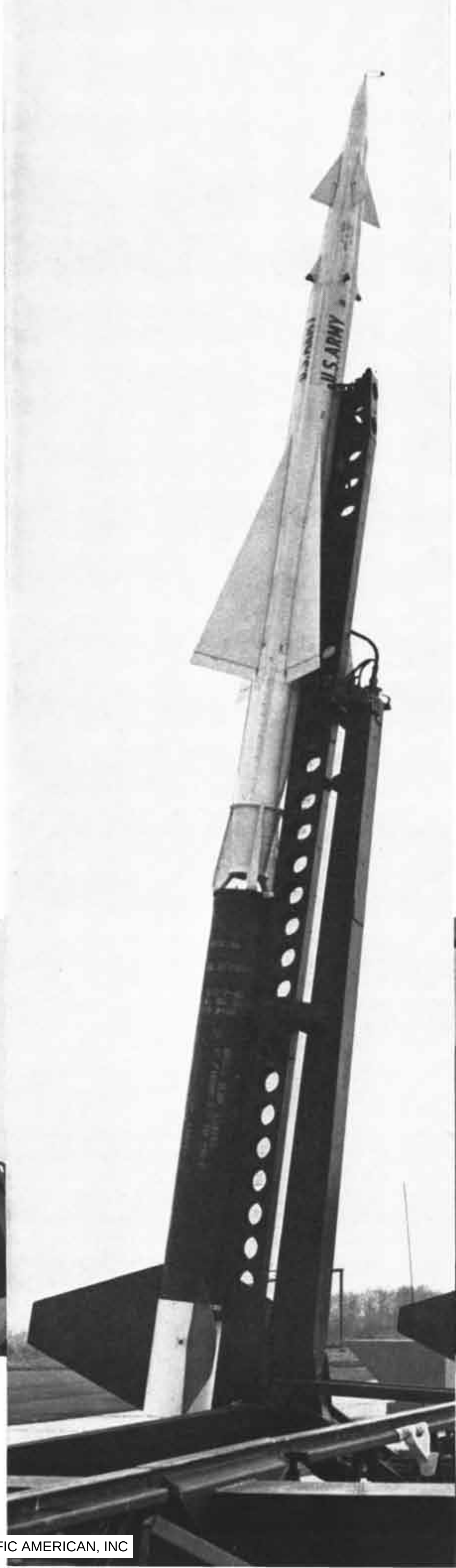


How light can you make a steel boom for any missile system without sacrificing strength? The proper selection of USS High-Strength Steels or Constructional Alloy Steels has cut the weight of similar equipment as much as ⅓—and *increased* the strength and service life.

Nuclear Control of the Cell

Present theories of cell physiology imply that materials are transported from the nucleus to the cytoplasm. This transfer has now been demonstrated by means of electron microscopy

by Helen Gay

Some 25 years ago the anatomy of the fruit fly facilitated an important step in the progress of genetics. It happens that the cells in the salivary glands of the larva of this insect grow to relatively gigantic size as the little creature approaches the pupal stage. Concurrently the genetic material contained in the threadlike chromosomes in the nuclei of these cells increases 1,000-fold. The chromosomes become thick cables, and a high-powered light microscope can easily resolve patterns of dark and light bands along their lengths. Geneticists and cytologists have been able to fix on the banding patterns the locations of the genes for a sizeable number of hereditary traits, and have gone on to map some genes even on the much smaller chromosomes of other organisms.

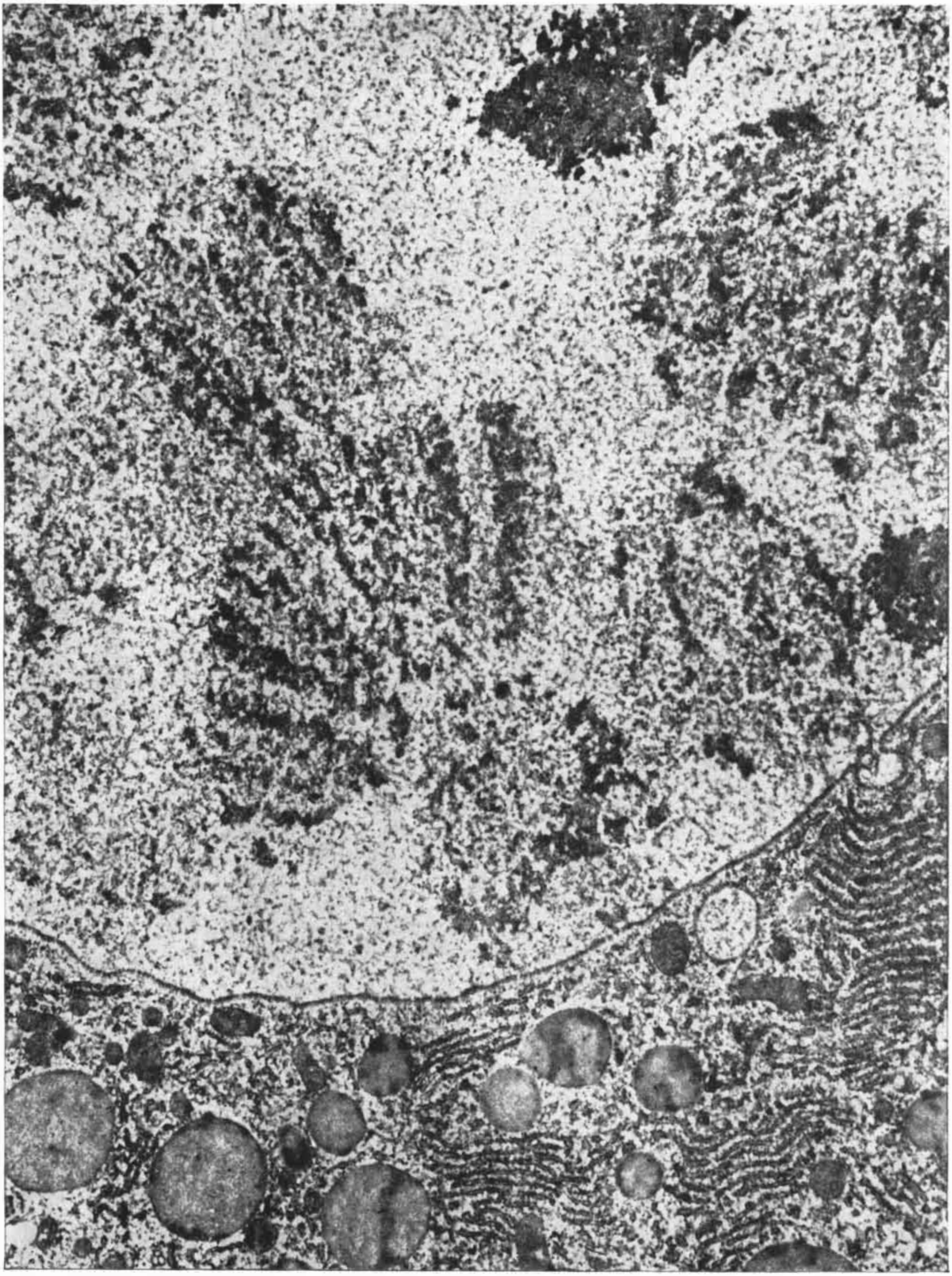
There remains, however, an enormous gap between the precise experimental and theoretical picture established by genetics and our understanding of how the information encoded in the chromosomes is expressed in the structure and function of the cell. How, for example, does the single fertilized egg-cell give rise to the variously differentiated and specialized cells of a multicelled organism? In recent years biochemists have begun to work out the general scheme. They have pretty well identified deoxyribonucleic acid (DNA), a giant molecule found in the chromosomes, as the primary hereditary material. And they have shown that ribonucleic acid (RNA), another giant molecule found in both the nucleus and the surrounding cytoplasm, acts as an intermediary in the synthesis of the many different kinds of protein that constitute the principal substance of the cell. It is apparent that the nucleus exerts a profound control over the cell as a whole. But biochemistry has outrun cellular anatomy and physiology. We do not know by what mechanism the biochemical influence of the nucleus is conveyed to the cytoplasm. Since the transfer must involve particles of molecular dimensions, we could not expect to discern it except in the most fortunate circumstances.

Such circumstances, it now appears, are afforded by the same accident of size that made the salivary-gland cells of the fruit fly so useful to geneticists. This time the electron microscope, with a magnifying power some 200 times that of the light microscope, has revealed what these cells have to show. In the laboratories of the Department of Genetics of the Carnegie Institution of Washington at Cold Spring Harbor, N.Y., my colleagues and I several years ago secured electron micrographs of thin sections of a cell that showed some hitherto unobserved structures. The membrane that encloses the nucleus was pocketed with minute "blebs," or blisters, extending into the cytoplasm and containing spurlike extensions of chromosomal material. The pictures at once suggested that nuclear material was being transferred to the cytoplasm; it looked as if the nucleus were bubbling off bits of chromosome.

We later discovered that membrane blebbing occurs at a crucial point in the larval life-cycle, when the salivary gland is preparing to synthesize a special protein later excreted by the gland. Knowing when to look for this process, we have been able to develop its details by examining a succession of cells under the electron microscope, and to correlate these observations with biochemical studies and with light-microscope pictures. We have thus been able to trace visually a sequence of events that carries chromosomal material through the nuclear membrane into the cytoplasm, and to describe at least one mechanism by which the nucleus controls a specific metabolic process in a cell.

That the nucleus plays the commanding role in the life of the cell represents one of the first insights of cell biology. Early investigators were impressed to see the always exactly equal division of the chromosomes in the dividing cell. They recognized that the nuclei of the variously specialized cells of an organism almost never show obviously visible differences from one another or from the single cell out of which they all arise. On the other hand, they understood that the cytoplasm is the region of the cell in which the major portion of the metabolic activity takes place and that differences in the cytoplasmic constitution of the cells of the

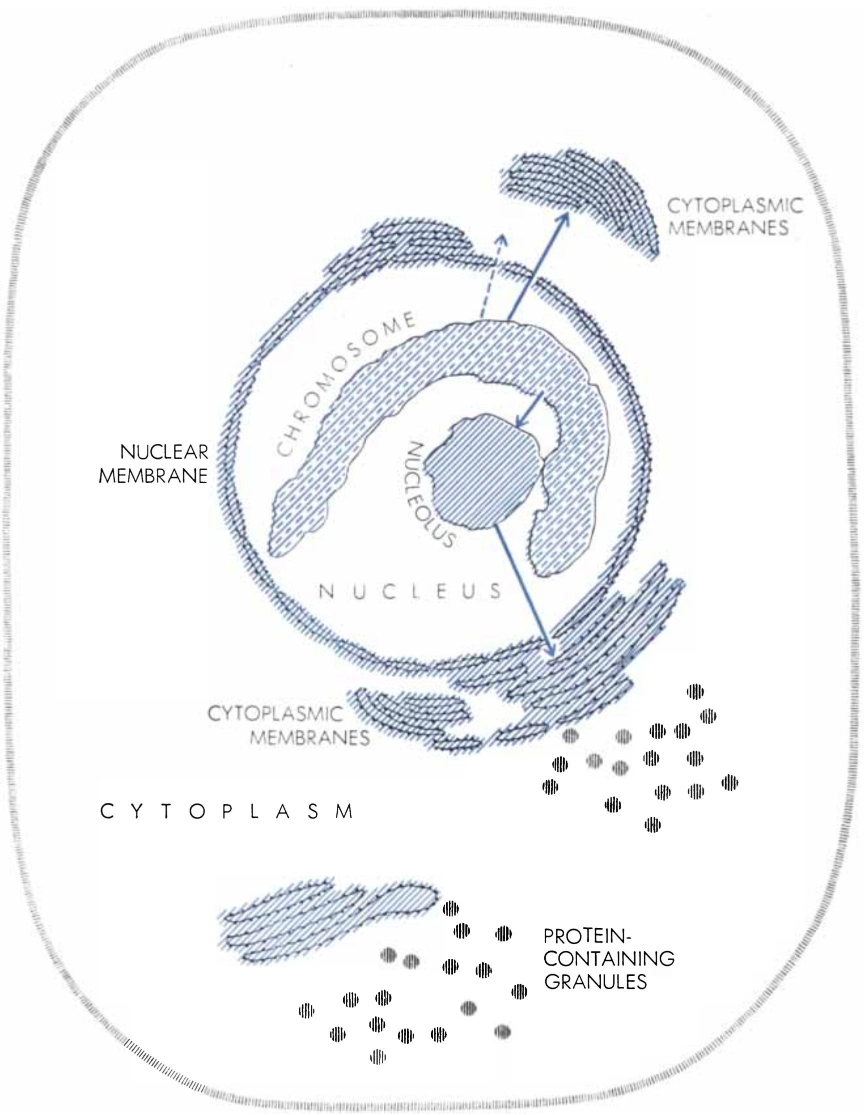
TRANSFER of material from chromosome to cytoplasm is shown in the electron micrograph on opposite page, which enlarges



22,000 diameters part of a giant salivary-gland cell from a fruit-fly larva. Drawing at left identifies the structures in the micrograph. Near the end of larval stage, the cell nuclei form blister-like blebs containing chromosomal material. Detached blebs (*lower right center*) are thought to evolve into cytoplasmic membranes associated with the formation of protein-containing secretion granules.

body account for the differences in their function. Sometimes at cell division the cytoplasmic material is unequally divided between the daughter cells, producing daughters of different size and appearance. It was tempting to ascribe the process of differentiation to such cytoplasmic changes. The best judgment on this question, however, is still that of Thomas Hunt Morgan, the father of modern genetics and also a pre-eminent embryologist. In 1934 he proposed that an explanation of the process be sought in a mutual interaction of the nucleus and cytoplasm involving reciprocal interchange of materials. Special regions and constituents in the cytoplasm of embryonic cells thus might react with the total gene complement to excite or inhibit the expression of the various potentialities carried in the genetic plan.

The findings of biochemistry thus far agree with this general picture. The DNA, as the primary genetic material, is apportioned equally to the chromosomes of the daughter cells at cell division. But equal apportionment has not been established for other constituents. The amount of RNA varies significantly in the chromosomes of different types of cells. Most nuclei also contain a nucleolus, a roundish body that forms at a special site on a particular chromosome and is made up of RNA and a high concentration of protein. During cell division the nucleolus appears at one stage and later disappears, its volume, shape and RNA content all varying in the process. Such changes in the chromosomal and nucleolar RNA make this nucleic acid suspect as the controlling agent of differentiation.

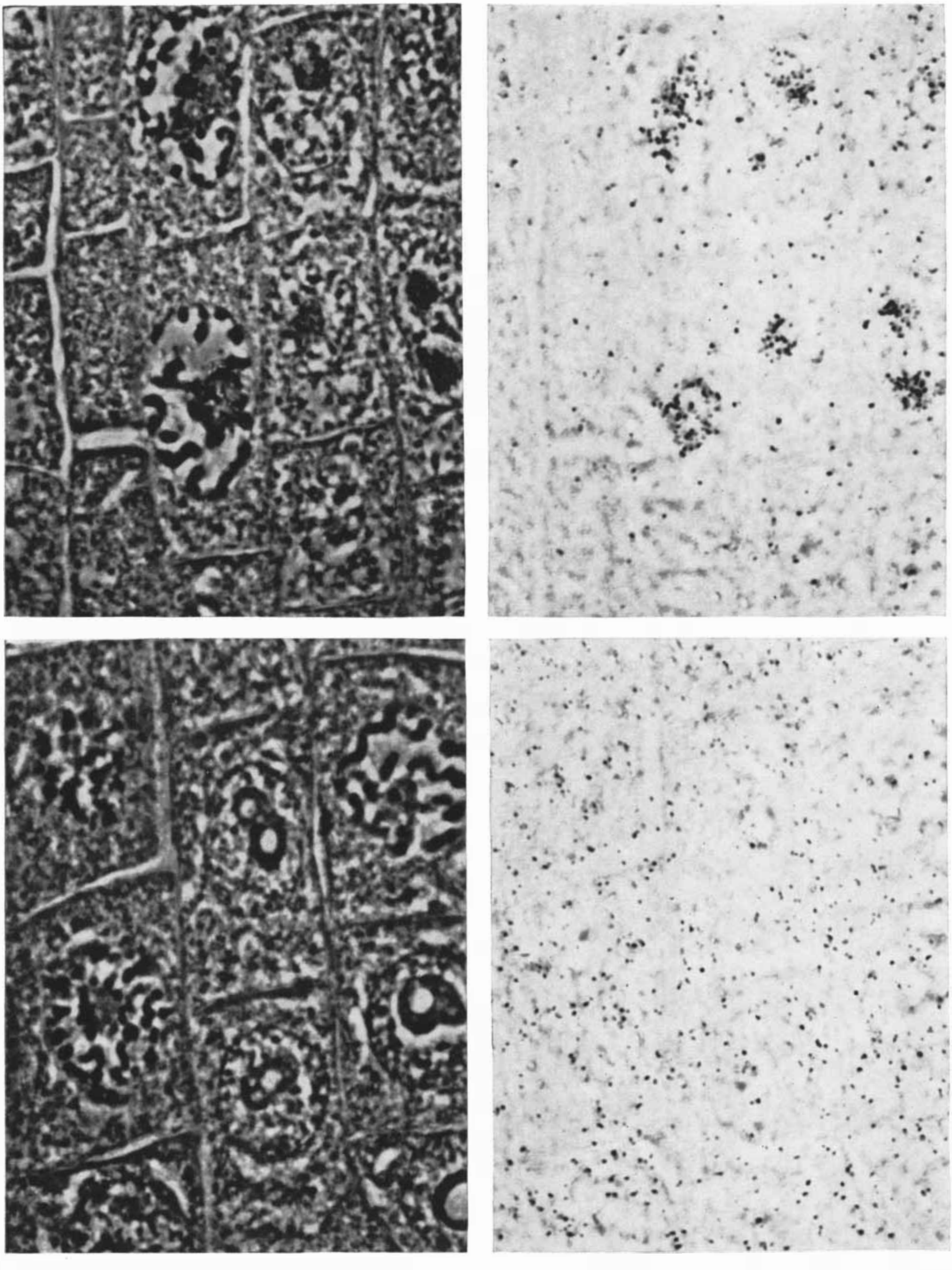


DISTRIBUTION OF DNA AND RNA, two substances that determine the form and function of cells, is shown in this schematic diagram. DNA (*broken hatching*) and RNA (*solid hatching*) are both found in chromosomes. RNA migrates (*solid arrows*), often via the nucleolus and nuclear membrane, into the cytoplasmic membranes, where it presides over protein synthesis. DNA leaves the nucleus (*broken arrow*) only in certain cells.

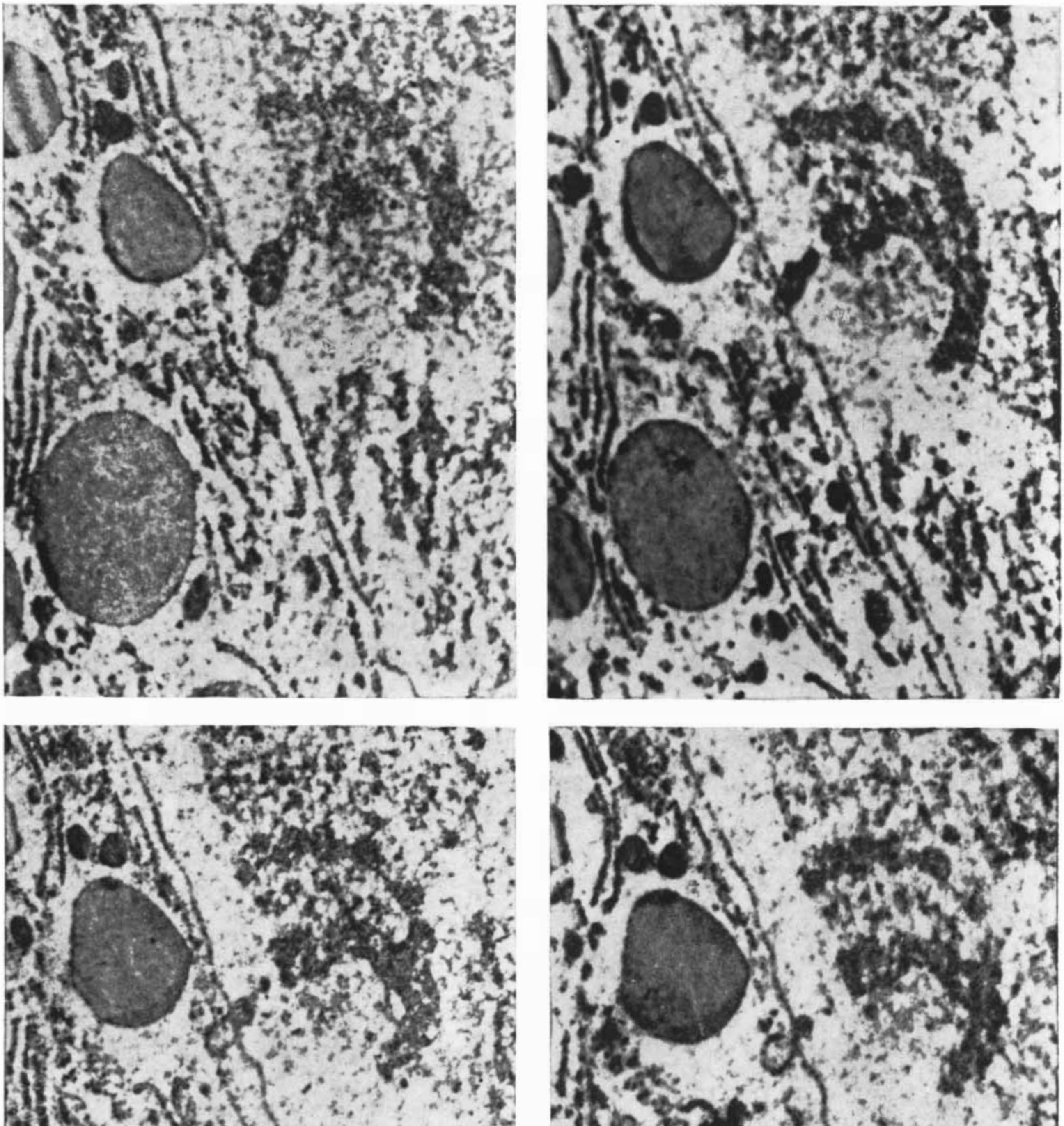
Some 20 years ago Torbjörn Caspersson in Sweden and Jean Brachet in Belgium independently discovered that in certain specialized cells, including the salivary-gland cells of the fruit fly, RNA turns up in high concentration in the nucleolus and in the cytoplasm when the cell is engaged in the synthesis of special proteins. This led them to propose that RNA is essential to protein production. Caspersson further proposed that the synthesis of protein in the cytoplasm is particularly influenced by the nucleolus and its associated heterochromatin (a substance of relatively limited genetic activity that is found in the chromosome at the site where the nucleolus is organized). Finding a high concentration of RNA outside the nuclear membrane in the cytoplasm preceding active protein synthesis, he suggested that the substance must migrate through the membrane.

The role of RNA in protein synthesis has been confirmed by experiments in the test tube with materials isolated from disrupted cells. So long as RNA is present, protein synthesis continues outside the cell. When the cellular particles that showed the highest RNA activity were examined under the electron microscope, they proved to be microsomes, fragments of certain cytoplasmic membranes that are found in almost all cells. These experiments show that RNA is essential to protein synthesis. DNA seems to be involved in some cases, specifically in the synthesis of proteins found in the nucleus. In general, it is proposed that RNA plays the key role in the elaboration of proteins in the cytoplasm and that it is the function of DNA to preside over the synthesis of RNA in accord with the genetic plan borne by the chromosomes [see "Nucleic Acids and Proteins," by Mahlon B. Hoagland; SCIENTIFIC AMERICAN, December, 1959].

The synthesis of proteins in the test tube does not, however, tell us precisely where these chemical reactions occur within the cell. Cytologists have secured some general answers to this question by the technique of labeling cellular substances with radioactive atoms. This technique includes radioautography, by which the labeled substances are made to record their locations in the cell on photographic film



MIGRATION OF RNA is shown in these photomicrographs of root cells from a bean plant. Cells at top were grown in a medium containing a labeled precursor of RNA. Radioautograph (*top right*) shows RNA concentrated in the nuclei of the cells, specifically in the nucleolus. After cells are transferred to unlabeled medium (*bottom*), uniform distribution of labeled RNA shows it has moved into cytoplasm. Photographs were made by Philip S. Woods and J. Herbert Taylor at Brookhaven National Laboratory.



STRUCTURE OF BLEB can be deduced from these electron micrographs of a series of sections through a salivary cell. Section at top left shows part of a chromosome touching the nuclear membrane just above the center of the picture. The base of the bleb appears at top right; cross section of the bleb, at bottom left. At bottom right the tip of bleb is shown almost free of membrane.

[*see illustration on page 129*]. When cells are grown in labeled precursors of RNA, the label first appears in the nucleolus and later in the cytoplasm, indicating the migration of RNA from the site of its synthesis in the nucleus into the cytoplasm. Radioautographs of the salivary-gland cells of the fruit-fly larva show this pattern of migration. Thanks to the large size of the salivary-gland chromosome, they also show that the heterochromatin portion of the chromosome near the nucleolus is especially active.

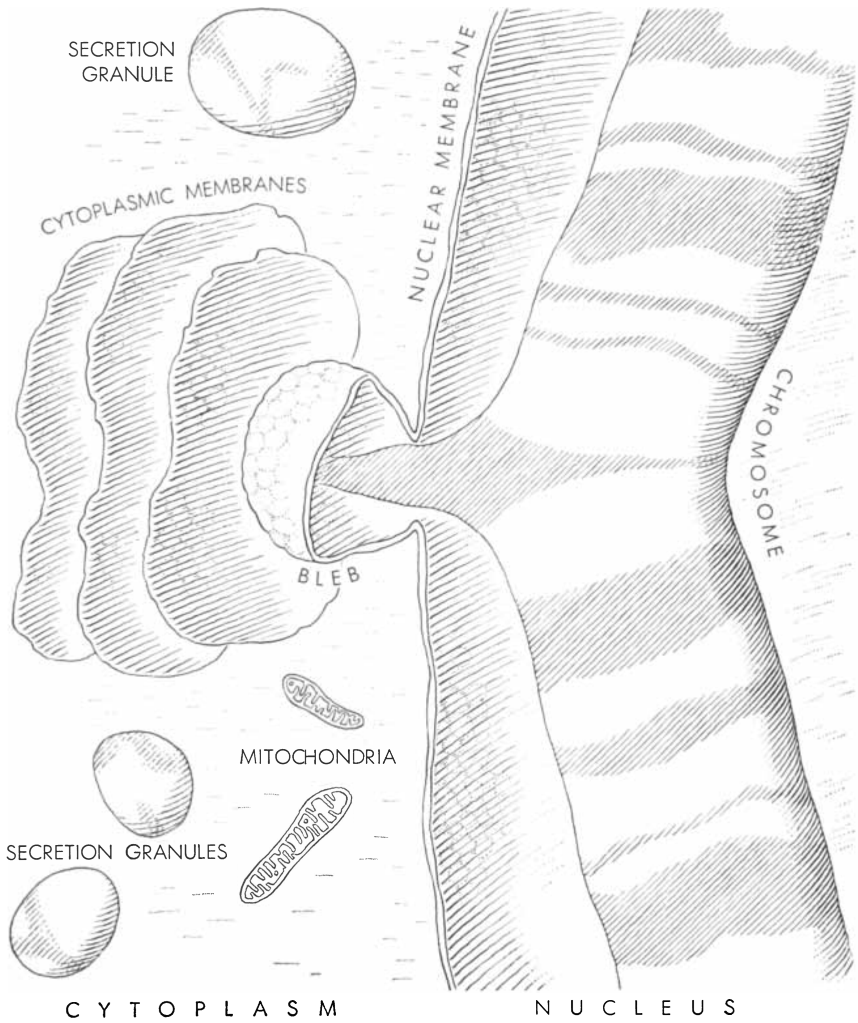
When the fruit-fly larva hatches from the egg, there is nothing especially distinguished about the cells of its salivary glands. There are about 100 cells of normal size in each gland, a number that is set aside early in embryonic life and never multiplies thereafter. As the larva proceeds to grow through two molts, however, the salivary gland becomes much bigger through increase in the size of these cells. Production of giant chromosomes proceeds apace with the tremendous increase in the volume of the cytoplasm. The kind and the number of cytoplasmic structures also increase. After the second molt, the salivary gland is a cylindrical sac made up of a single layer of about 100 exceptionally large cells. The transformation of the cells is climaxed by the appearance in the cytoplasm of a large number of small round "secretion granules."

As the result of these changes the salivary gland assumes the capacity to perform a new function. As the word "salivary" implies, the first function of the gland is to secrete a digestive fluid. But this fluid is needed only in the molting phases, when the larva consumes enormous quantities of food. After the second molt, as the time of pupation approaches, both food intake and saliva production decline sharply. The secretion granules now begin to show up in the cell. Just before pupation these granules break down and empty the substance they contain into the cavity of the gland. This substance, expelled from the mouth of the larva, serves as a sort of glue to attach the pupa to some solid surface. Chemical analysis shows it to be made up of a great deal of protein combined with a carbohydrate. In these cells it is thus possible to observe the appearance of special protein-containing structures and to fix the exact time when the protein is produced. The cells, in other words, furnish a model demonstration of the crucial process of differentiation.

Coincident with the first signs of secretion granules in the cytoplasm, the electron microscope shows the appearance of blebs in the membrane of the nucleus. By preparing a long series of consecutive thin sections of cells at this stage, we have succeeded in constructing three-dimensional models of the nuclear structures involved in the blebs. They show that the material in the bleb is continuous with and part of a giant chromosome. In some cases the chromosomal extension can be traced to a special region in the chromosome that is rich in the same heterochromatin substance that is involved in the organization of the nucleolus. These regions often lie close to the nuclear membrane.

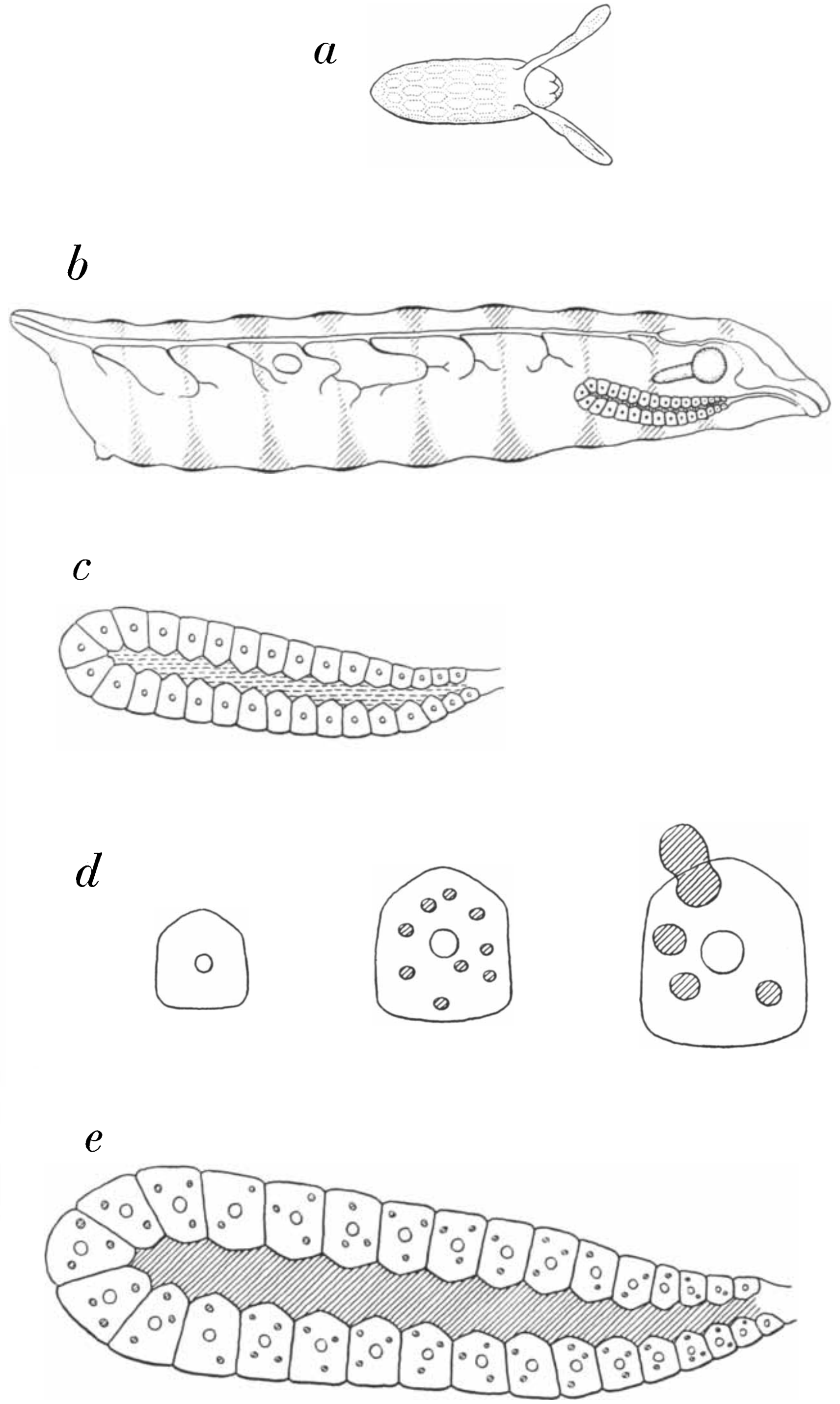
Outside the membrane, in the cytoplasm, the electron micrographs show bodies that appear to be detached blebs. The contours of these structures resemble the blebs on the nucleus and, like the nuclear membrane, they are double-layered. Often they lie in great numbers, parallel to one another and to the nuclear membrane near the bleb, forming relatively well-organized masses. Occasionally one of these bodies is observed in contact with the nuclear membrane. The pictures clearly suggest that functionally active regions of the chromosomes are releasing materials that pass into the cytoplasm by means of nuclear-membrane blebs. The detached segments of the nuclear membrane are also identical in appearance with the cytoplasmic membranes that have been identified with the process of protein synthesis. In the salivary-gland cell they are clearly involved in the formation of the protein-loaded secretion granules. Some pictures indeed show these membranes surrounding a granule in the process of formation.

Generalizing from what is observed in the special case of the salivary-gland cell,



THREE-DIMENSIONAL MODEL OF BLEB and adjacent areas is built up from sectional photographs like those on opposite page. Structural similarities between the cytoplasmic and the nuclear membranes suggest that the former are the "coats" of blebs that have broken away from the nuclear membrane. The fate of the material within blebs is uncertain.

it is possible to envision this process as one by which the nuclei in all cells exert their control over activity in the cytoplasm. Since the process involves the transfer of molecular particles, it would not ordinarily be visible, even in electron micrographs. In the fruit fly, however, it is adapted to the production of large quantities of protein in a short time. The extraordinary increase in size of the chromosomes, the blebbing of the nuclear membrane and the shedding of sections of nuclear membrane into the cytoplasm all would facilitate production of protein

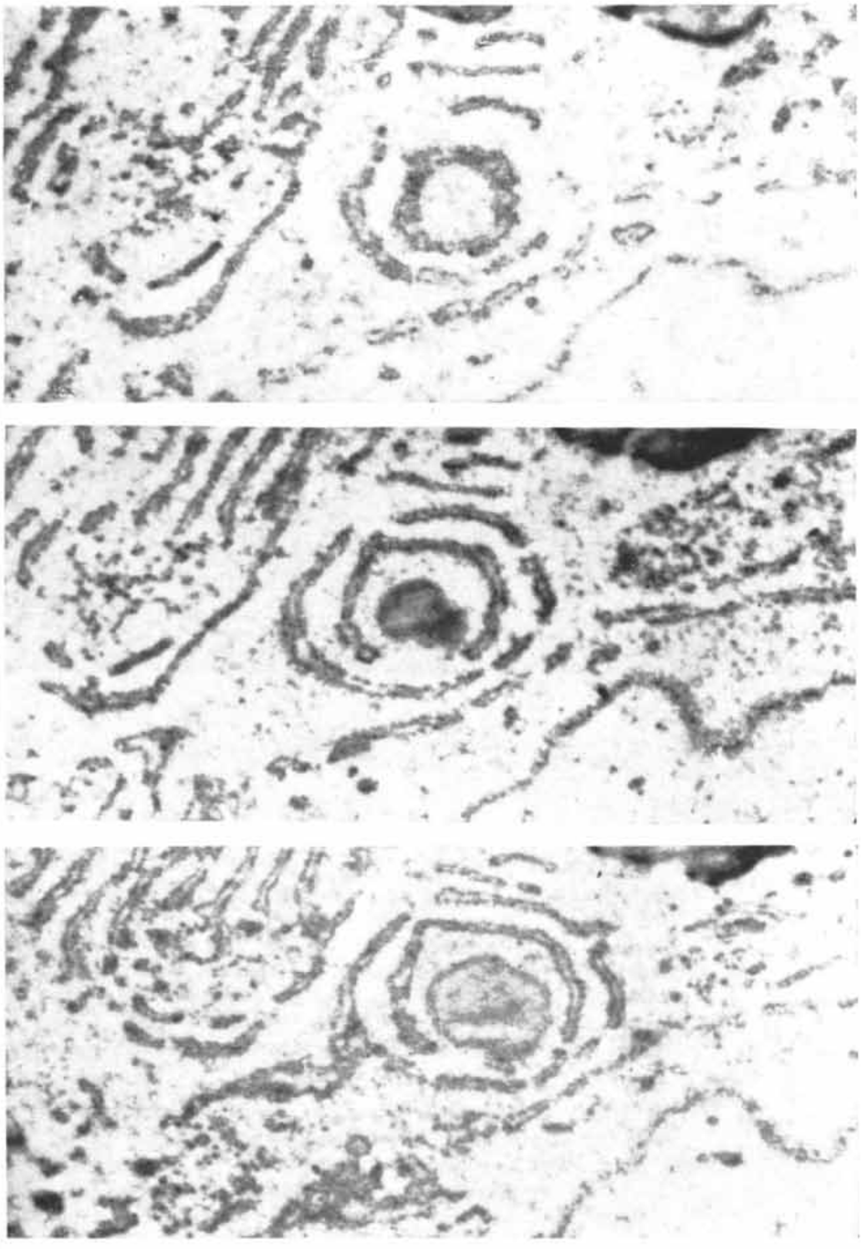


CHANGES IN SALIVARY GLAND of the fruit fly are summarized in these drawings. The development of the insect begins with its egg (*a*). In the larva (*b*) the salivary gland (*c*) is a cylindrical sac of about 100 cells. As the gland grows, the cells increase in size (*d*) but not in number. At a certain stage in development the cells produce secretion granules containing protein (*hatching*); these coalesce into droplets that pass into the cavity of the gland (*e*). The protein is part of the "glue" that attaches the insect's pupa to a surface.

in volume. The generalization is supported, moreover, by the observation of membrane-blebbing and related phenomena in other large cells.

One may therefore speculate in this vein: A special region in the chromosome of a cell, characterized by the composition of its DNA and associated RNA, confers its specificity upon the section of nuclear membrane that forms the bleb. Our observation that the chromosomal region is rich in heterochromatin corresponds with Caspersson's suggestion that this substance, which has been found to contain both RNA and DNA, plays an important role in protein synthesis. Moreover, biochemical tests show that RNA and DNA both appear in the blebs of the nuclear membrane. The section of membrane released into the cytoplasm thus varies in accord with the specificity of the chromosomal region involved in its production. In the cytoplasm it becomes a cytoplasmic membrane, a carrier of a particular type of RNA designed to direct the synthesis of a specific protein. The cell is transformed in structure and function under the domination of a new biochemical process that has been initiated by a special region on one of its chromosomes.

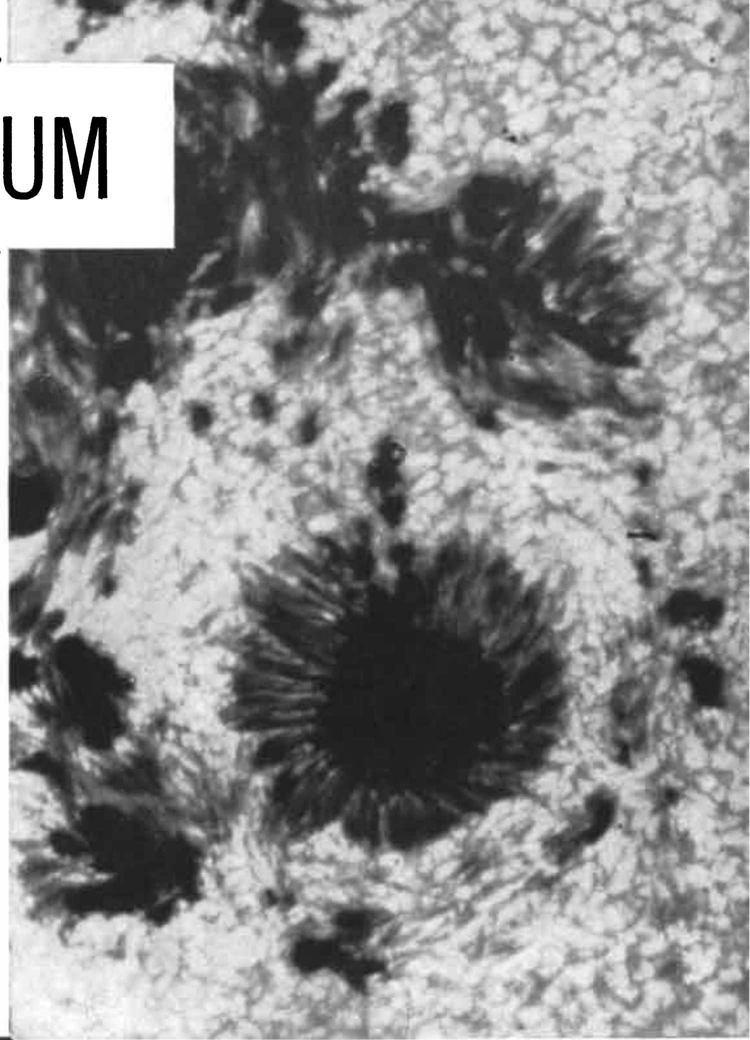
The mechanism observed in the fruit



MEMBRANES ENCLOSE SECRETION GRANULES during their formation, as shown in this series of greatly enlarged sections. The ring in the top picture is the "rim" of a cup-like bit of cytoplasmic membrane. Subsequent sections show the granule within the cup.

THE P-E SPECTRUM

news of advanced systems and instruments from Perkin-Elmer

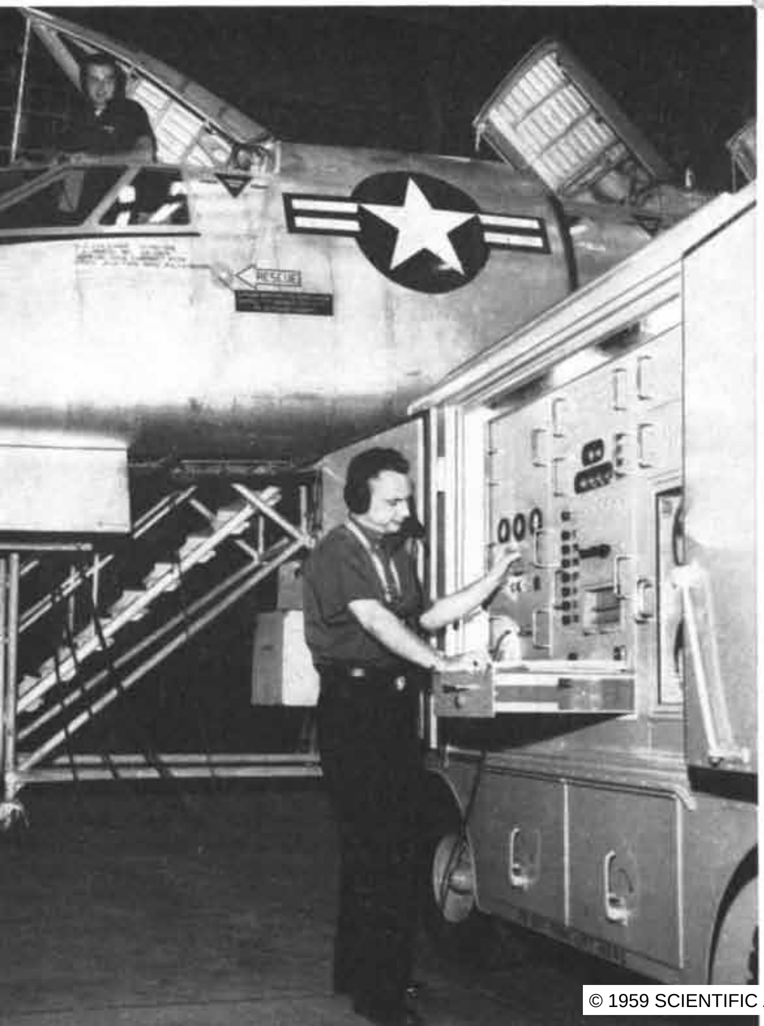


TV-EQUIPPED SOLAR TELESCOPE TAKES SHARPEST-EVER SUN SPOT PHOTOGRAPHS

This past summer's Stratoscope I flights employed a closed-circuit television hook-up for ground-based aim, control and focus of a sun telescope borne 80,000 feet high in an unmanned balloon. Result: sun spots were photographed with unprecedented sharpness, as the accompanying photo shows.

This is an active group of sun spots that caused a magnetic storm on earth the day before the flight. The spots are dark cores of relatively cool gases imbedded in a strong magnetic field. Enveloping them are wispy filaments of outward-moving warmer gases.

These balloon telescope experiments—sponsored jointly by the Office of Naval Research and the National Science Foundation, and under the direction of Dr. Martin Schwarzschild of Princeton University — are providing fundamental data of value in such fields as communications, thermo-nuclear reactions and space travel. In this year's flights, the same basic 12-inch telescope-camera system designed and built by Perkin-Elmer for the first successful high-altitude telescope flights in 1957 was used. Perkin-Elmer now is designing a much larger 36-inch balloon telescope, known as Project Stratoscope II, to be flown in 1961 for the study of planets, galaxies and nebulae.



"NEW CONCEPT" POTENTIOMETER HELPS CHECK OUT B-58 AUTOMATIC FLIGHT CONTROL SYSTEM

A mobile test set, built by Eclipse-Pioneer Division of Bendix Aviation Corp. to check out the complex automatic flight control system of the Air Force's Convair-built B-58 Hustler bomber, utilizes a unique type of a.c. potentiometer developed by Perkin-Elmer. The Vernistat* is based on a new concept in relating shaft rotation to voltage. In the B-58 test set, several Vernistats provide accurate sources of test voltages used to simulate control system signals. An alternative method of supplying voltage levels would have necessitated several additional components and would have cost four times as much as the Vernistat system.

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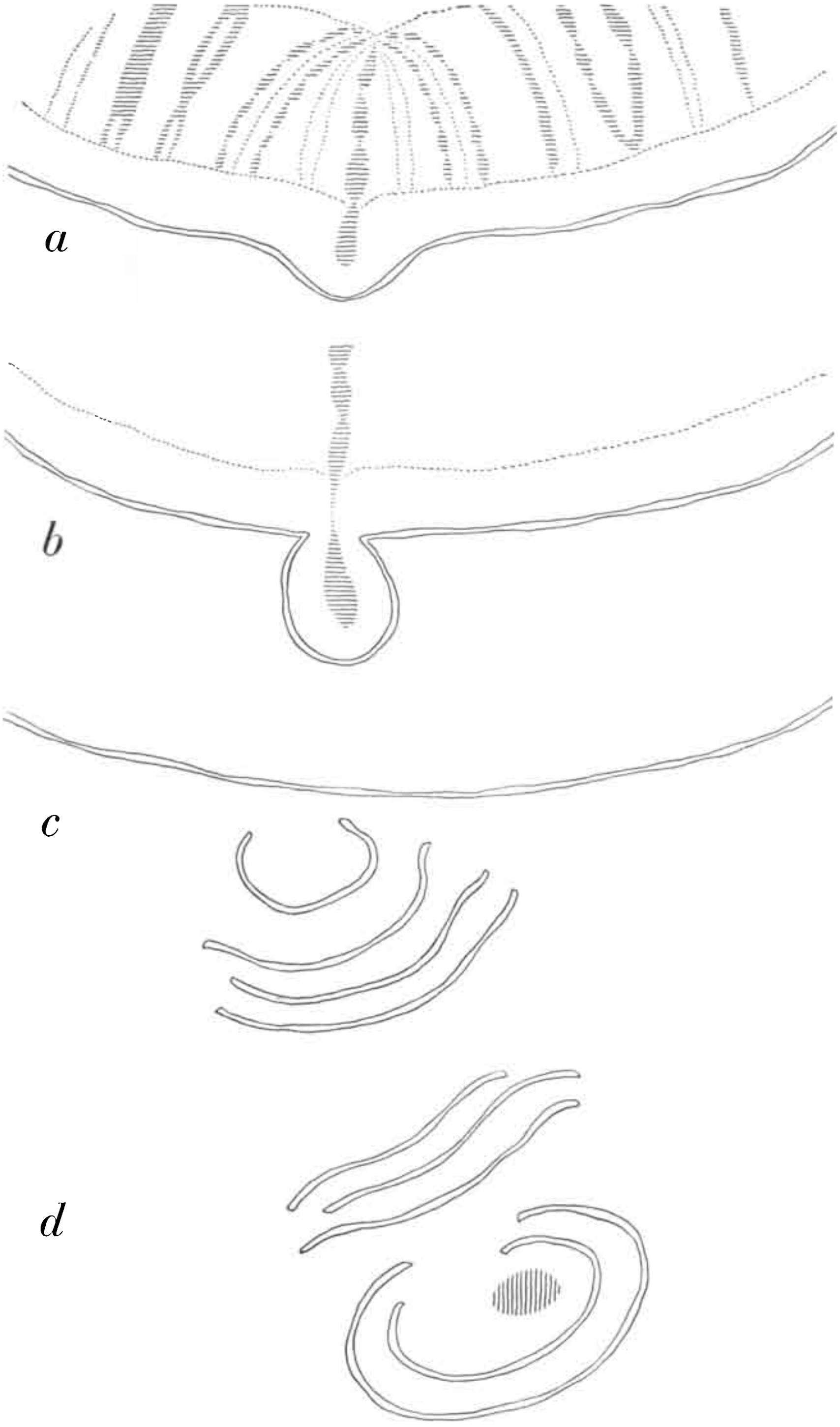
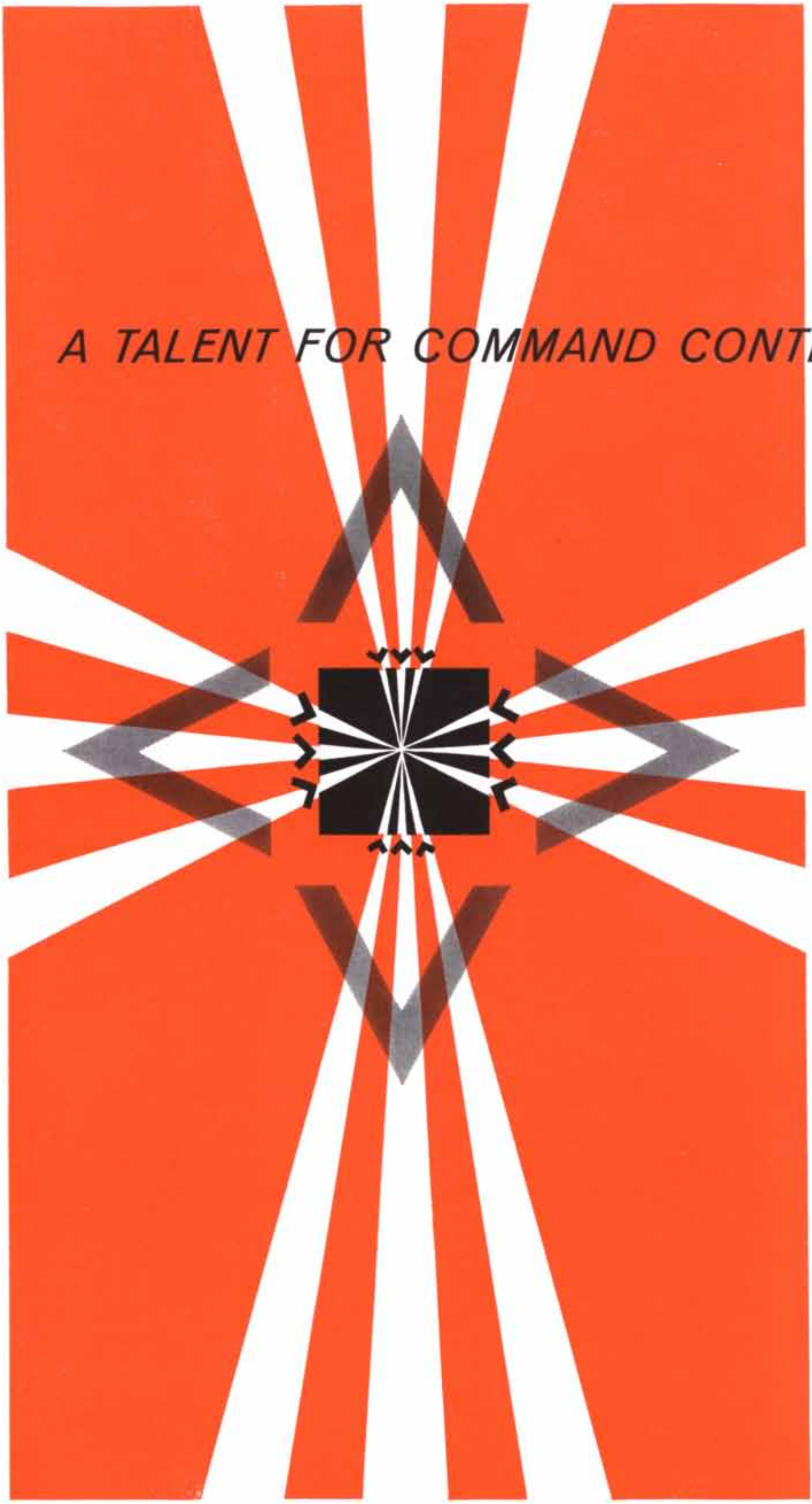
fly may be only one of a number of possible alternative systems by which material is transferred from the nucleus to the cytoplasm. In developing egg- and sperm-cells of several kinds of invertebrates the electron microscope has shown that special kinds of RNA-containing cytoplasmic membrane appear to arise from the nuclear membrane, though probably by a mechanism different from blebbing. The process so fully demonstrated in the giant cells of the salivary gland has given us leads to the discovery of these other mechanisms, and a new perspective for exploring the questions of cellular differentiation.



EVOLUTION OF A BLEB is depicted schematically in these drawings. Blebbing begins when a bit of chromosome (*horizontal hatching*) approaches the nuclear membrane (*a*). The bleb grows (*b*) and breaks free (*c*), flattening into a cytoplasmic membrane. These membranes probably synthesize the protein of the secretion granule (*vertical hatching*).

A TALENT FOR COMMAND CONTROL SYSTEMS



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The Mechanism of Breathing

Practical problems such as breathing at high altitude have in recent years focused attention on the marvelous system that brings oxygen to the blood and removes carbon dioxide

by Wallace O. Fenn

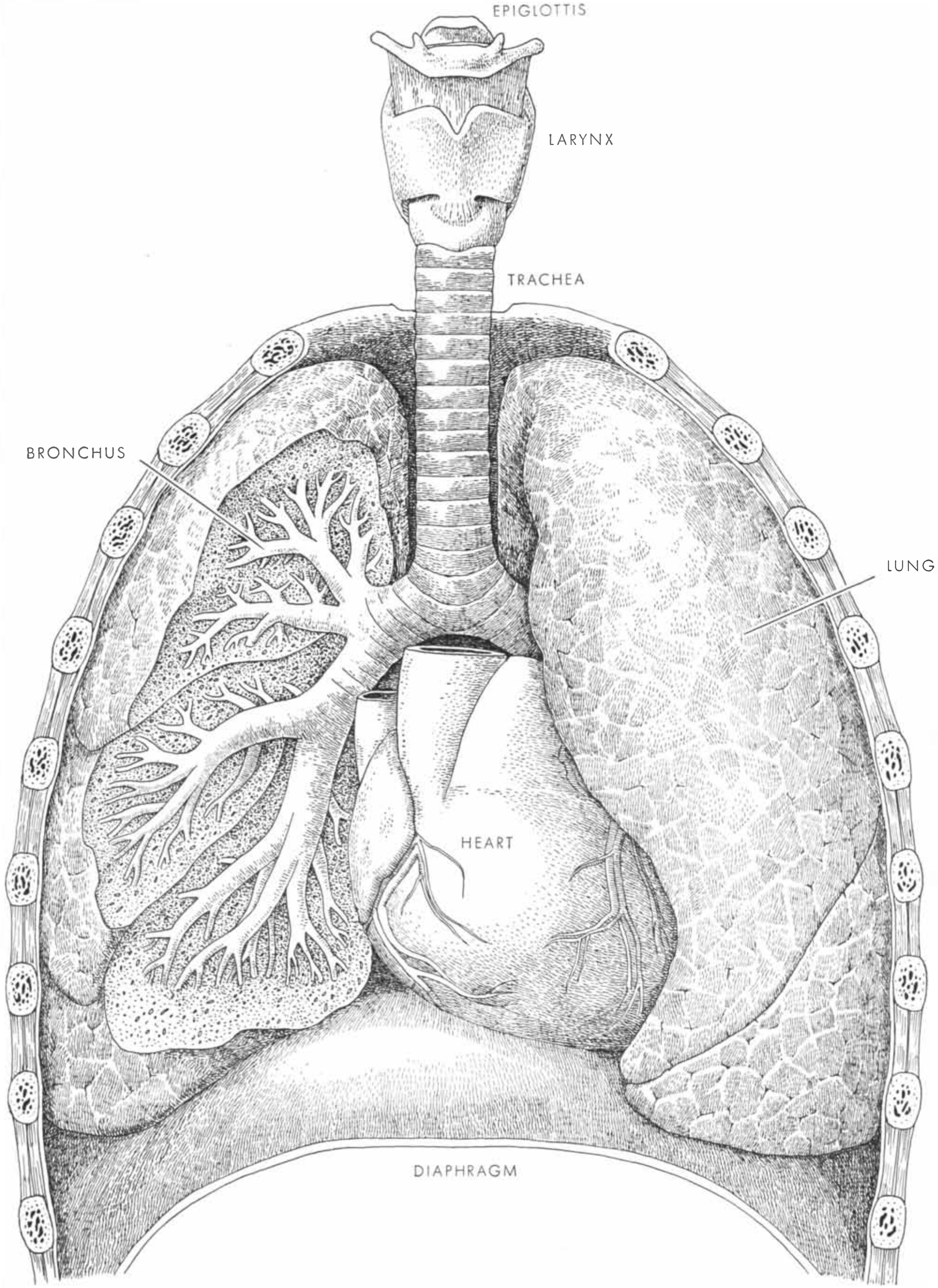
"As easy as breathing" is easy indeed, for the breathing mechanism operates with almost no effort at all. On the other hand, in some conditions of disease the labor of breathing can become an agony. The mere holding of the breath is enough to demonstrate that it is the breath of life. Breathing can be unconscious, since it continues in sleep. But voluntary effort may amplify or diminish it. In this respect breathing differs from the beating of the heart, which is not ordinarily subject to voluntary control. Breathing responds primarily to the demands of the body, from which it scavenges carbon dioxide and to which it supplies oxygen. Yet it also accommodates speaking, singing, laughing, sighing, sobbing, yawning, coughing, hiccoughing and straining—all of which require special modification of the rhythm of breathing without serious disturbance of the total ventilation per minute. All in all, breathing is a mechanism deserving of study in its own right, an example of the biological engineering that so marvelously applies the laws of physics and chemistry to the processes of the body. But it is the practical problems of breathing at high altitudes or under water, of artificial respiration and of duplicating the lung artificially that have focused attention on the mechanism in recent years and revealed aspects of its perfection not previously appreciated.

A man at rest usually breathes about seven liters of air per minute. Breathing keeps this volume fairly constant and thereby stabilizes the concentration of carbon dioxide in the arterial blood. Until Lavoisier demonstrated the essential role of oxygen in respiration it was commonly thought that the chief function of respiration was to cool the blood or to produce the voice. It is not the need for oxygen, however, but the need to eliminate carbon dioxide that ordinarily sets the rate of breathing. During exercise, for example, the volume of air breathed increases in proportion to the increase in the amount of carbon dioxide that must be eliminated from the blood. Through the activity of nerve centers in the brain the ventilation is unconsciously adjusted so that about 20 liters of fresh air actually reach the gas-exchanging surface of the lung for every liter of carbon dioxide produced. The need for oxygen takes precedence over the elimination of carbon dioxide only when oxygen is in short supply. Then the body manages to tolerate some deviation in the carbon dioxide level in order to satisfy the more pressing need.

The most important organ of respiration is of course the lung, where the exchange of oxygen and carbon dioxide takes place. The other respiratory structures consist of the tubes or passageways through which air passes to and from the lungs, the rib cage that encloses the lungs, and the muscles that cause the lung to expand and contract. The lung itself contains no muscles, but it adheres closely to the chest wall and the diaphragm and follows their motions. A thin layer of fluid at once holds together and separates the pleurae: the membranes that form the covering of the lungs and the lining of the chest. During inspiration—or breathing in—the dome-shaped muscle of the diaphragm contracts and flattens out, extending the chest cavity downward. At the same time the outer muscles of the ribs and other muscles of the chest contract, raising the ribs and increasing the diameter of the chest. The enlargement of the chest lowers the air pressure in the lungs. Under the pressure of the atmosphere, air rushes in to fill them. In quiet breathing, expiration—or breathing out—is accomplished without additional muscular effort, as the chest and lungs return to their resting positions. In heavy breathing, expiration is aided by the contraction of abdominal muscles that push the diaphragm upward, and by muscles on the inside of the rib cage that force the ribs downward. Inspiration always requires muscular effort, but expiration is ordinarily a purely passive process.

Like a rubber balloon, the lung inflates and stretches as the air enters, and collapses as the air leaves. Yet the lung is very different from a thin-walled elastic bag; it actually appears solid to the naked eye. An average pair of human lungs weighs only one kilogram, even though they hold about three liters of air at the end of expiration. Since the density of human tissue is about one kilogram per liter, this capacity is evidence that the lungs are approximately three fourths air space. It is the low density of the lungs that causes the butcher to call them "lights." The bronchi, which lead from the trachea into the lungs, branch and rebranch like a tree. With a microscope one can see that the smallest branches, the bronchioles, end in many small sacs, the alveoli. Where the routes to the alveoli from the trachea are short, the tubes are apparently smaller in diameter; as a result all of the alveoli, regardless of their distance from the trachea, tend to expand simultaneously—a neat engineering trick!

It was the plight of the aviator at high altitudes that stimulated physiologists to study breathing more closely. Since the air at, say, 40,000 feet is thin, the aviator must inhale oxygen from a mask under a pressure somewhat higher than that of the surrounding atmosphere. Otherwise the oxygen pressure in the lung might not be high enough to force sufficient oxygen into the blood. This "pressure-breathing" is sometimes used



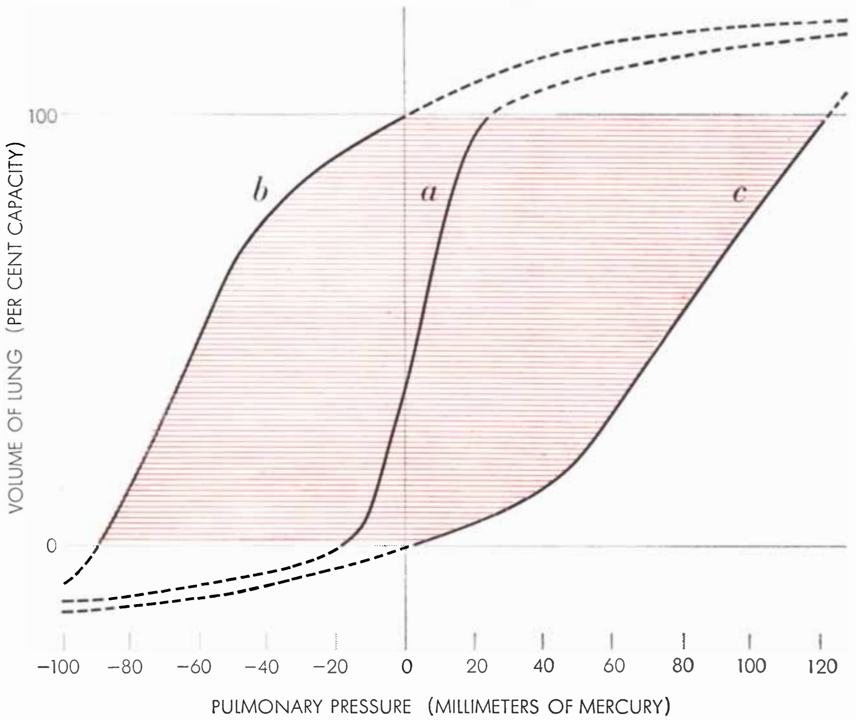
PRINCIPAL ORGANS OF BREATHING are depicted in this drawing, in which the ribs have been cut away. At the left side of the drawing the great vessels of the heart and part of one lung have also been cut away to show how the trachea branches into a bronchus, which branches in turn throughout the lung into bronchioles. Structure is depicted in finer detail in drawings on page 144.

in hospitals to open up collapsed alveoli or to offset pulmonary edema, a condition in which fluid leaks into the membranes and air spaces of the lung and impairs the diffusion of oxygen into the blood. In pressure-breathing the compressed oxygen (or air) expands the lung and inflates the chest somewhat. But pressure-breathing can also induce untoward effects such as stagnation of blood in the veins and impairment of return of blood to the heart. This may lead to loss of consciousness and have other serious consequences, since the heart cannot pump blood out when no blood comes in.

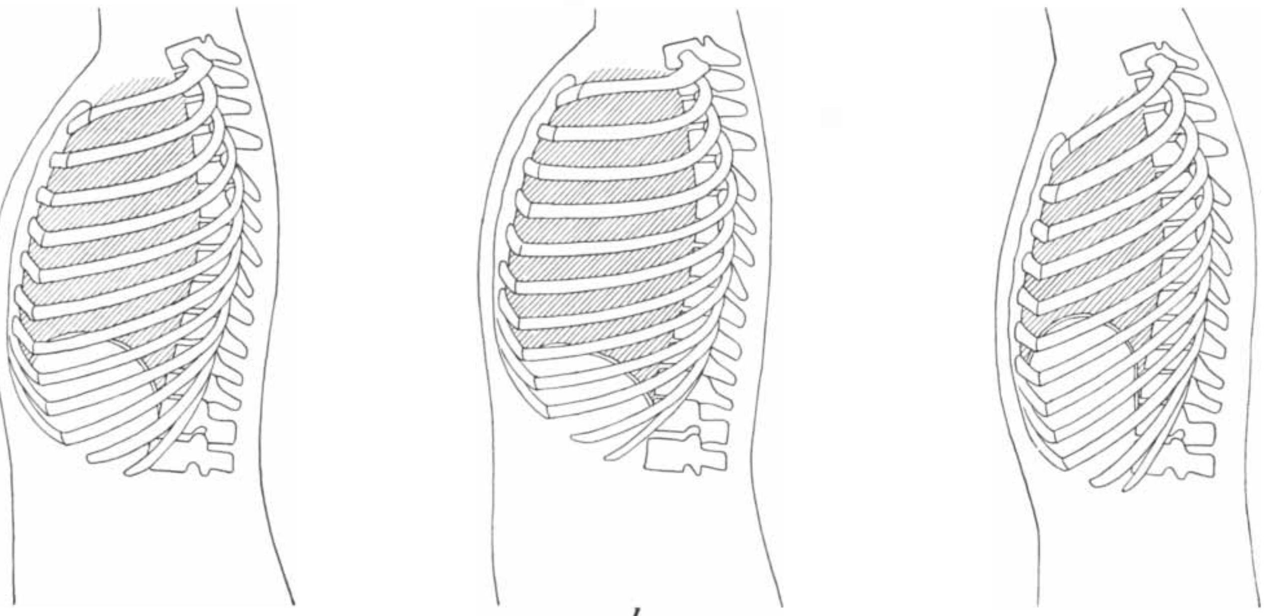
Physiologists studying the breathing apparatus began constructing "pressure-volume" curves in order to ascertain how much the lung was expanded by various pressures. They soon found that similar curves had been constructed many years before by F. Rohrer and A. Jaquet in Switzerland; these results had apparently been forgotten by later students of the subject. Jaquet had put to good scientific use a curious device called the pneumatic differentiation cabinet, which had been employed by clinicians in the U. S. for some years. The subject sat inside a closed cabinet and breathed through a tube to the outside, while a bellows arrangement alternately rarefied and compressed the air around him. In this way the apparatus induced "artificial respiration" and supposedly cured the patient of a variety of ailments. In principle the device resembled the "iron lung," so widely used nowadays to ventilate the lungs of patients paralyzed by poliomyelitis. Jaquet set the air pressure in the chamber at various positive and negative limits and collected the air taken in or expired through the tube at each breath. He then plotted the volumes against the pressure changes required to produce them. The result was a pressure-volume curve of the chest and lung quite comparable to those made recently by the simpler procedure of measuring the pressure when the subject stops breathing and relaxes with different amounts of air in the lungs.

An inflated balloon gives only one such pressure-volume curve. But in a chest-lung system there are three distinctly different curves and an infinite number of intermediates. The three curves represent three different conditions: (a) when all the muscles are completely relaxed, (b) when all the inspiratory muscles contract maximally and (c) when all the expiratory muscles contract maximally [*see illustration below*]. The curves have a significance that goes beyond pressure-breathing. In fact, they describe the mechanical limits of the breathing apparatus more or less completely. They plot the net effect of all such factors as the pressures developed by the muscles of the diaphragm and chest, the weight of the abdominal viscera (which pull down on the diaphragm), the tenseness of the abdominal wall (which resists the weight of the viscera), the stiffness or compliance of the chest wall and the stiffness or compliance of the lung itself.

As the curves show, the lungs increase in volume when air is forced into them under pressure, and decrease in volume when air is withdrawn from them under negative pressure. At atmospheric pressure the lungs attain their maximum volume when all of the inspiratory muscles are maximally contracted and the glottis is open. Negative pressure is then required (that is, air must be sucked out of the lungs) to decrease the volume. Similarly the lungs find their minimum volume at atmospheric pressure when all of the expiratory muscles are maximally contracted and the glottis is open [*curve c in illustration*]. If the muscles remain active, and positive pressure is applied to the airway, the volume of the lung increases along curve *c*, the pressure required at each point being just equal to the maximum pressure which the expiratory muscles can develop at that volume. As might be expected, the voluntary expiratory pressure is greatest when the lungs are maximally inflated, and the voluntary inspiratory pressure is greatest when the lungs are maximally deflated. When all the respiratory muscles are relaxed—the condition at the end of a normal expiration—the volume of the lungs at atmospheric pressure is about midway between its maximum and minimum, the exact volume varying with posture. The pressure-volume curve derived when the muscles are relaxed [*curve a*] is shaped like a stretched-out "S" and crosses the vertical line marking atmospheric pressure. At the point of crossing, the volume is equal to that reached at the end of normal respiration. The curve determined with inspiratory muscles contracted is pushed to the left of this; the curve determined with expiratory mus-



SET OF THREE CURVES shows the typical relationship of the volume of air in a pair of lungs to the internal pressure under three conditions: (*a*) when all muscles of breathing are relaxed; (*b*) when inspiratory muscles are fully contracted; (*c*) when expiratory muscles are fully contracted. Zero pressure indicates atmospheric pressure. Zero lung volume indicates the maximum volume attainable by inspiratory effort; 100-per-cent volume indicates the minimum volume attainable by expiratory effort. Thus shaded area includes the whole range of pressure-volume values possible by voluntary effort. Extreme external pressure or suction can extend the volume of the lung beyond these limits toward the bursting point (*broken lines at upper right*) or toward lung collapse (*broken lines at lower left*).



CHEST POSITIONS corresponding to the curves on facing page illustrate the effects of muscle contraction on the size of the lungs (*hatched area*). At the end of a normal expiration (*a*) the respiratory muscles are relaxed. In maximum inspiration (*b*) the chest is enlarged by the flattening of the diaphragm and the raising of the ribs. In maximum expiration (*c*) the diaphragm is pushed upward beyond its resting position by the abdominal muscles, and the ribs are forced downward, thus decreasing the size of chest cavity.

cles contracted is pushed to the right.

The resting volume of the lungs at the end of a normal expiration depends partly on posture; it is less in the supine than in the standing position. This is chiefly due to the fact that in the supine position the viscera push up against the diaphragm. The effect is easily demonstrated by a simple experiment. After standing quietly and breathing normally, the subject holds his breath at the end of a normal expiration and lies down quickly before starting to breathe again. He will usually begin by breathing out instead of in. In the reverse experiment, where the subject, lying supine, holds his breath at the end of expiration and stands up, he will start by breathing in. Effects of other changes in posture can be similarly demonstrated. If the subject holds his breath at the end of expiration while lying on his stomach and then lifts his head and raises himself on his elbows, his first respiratory motion will be inspiration. This effect, incidentally, is the basis for the new method of artificial respiration adopted by the armed services. The operator alternately raises the shoulders of the prone subject and presses on the subject's lower ribs. These maneuvers alternately increase and decrease the volume of the thorax and thus move the air in and out.

In quiet breathing the muscles of course do not contract maximally. In fact, the expiratory muscles do not contract at all; the recoil of the chest wall and the collapse of the stretched lung-tissue do the work of expiration. At the end of a normal expiration, when all the muscles are at rest, the lung has a tendency to collapse further. It is prevented from doing so by its close adherence to the chest wall. Thus the lung pulls itself inward while the chest wall pulls it outward. When the lung is separated from the chest wall, for instance by allowing air to enter the fluid-filled space between them, the lung collapses and the chest expands somewhat. The lung and the chest act like coupled springs. With the springs hooked together, extension of the lower spring (the lungs) also pulls down the upper spring (the chest) until the tension in the two springs is equal. It is easier to move the point of attachment of the springs upward, stretching the lung spring and relaxing the chest spring, than it is to stretch the lower spring the same amount when it is unattached. This is essentially what happens in inspiration. The elasticity of the chest helps the lungs to expand; up to a point it is easier to inflate both the chest and lungs than to inflate the lungs alone. When the chest reaches its resting volume, however, further inflation requires muscular work. From this point onward it is harder to inflate both the lungs and chest than the lungs alone. In the spring model this is the point at which further raising of the point of attachment requires effort to compress the upper spring as well as to extend the lower spring. If a bubble of air is introduced between the lungs and the chest wall, it tends to expand slightly, being pulled in opposite directions by the two "springs." The air pressure in such a bubble is about five centimeters of water less than atmospheric pressure, this being a measure of both the tendency of the lungs to collapse and the tendency of the chest to expand.

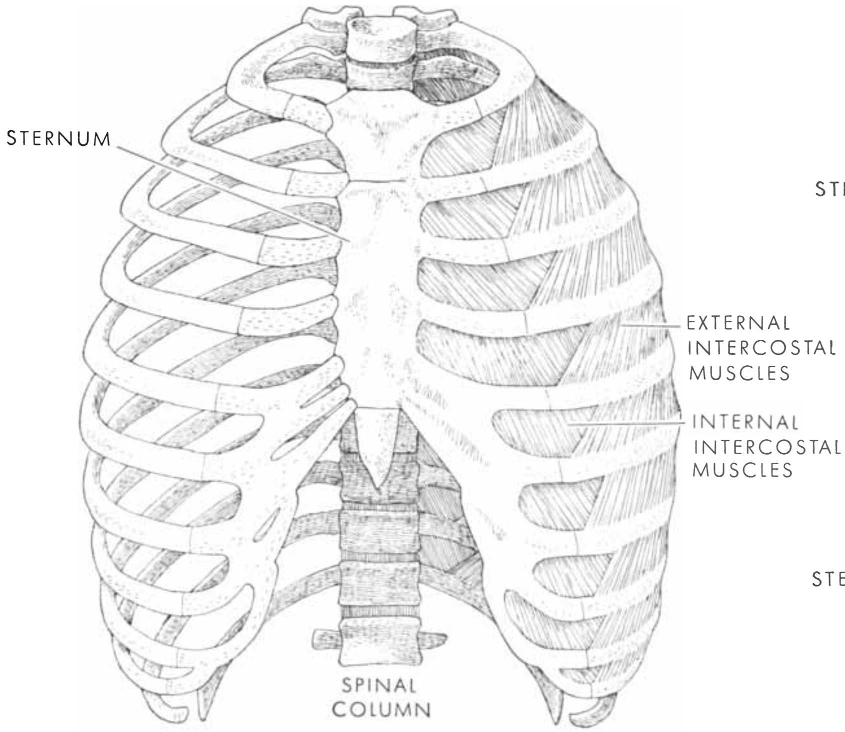
The resistance of the lung to collapse thus depends on the chest and is limited by the strength of the inspiratory muscles. The inspiratory muscles contract maximally either to resist a high pressure outside the body (which is tending to collapse the chest) or to withstand strong negative pressure inside the lungs (which would have the same effect). To conceive this unlikely situation, imagine sitting on the bottom of a swimming pool and trying to breathe air at atmospheric pressure through a tube reaching to the surface. The pressure in the lung is then atmospheric, but the pressure exerted on the surface of the body by several feet of water is much greater. Actually the inspiratory muscles cannot overcome a pressure greater than that produced by about four feet of water; breathing air at atmospheric pressure is impossible in deeper water. In addition to the inhibition of breathing, the pressure differential has the following consequence. High pressure on the body surface forces large quantities of blood into the right side of the heart, which then tends to pass it along to the lungs, where pressure is low. At the same time the left side of the heart must pump blood out of the lungs into regions of abnormally high pressure. With the right heart pumping more blood into the pulmonary blood vessels and the left heart pumping less blood out of them, these vessels dilate. They might possibly be expected to rupture under such conditions. The evidence that this can actually occur, however, is slim—few persons have tried this rather drastic experiment.

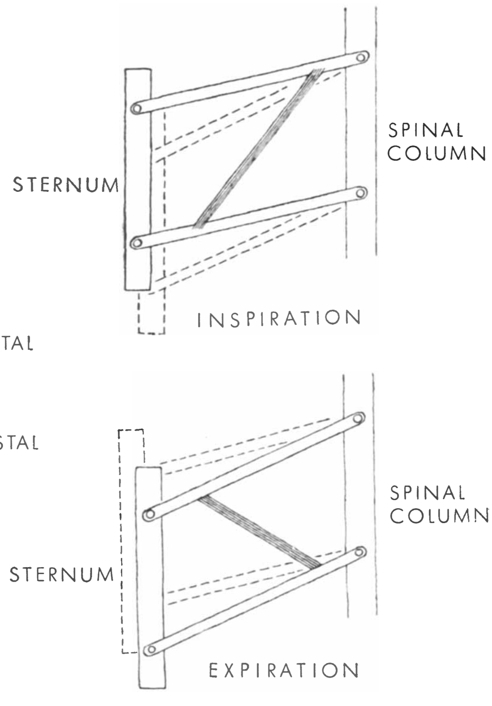
The lung itself can rupture if it is blown up too far. But there is little danger of this, regardless of the pressure inside the lung, so long as the organ is held to its normal size by the rigid chest wall around it. In this respect the lung resembles a football; the pressure inside a football is high compared with atmospheric pressure, but the pigskin cover takes up the pressure and keeps the rubber bladder from stretching to the breaking point. Similarly the normal straining movements of the body may force the pressure in the lung above 100 millimeters of mercury. But the chest keeps the lung volume within normal range and protects the lung wall from excessive stress. There are circumstances, however, when the chest may not be able to confine the lungs sufficiently. In practicing escape from the high-pressure air-lock of a sunken submarine, the submariner must blow out air continuously as he ascends. If he fails to do this and closes his glottis in panic, the high-pressure air in his lungs will expand so greatly, as he rises to regions of lower water pressure, that his chest will be forced to expand, permitting the lungs to inflate to dangerous levels. Lungs have often ruptured under these conditions. Air may then be forced into the bloodstream, forming bubbles which are pumped out of the heart in the arterial blood. If one of these bubbles reaches a vital spot in the brain, it may block the flow of blood and cause loss of consciousness and perhaps cessation of breathing and death. The victim must be put promptly into a compression chamber and subjected again to high pressure in order to force the offending bubbles into solution.

The pressure changes in the lung are ordinarily of a small order. In quiet breathing the pressure in the air spaces of the lung falls and rises only slightly during inspiration and expiration. This small variation in pressure, equivalent to the pressure of a few centimeters of water or a few millimeters of mercury, is enough to move the air in and out. The pressure-volume curve of natural breathing is a small ellipse [*see illustration on page 146*], the height of the ellipse measuring the volume of air exhaled or inhaled and its width indicating the pressure differential. When breathing is obstructed, as in asthma, the changes in pressure must be greater, and the pressure-volume ellipse widens.

The changes in pressure within the lung can be measured fairly accurately by causing the subject to breathe through a tube that can be momentarily closed and opened for a few hundredths of a second while a continuous record is taken of the pressure in the tube between the mouth and the shutter. Each time the flow stops, the pressure in the tube immediately falls or rises to equal that of the air inside the lungs. The pressure changes measured in this way are those required to move the air in and out of the lungs.

To measure the total work done by the muscles in breathing requires in addition a consideration of the elastic recoil of the chest, diaphragm and abdominal wall, which to some degree assist in the expansion of the lungs. Thus at any moment in the respiratory cycle the pressure required is given by the



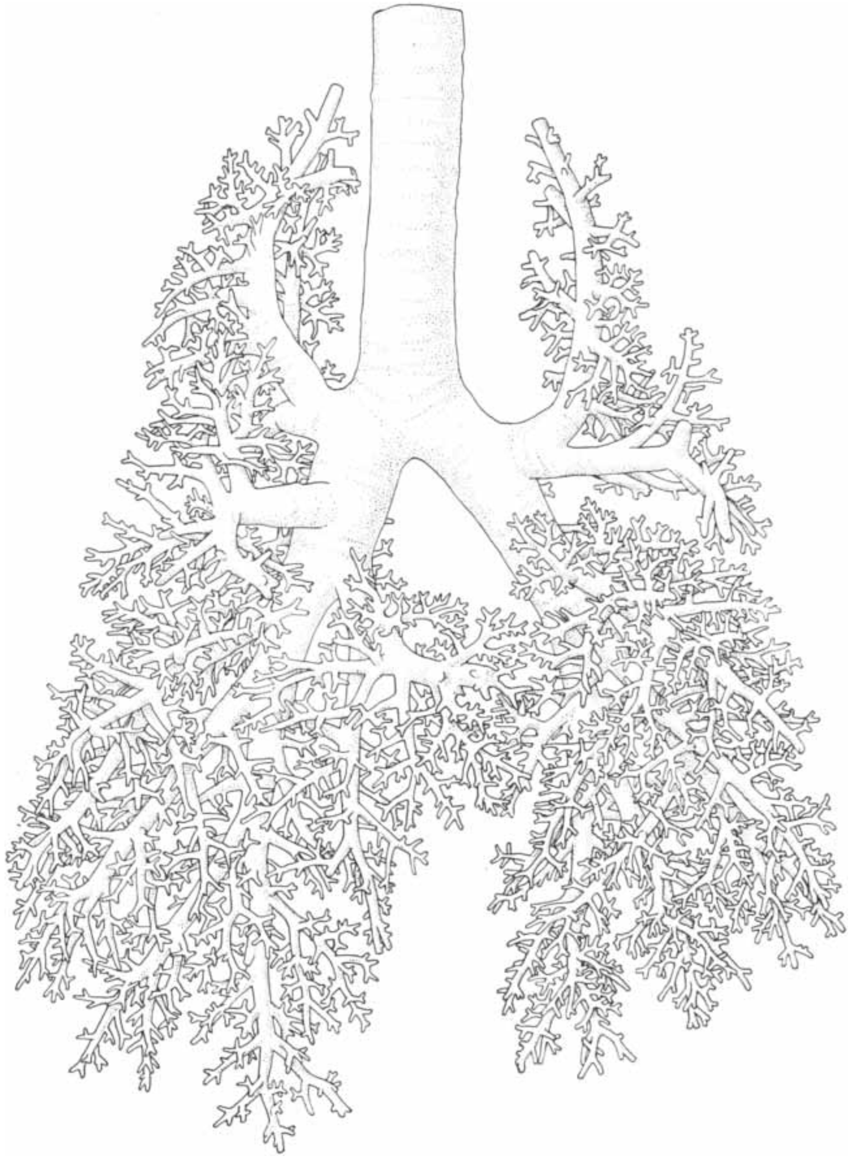


RIB CAGE is hinged to the spinal column and to the sternum, and adjacent ribs are connected by two sets of muscles (*omitted on the left side of this drawing*). The mechanism (*diagrammed at right*) is such that the contraction of the external intercostal muscles raises the ribs and sternum (*upper diagram*) and the contraction of the internal intercostal muscles lowers them (*lower diagram*).

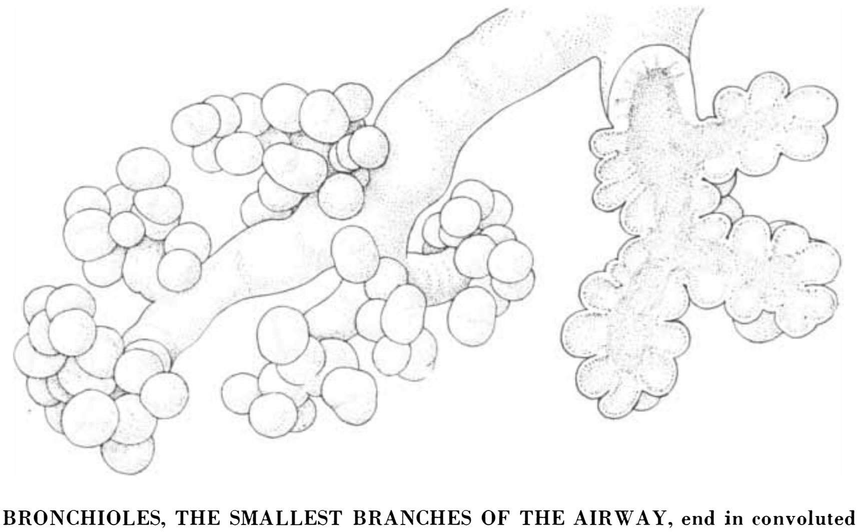
difference between the pressure in the lung at that moment and pressure of air that would have to be forced into the resting lung to expand it to the same volume. In the pressure-volume diagram the active inspiratory pressure developed by the force of the contracting muscles is therefore indicated by the horizontal distance between the appropriate point on the breathing loop and the pressure-volume curve of the resting system. A small portion of the force is exerted during inspiration and expiration to overcome the viscous resistance of the air flow in the trachea, bronchi and bronchioles. The major portion of the muscular effort, however, is exerted during inspiration to overcome the elastic recoil of the lungs and the thoracic cage. During expiration the elastic recoil of the lung serves to collapse the chest, to move air out and to overcome any frictional resistance in the lungs and chest and any resistance that may be offered by persistent activity of the inspiratory muscles. If more pressure is needed, the expiratory muscles are activated.

In each case the work done can be deduced from a pressure-volume diagram. The total work of one breath is given by the area between the inspiratory side of the breathing loop and the pressure-volume curve of the breathing mechanism at rest. For one breath this is equivalent to raising one pound one and a half inches. In labored breathing, however, the breathing loop overlaps the resting pressure-volume curve; the area of this overlap represents the work done by expiratory muscles in the total breathing cycle.

As the pressure-volume diagram shows, the breathing loop normally covers only a small fraction of the area between the curve derived with the inspiratory muscles contracted and that derived with the expiratory muscles contracted. This indicates that in normal breathing the muscles do much less work than they are capable of doing. Even if a person tried to breathe as deeply and as quickly as possible, it is not likely that his muscles would exert their maximum pressures. With an open airway the volume of the lungs changes so rapidly that the muscles do not have time to develop the maximum pressure at every volume, and the breathing loop still does not cover much of the available area. If the subject were made to move air in and out through a small hole, however, it might be possible to force the muscles to develop maximum pressure and produce all the work represented by the total area between



BRANCHED PATTERN OF THE AIRWAY was drawn from a cast made by Hermann Rahn of the University of Buffalo School of Medicine. Liquid plastic was allowed to enter all but the smallest branches of the airway before hardening; tissues were then dissolved.

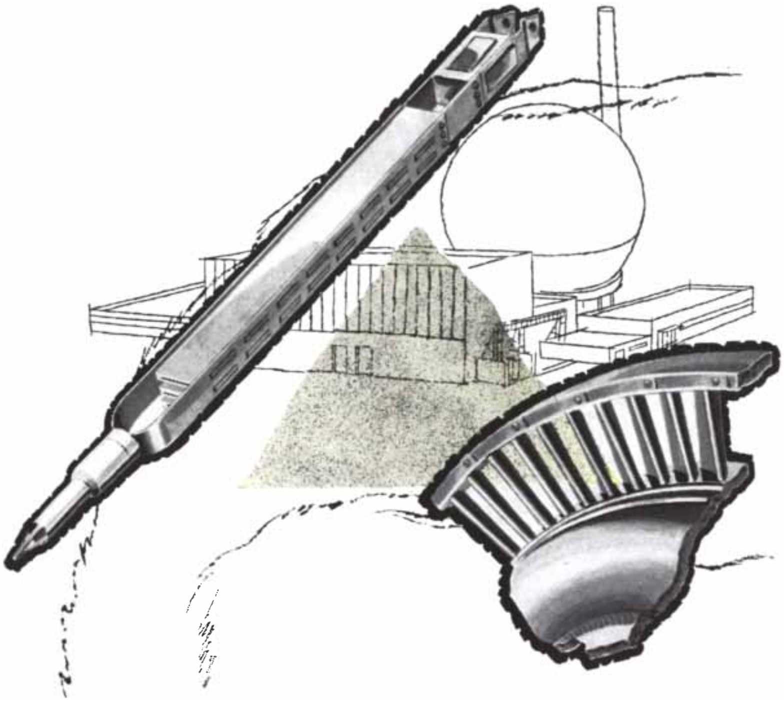


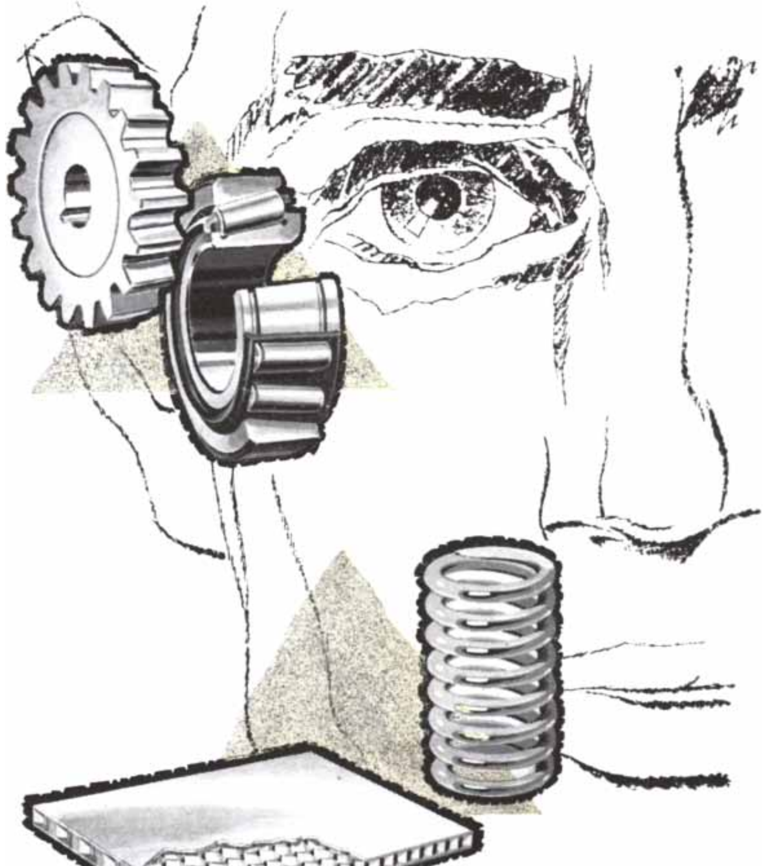
BRONCHIOLES, THE SMALLEST BRANCHES OF THE AIRWAY, end in convoluted air sacs, or alveoli. The structures, which have been cut open at right, are greatly enlarged. The thinness of alveolar walls permits oxygen and carbon dioxide to diffuse through them.

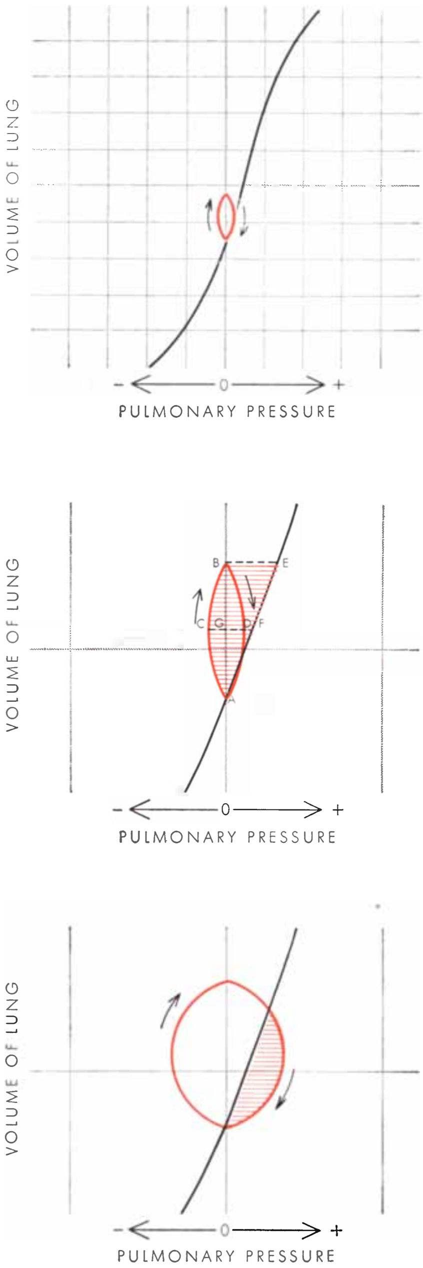
the two pressure-volume curves of contracted muscle.

Since the object of breathing is to get a certain volume of fresh air down to the blood every minute, one may wonder which is more efficient: rapid shallow breathing or slow, deep breathing. To settle this question one must consider that the exchange of oxygen and carbon dioxide takes place only in the tiny, thin-walled alveoli and not in the trachea, bronchi and bronchioles. In each breath, therefore, approximately 150 cubic centimeters of air ventilate dead space and accomplish nothing so far as gas exchange is concerned. The more breaths one takes per minute, the greater the amount of this useless ventilation. From this point of view it is cheaper to take a few large breaths rather than many small ones. On the other hand, the pressure-volume diagram shows that the work done with each breath increases as the square of the volume. From this point of view it is cheaper to take many small breaths per minute. It is apparent that greatest efficiency lies somewhere between the two extremes. Careful calculation indicates that approximately 15 breaths per minute, each of about 500 c.c. in volume, provide the necessary ventilation of the alveoli with the least possible expenditure of energy. Recently my colleagues Emilio Agostoné and Fred Thimm made similar calculations for the dog, cat, rabbit and guinea pig and found that each species has selected the breathing frequency that will do the job with the least work. The principle of least effort and minimum work thus seems to have played a fundamental role in the process of evolution.

A crucial feature of the breathing apparatus is the thin layer of fluid that causes the lung to adhere to the interior wall of the chest. Without it the lungs would not follow the chest wall when it expands and the whole mechanism would fail. This adherence can be broken by introducing a hollow needle into the intrapleural space between the lung and the chest wall, permitting air to leak into the space. The lung thereupon collapses. This "pneumothorax" procedure is often used to permit a diseased lung to heal without the mechanical disturbance of continual expansion and contraction. The remarkable fact is that air introduced in this manner around the lung spontaneously disappears in the course of time. The lung slowly expands until within a few weeks it again adheres to the chest wall. If the lung needs still more rest, the patient







PRESSURE-VOLUME CURVE of quiet breathing is a small ellipse (*at top and enlarged at center*). The work of respiration is indicated by the hatched area between the inspiratory side (*ascending arrow*) of the breathing loop and the pressure-volume curve of the resting lung (*black curve*). Area within the loop represents work of moving air in (*left of zero*) and out (*right of zero*). Triangular area to right of zero represents the elastic work of expanding the lung and chest. At point C on the loop, the muscle force is given by CF, the horizontal distance to the resting curve. Of this only CG moves air inward. At point D the elastic recoil equals GF; fraction DF overcomes the frictional resistance of the tissues; fraction GF moves air outward. In deep breathing, expiratory muscles are used, and the breathing loop overlaps the resting curve (*bottom*). The area of the overlap (*shaded*) represents the work of these muscles.

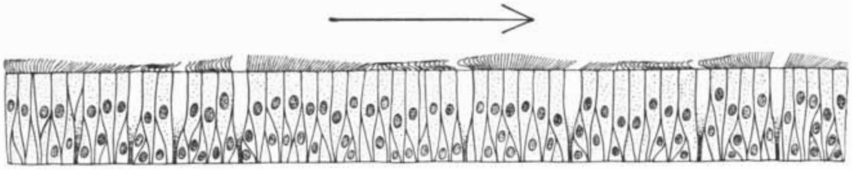
may come back to the hospital for a "refill" of air. If a relatively insoluble gas such as sulfur hexafluoride is used for this purpose instead of air, the absorption of the pneumothorax can be delayed about a month, but can never be avoided altogether.

This reabsorption of air in the intrapleural space provides an important protection for the breathing apparatus. The negative pressure set up by the opposed-spring action of the lung and chest wall would otherwise cause a bubble of air, however small, to grow in the space and eventually separate the lung from the chest. The mechanism by which the gas is reabsorbed depends upon the special properties of the hemoglobin in the red blood corpuscles, which determine to a large extent the relative solubilities of carbon dioxide and oxygen in the blood. When blood passes through the tissues, it gains carbon dioxide and loses oxygen in about equal amounts. In this process the pressure of carbon dioxide increases only six millimeters of mercury, whereas the oxygen pressure falls by about 60 millimeters of mercury. Hence the total gas pressure in the venous blood is 54 millimeters less than that in arterial blood. The total pressure in a bubble in the intrapleural space, however, is only five millimeters less than atmospheric pressure and is therefore always greater than the sum of all the gas pressures (of nitrogen, oxygen, carbon dioxide and water) in the venous blood. The bubble thus tends to come into equilibrium with the venous blood by simple diffusion of the gases until the pressure of each gas is the same in the bubble as in the blood. If the volume of the bubble remained constant, its total pressure would fall until it equaled the total pressure of the gases in the venous blood. But the bubble is not a rigid container; it remains not at constant volume but at constant pressure. Consequently it contracts as the gases diffuse out of it, keeping the partial pressure of each gas slightly higher than the corresponding pressure in the blood. Thus the flow of each gas from the shrinking bubble is aided by a diffusion gradient until the bubble completely disappears.

An equally ingenious pumping mechanism regulates the amount of fluid in the intrapleural space. The negative pressure created by the opposite pulls of the lung and the chest wall would tend to cause excess fluid to seep in. But the tendency of the lungs to absorb fluid as well as air is an even more important factor. The pleural fluid contains the same salts as blood plasma, but it lacks the proteins that are present in rather high concentration (6 per cent) in the plasma. An osmotic pressure-gradient therefore causes water to flow from the fluid into the bloodstream. In most of the capillaries of the body the tendency to absorb fluid is balanced by the tendency of the capillary blood pressure to force fluid out. Thus if it were not for the osmotic pressure of the blood proteins, water would leak out of the capillaries, and we would all be blown up like footballs, with a tight and turgid skin. The situation in the lungs is different, however, because the blood pressure in the pulmonary circuit is only a fifth or sixth of that of the general circulation and does not completely balance the tendency of the blood proteins to absorb water. Water therefore tends to flow into the pulmonary capillaries from the surrounding fluid. Recently a group of investigators at the University of Milan succeeded in measuring this osmotic pressure-gradient. They applied a porous capsule filled with salt solution (equal in concentration to that of blood) to the surface of the lungs and measured the pressure required to prevent this water from being absorbed by the blood. They found that the lung capillaries exert a negative pressure of 14 millimeters of mercury; at other sites in the body they observed no such pressure. This remarkable feature of the breathing apparatus prevents fluid from accumulating not only in the intrapleural space but also in the air spaces of the lung, where it might interfere with the diffusion of oxygen.

The airway in smaller bronchi and bronchioles is also kept clear of obstruction by the whiplike cilia of the epithelial cells that line their passages. These microscopic fibers beat in rhythmic waves to push fluid or mucus up toward the glottis. A. C. Hilding of Duluth, Minn., has introduced plugs of mucus into sections of the airway taken from chickens and, by means of a manometer, determined that the cilia are capable of producing a negative pressure of four centimeters of water.

Another mechanism for clearing obstructions from the airway is the cough. In coughing a forcible expiratory effort against a closed glottis first raises the air pressure in the chest. The glottis then opens suddenly, reducing the pressure in the trachea and large bronchioles to the atmospheric level. The high pressure still remaining in the main air spaces of the lung around the trachea collapses the membranous back wall of the trachea inward [*see bottom illustration on page 148*]. As a result the air passes out



CILIARY EPITHELIUM lining the trachea, bronchi and bronchioles is shown in this longitudinal section. The hairlike cilia beat rhythmically in waves to propel mucus and other material toward the glottis (*here to the right*). Cells without cilia are gland cells.

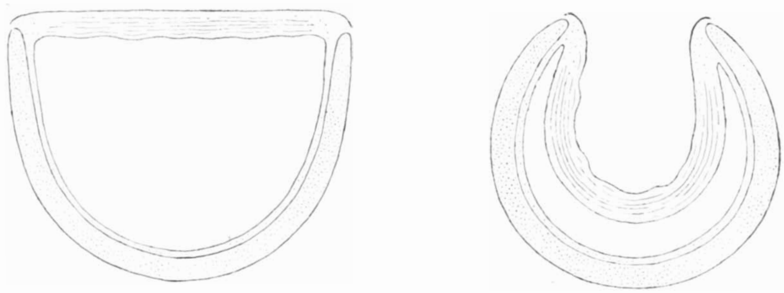
through a much-narrowed trachea with great force and velocity, blowing out foreign material or mucus with it.

A sneeze might be described as an upper respiratory cough. In the preparatory stages more and more air is inspired, and at the climax the air is expelled with explosive force. The glottis in this case is wide open, and the air meets its chief resistance in the mouth or nasal passages so that the expiratory blast serves to clear the passages of the nose or mouth just as a cough clears the bronchi and trachea.

Yawning aids respiration by ventilating the lung more completely. In ordinary breathing apparently not all the alveoli of the lung are equally ventilated, and some may actually close down at times. The blood that passes through collapsed alveoli enters the arterial stream without being oxygenated and dilutes the average oxygen content of the blood. In other words, the arterial blood becomes slightly more venous. Collapsed alveoli may be opened up by the long, deep inspiration of the yawn. Since most of the muscles of the body participate in this maneuver, the yawn may also serve the purpose of squeezing the stagnant blood out of vessels in which it has accumulated.

A hiccough, on the other hand, is an abnormal response serving no known purpose. It is a spasmodic contraction of the diaphragm resulting from some stimulation either in the diaphragm itself or in the respiratory center of the brain, caused perhaps by substances in the blood or by local circulatory abnormalities. The vocal cords, which are usually open during inspiration (vocalization is normally produced only during expiration), apparently close in the hiccough, and their vibrations produce the characteristic sound. Persistent hiccoughs can generally be halted by inhalation of air containing 5 to 7 per cent carbon dioxide.

The engineering of the breathing apparatus stands among the many marvels displayed by the human body. The lungs offer an area at least half the size of a tennis court for diffusion of oxygen and carbon dioxide between blood and air. The lung membrane through which the exchange takes place is of such exquisite delicacy and thinness that it has not been equaled in effectiveness by any of the artificial lungs designed for oxygenation of blood during operations on the heart. The effort required to renew the air in the lung is negligible, and energy to sustain it can be supplied (at 5 per cent efficiency) by two lumps of sugar or their equivalent per day. The breathing mechanism is a marvelously well-adapted structure and provides ample reason for any thinking man to stand in awe before the processes that have brought it all to pass: "So curiously are we wrought, so fearfully and wonderfully are we made!"



CROSS SECTION OF THE TRACHEA is shown as it appears normally (*left*) and as it probably appears during a cough (*right*). The U-shaped cartilage (*outer layer*) does not cover the back portion of the tube. Under external pressure the unprotected part folds inward, narrowing the airway and increasing velocity of the air being expelled through it.

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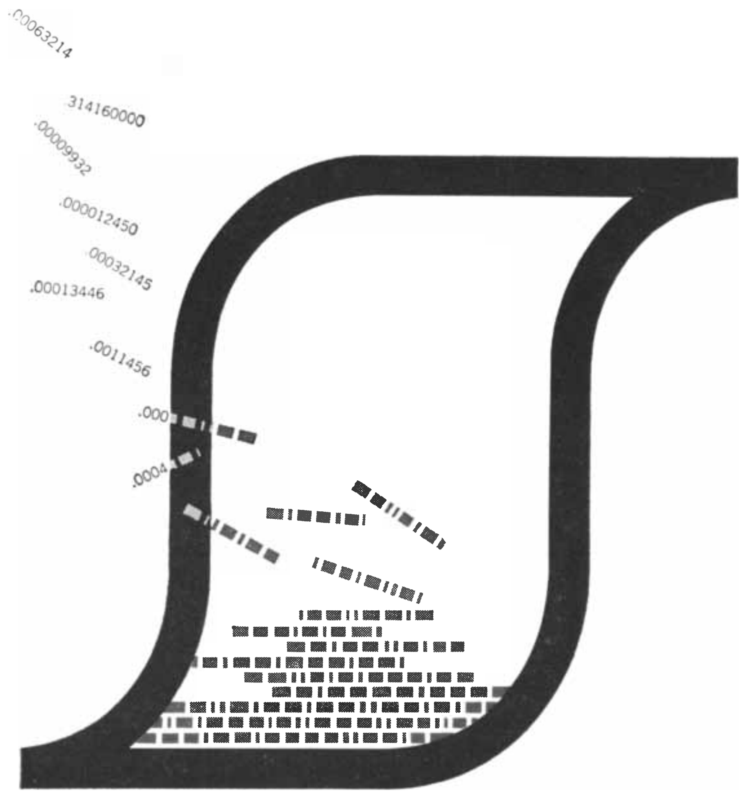

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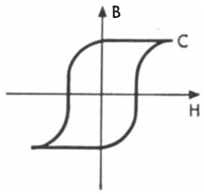

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MATHEMATICAL GAMES

A fanciful dialogue about the wonders of numerology

by Martin Gardner

Numerology, the study of the mystical significance of numbers, has a long, complicated history that includes the ancient Hebrew cabalists, the Greek Pythagoreans, Philo of Alexandria, the Gnostics, many distinguished theologians and those Hollywood numerologists who prospered in the 1920's and 1930's by devising names (with proper "vibrations") for would-be movie stars. I must confess that I have always found this history rather boring. Thus when a friend of mine suggested that I get in touch with a New York numerologist who calls himself Dr. Matrix, I could hardly have been less interested.

"But you'll find him very amusing," my friend insisted. "He claims to be a reincarnation of Pythagoras, and he really does seem to know something about mathematics. For example, he pointed out to me that 1960 had to be an unusual year because 1,960 can be expressed as the sum of two squares—14^2 and 42^2—and both 14 and 42 are multiples of the mystic number 7."

I made a quick check with pencil and paper. "By Plato, he's right!," I exclaimed. "He might be worth talking to at that."

I telephoned for an appointment, and several days later a pretty secretary with dark, almond-shaped eyes ushered me into the doctor's inner sanctum. Ten huge numerals from 1 to 10, gleaming like gold, were hanging on the far wall behind a long desk. They were arranged in the triangular pattern which is made commonplace today by the arrangement of bowling pins, but which the ancient Pythagoreans viewed with awe as the "Holy Tetractys." A large dodecahedron on the desk bore a calendar for each month of the new year on each of its 12 sides.

Dr. Matrix entered the room through a curtained side door; he was a tall, bony figure with a prominent nose and bright, penetrating eyes. He motioned me into a chair. "I understand you write for *Scientific American*," he said with a crooked smile, "and that you're here to inquire about my methods rather than for a personal analysis."

"That's right," I said.

The doctor pushed a button on a side wall, and a panel in the woodwork slid back to reveal a small blackboard. On the blackboard were chalked the letters of the alphabet, in the form of a circle that joined Z to A [*see illustration on page 152*]. "Let me begin," he said, "by explaining why 1960 is likely to be a favorable year for your magazine." With the end of a pencil he began tapping the letters, starting with A and proceeding around the circle until he counted 19. The 19th letter was S. He continued around the circle, starting with the count of 1 on T, and counted up to 60. The count ended on A. S and A, he pointed out, are the initials of SCIENTIFIC AMERICAN.

"I'm not impressed," I said. "When there are thousands of different ways that coincidences like this can arise, it becomes extremely probable that with a little effort you can find at least one."

"I understand," said Dr. Matrix, "but don't be too sure that's the whole story. Coincidences like this occur far more often than can be justified by probability theory. Numbers, you know, have a mysterious life of their own." He waved his hand toward the gold numerals on the wall. "Of course those are not numbers. They're only symbols for numbers. Wasn't it the German mathematician Leopold Kronecker who said: 'God created the integers; all the rest is the work of man'?"

"I'm not sure I agree with that," I said, "but let's not waste time on metaphysics."

"Quite right," he replied, seating himself behind the desk. "Let me cite a few examples of numerological analysis that may interest your readers. You've heard, perhaps, the theory that Shakespeare worked secretly on part of the King James translation of the Bible?"

I shook my head.

"To a numerologist, there's no doubt

about it. If you turn to the 46th Psalm you'll find that its 46th word is 'shake.' Count back to the 46th word from the end of the same psalm [the word *selah* at the end is not part of the psalm] and you reach the word 'spear.' "

"Why 46?," I asked, smiling.

"Because," said Dr. Matrix, "when the King James Authorized Version was completed in 1610, Shakespeare was exactly 46 years old."

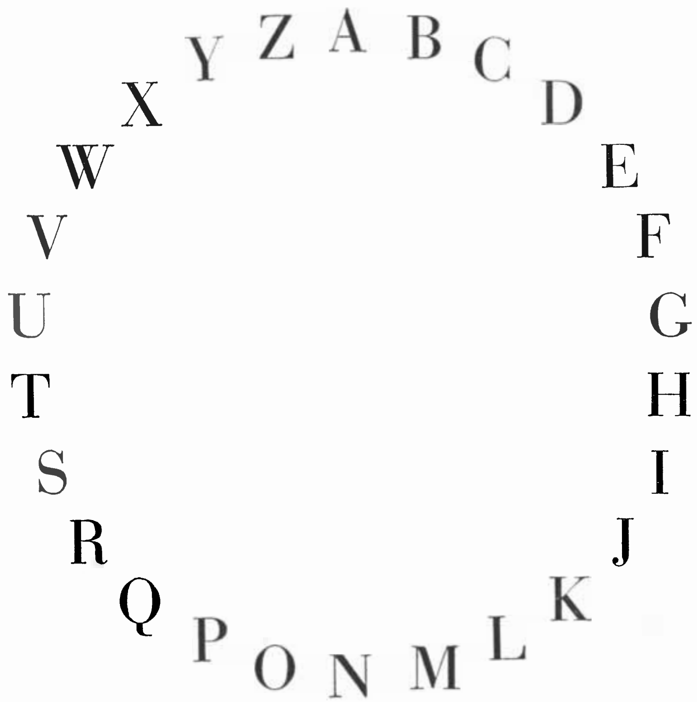
"Not bad," I said as I scribbled a few notes. "Any more?"

"Thousands," said Dr. Matrix. "Consider the case of Richard Wagner and the number 13. There are 13 letters in his name. He was born in 1813. Add the digits of this year and the sum is 13. He composed 13 great works of music. *Tannhäuser*, his greatest work, was completed on April 13, 1845, and first performed on March 13, 1861. He finished *Parsifal* on January 13, 1882. *Die Walküre* was first performed in 1870 on June 26, and 26 is twice 13. *Lohengrin* was composed in 1848, but Wagner did not hear it played until 1861, exactly 13 years later. He died on February 13, 1883. Note that the first and last digits of this year also form 13. These are only a few of the many important 13's in Wagner's life."

Dr. Matrix waited until I had finished writing; then he continued. "Important dates are never accidental. The atomic age began in 1942, when Enrico Fermi and his colleagues achieved the first nuclear chain-reaction. You may have read in Laura Fermi's biography of her husband how Arthur Compton telephoned James Conant to report the news. Compton's first remark was: 'The Italian navigator has reached the New World.' Did it ever occur to you that if you switch the middle digits of 1942, it becomes 1492, the year that Columbus, an earlier Italian navigator, discovered the New World?"

"It most assuredly has not," I answered.

"The life of Kaiser Wilhelm I is numerologically interesting," he went on. "In 1849 he crushed the socialist revolution in Germany. The sum of the digits in this date is 22. Add 22 to 1849 and you get 1871, the year Wilhelm was crowned emperor. Repeat this procedure with 1871 and you arrive at 1888, the year of his death. Repeat once more and you get 1913, the last year of peace before World War I destroyed his empire. Unusual date patterns are common in the lives of all famous men. Is it coincidence that Raphael, the great painter of sacred scenes, was born on April 6 and died on April 6, and that both dates fell on Good Friday? Why is evolution a key to the philosophies of both John Dewey and Henri Bergson? Because both men were born in 1859, the year Darwin's *Origin of Species* was published. Do you think it accidental



Dr. Matrix's alphabet circle

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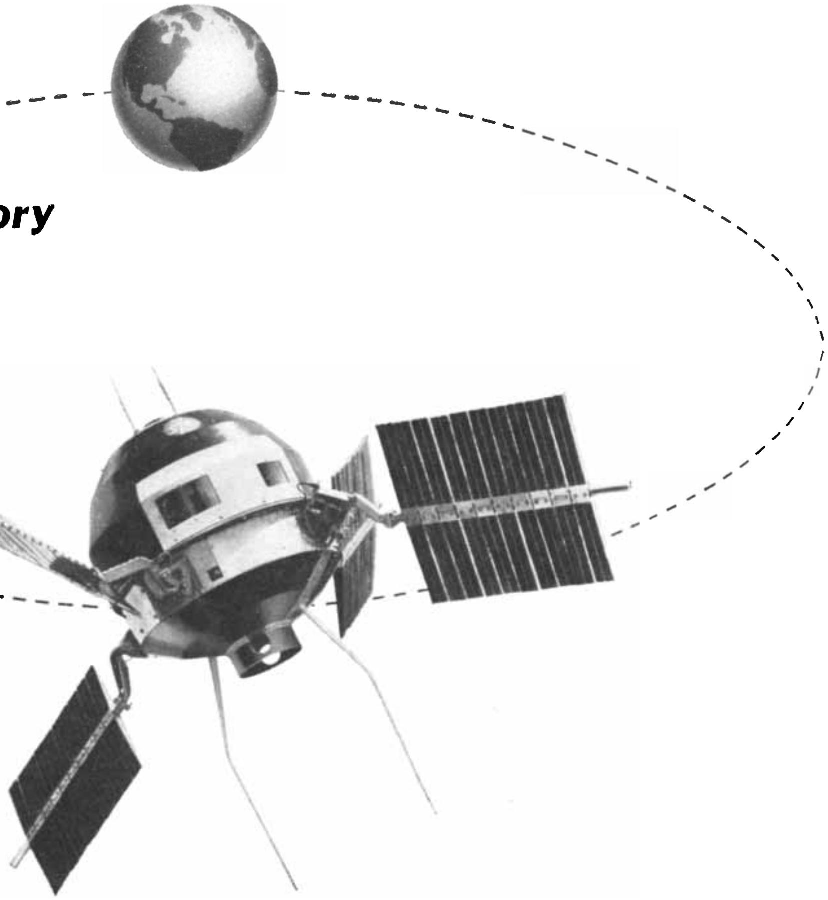
with paddles capturing sunlight for power



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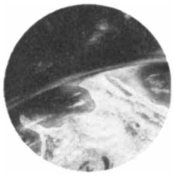

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that Houdini, the lover of mystery, died on October 31, the date of Halloween?"

"Could be," I murmured.

The doctor shook his head vigorously. "I suppose you'll think it coincidental that in the library's Dewey decimal system the classification for books on number theory is 512.81."

"Is there something unusual about that?"

"The number 512 is 2 to the ninth power and 81 is 9 to the second power. But here's something even more remarkable. First, 11 plus 2 minus 1 is 12. Let me show you how this works out with letters." He moved to the blackboard and chalked on it the word ELEVEN. He added TWO to make ELEVEN-TWO, then he erased the letters of ONE, leaving, ELEVTW. "Rearrange those six letters," he said, "and they spell TWELVE."

I dabbed at my forehead with my handkerchief. "Do you have any opinion about 666," I asked, "the so-called Number of the Beast [*Revelation* 13:18]? I recently came across a book called *Our Times and Their Meaning*, by a Seventh-Day Adventist named Carlyle B. Haynes. He identified the number with the Roman Catholic Church by adding up all the Roman numerals in one of the Latin titles of the Pope: VICARIUS FILII DEI. It comes to exactly 666." [V = 5, I = 1, C = 100, I = 1, U = 5, I = 1, L = 50, I = 1, I = 1, D = 500, I = 1. U is taken as V because that is how it used to be written.]

"I could talk for hours about 666," the doctor said with a heavy sigh. "This particular application of the Beast's number is quite old. Of course it's easy for a skillful numerologist to find 666 in any name. In fact, if you add the Latin numerals in the name ELLEN GOULD WHITE, the inspired prophetess who founded Seventh-Day Adventism—counting W as a 'double U' or two V's—it also adds up to 666. [L = 50, L = 50, U = 5, L = 50, D = 500, W = 10, I = 1.] Tolstoy's *War and Peace* [Volume III, Part 1, Chapter 19] has a neat method of extracting 666 from L'EMPEREUR NAPOLEON."

"I think it was the mathematician Eric Temple Bell," I said, "who discovered that 666 is the sum of the integers from 1 to 36, the numbers on a roulette wheel."

"True," said Dr. Matrix. "And if you put down from right to left the first six Roman numerals, in serial order, you get this." He wrote DCLXVI (which is 666) on the blackboard.

"But what does it all mean?," I asked.

Dr. Matrix was silent for a moment. "The true meaning is known only to a few initiates," he said unsmilingly. "I'm afraid I can't reveal it at this time."

"Would you be willing to comment on the coming presidential campaign?," I asked. "For instance, will Nixon or Rockefeller get the Republican nomination?"

"That's another question I prefer not to answer," he said, "but I would like to call your attention to some curious counterpoint involving the two men. 'Nelson' begins and ends with N. 'Rockefeller' begins and ends with R. Nixon's name has the same pattern in reverse. 'Richard' begins and almost ends with R. 'Nixon' begins and ends with N. Do you know when and where Nixon was born?"

"No," I said.

"At Yorba Linda, California—in January, 1913." Dr. Matrix turned back to the blackboard and wrote this date as 1-1913. He added the digits to get 15. On the circular alphabet he circled Y, L and C, the initials of Nixon's birthplace, then he counted from each letter to the 15th letter from it clockwise to obtain NAR, the initials of Nelson Aldrich Rockefeller! "Of course," he added, "of the two men, Rockefeller has the better chance to be elected."

"How is that?"

"His name has a double letter. You see, because of the number 2 in 20th century, every president of this century must have a double letter in his name, like the OO in Roosevelt and the RR in Harry Truman."

"Ike doesn't have a double letter," I said.

"Eisenhower is the one exception so far. He managed to squeak through by virtue of his double initials: D. D."

"I observe that you make frequent use of that circular alphabet," I said.

"It's one of many valuable tools," Dr. Matrix replied, "for exploring the numerical underpinnings of our lives. The other day a young man from Brooklyn came to see me. He had renounced a vow of allegiance to a gang of hoodlums and he thought he ought to leave town to avoid punishment by gang members. Could I tell him by numerology, he wanted to know, where he should go? I convinced him he should go nowhere by taking the word ABJURER [one who renounces] and substituting for each letter the letter directly opposite it on the alphabet circle."

Dr. Matrix drew chalk lines on the blackboard from A to N, B to O, and so on. The new word was NOWHERE. "If you think that's a coincidence," he said, "just try it with even shorter words. The

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odds against starting with a seven-letter word and finding a second one by this technique are astronomical."

I glanced nervously at my wrist watch. "Before I leave, could you give me a numerological problem or two that I could ask my readers to solve?"

"I'll be delighted," he said. "Here's an easy one." On my notepaper he wrote the letters: OTTFFSSENT.

"On what basis are those letters ordered?," he asked. "It's a problem I give my beginning students of Neo-Pythagoreanism."

Beneath these letters he wrote:

$$\begin{array}{r} \text{FORTY} \\ +\ \text{TEN} \\ +\ \text{TEN} \\ \hline \text{SIXTY} \end{array}$$

"Each letter in that addition problem stands for a different digit," he explained. "There's only one solution, but it takes a bit of brain work to find it."

I pocketed my pencil and paper and stood up. Organ music continued to pour into the room. "Isn't that a Bach recording?," I asked.

"It is indeed," answered the doctor as he walked me to the door. "Bach, you may have heard, was a deep student of our science. He knew that the sum of the values of BACH—taking A as 1, B as 2, and so on—is 14, a multiple of the divine 7. He also knew that the sum, using an old German alphabet, is 41, the reverse of 14, as well as the 14th prime number when you include 1 as a prime. The piece you're hearing is a work in which the pattern of notes exploits this 14-41 motif. Magnificent harmony, don't you think? If only our modern composers would learn a little numerology, they might come as close as this to the music of the spheres!"

I left the office in a slightly dazed condition; but not too dazed to notice again on my way out that the doctor's secretary had 1 upturned nose, 2 luminous eyes and a most interesting over-all figure.

The three braid problems presented in this department last month are solved as follows: (1) Pass the plaque under strand C from right to left, then under strands A and B from left to right. (2) Pass the plaque under the center of strand B from left to right. (3) Pass the plaque, left to right, under all strands.

The letters of MANY A SAD HEART CAN WHISPER MY PRAYER rearrange to form the message A MERRY CHRISTMAS AND A HAPPY NEW YEAR.

THE AMATEUR SCIENTIST

How a group of amateurs, with professional guidance, unearthed an early Indian village

Conducted by C. L. Stong

Many archaeologists wish that amateur diggers would simply go away. The discipline of excavating the past has grown so complex, they explain, that those without formal training rarely accomplish much beyond the destruction of priceless sites. Other archaeologists take a more kindly view of amateurs; a few even encourage them to dig. One of these is Maurice Robbins, director of the Massachusetts Archaeological Society at Attleboro, Mass. He writes: "When the amateur sees ancient relics being destroyed by earth-moving machinery, when he realizes that there are not enough professionals to excavate even a small percentage of the available sites, mere talk or even the enactment of laws will not dissuade him from taking a hand in 'dirt archaeology.' The only alternative, in my opinion, is to educate and cooperate. As the old adage puts it: 'If you can't lick 'em, join 'em!' The soundness of this approach to the 'amateur problem' was demonstrated by our Society during the recent excavation near Middleboro, Mass., of an Indian village dating back to 2300 B.C.

"Most of the work at this site, which was designated as Wapanucket No. 6, was performed by members of the Cohannet Chapter of the Massachusetts Archaeological Society. The group is composed of shoe craftsmen, electricians, a florist, a clergyman, a newspaper reporter, a professor of history, several engineers, and other laymen ranging in age from about 20 to over 60. During the five years prior to their work at Wapanucket No. 6 these amateurs had taken courses in cultural anthropology and archaeological techniques that were offered free by the Society's Bronson Museum at Attleboro. During the summers the group had also excavated a number of minor sites in the immediate vicinity, where the usual archaeological pattern of the northeastern states was found.

"In the course of this preliminary work the amateurs learned a lot about the dusty volume in which the story of man's rise is recorded, and about the characters in which the volume is written: those of stone, baked clay, bone and stained soil. They encountered at first hand the ancient authors who wrote without effort to conceal their faults or enhance their virtues. Such errors as may creep into the story, the amateurs learned, are those of translation and are chargeable to the reader. Most important, the group came to have deep respect for a unique weakness of the book: the fact that the very act of reading destroys it! No sentence, much less a paragraph, can be scanned in the original but once. They learned that those who would enjoy the thrill of being the first—and the last—to turn the ancient pages assume a heavy responsibility. They must pay for the privilege by reading carefully and recording all data in detail so precise that others in this or future generations may correct errors in the original translation.

"By the time work began at Wapanucket No. 6, much was known about the Indians who for some thousands of years had inhabited the region. But following the excavation it became apparent that a number of prior conclusions, particularly those concerning certain people who lived here some 3,000 years ago, would have to be altered considerably. In general, three cultural levels are encountered in the northeastern states. As one sinks his shovel into the earth at favored sites, arrowheads and related artifacts of the most recent Indians are turned up near the surface; at lower levels the remains of older cultures are found. The deepest layer is associated with a people who appear to have come into the area between 6000 and 5000 B.C., and it records what is called the Paleo-Indian occupation. Little is known about these ancient wanderers beyond the fact that they made fluted spear points of the Folsom type, also found in the U. S. Southwest. What may have happened to these early tribes is anybody's guess. They simply disappeared. If any clue to their fate remains, it has yet to be discovered.

"The intermediate layer, the one next above the Paleo-Indian, records the period of Archaic occupation. This culture persisted for some 4,000 years: from about 5000 B.C. to 1000 B.C. The remains of these people trace a gradual but pronounced cultural evolution. Implements made in 5000 B.C. exhibit less finish and variety than those of 1000 B.C. Distinctions between the two types of artifact have enabled archaeologists to divide the Archaic period into early and late components. Wapanucket No. 6 was the site of late Archaic occupation. Although the nature of the period is the subject of considerable discussion among archaeologists, it is agreed in general that the economy of these Indians was based on hunting, fishing and food-gathering. Agriculture and clay pottery were unknown. The bow and arrow did not come into use until late Archaic times. Prior to this the Archaic people hunted and fought with lances and spears.

"Finally, at about 1000 B.C., the 'Woodland' cultures arose. These peoples were primitive farmers who raised corn, beans, pumpkins and squash. They were also excellent potters and produced handsome clay vessels. Because of a plentiful and secure supply of food the Woodland people could live together in fairly large communities and build permanent villages. The agricultural traits of the Woodland people had a far-reaching effect on their culture. Freedom from the necessity of roaming the countryside in search of food left them time to think of nonmaterial things. After a few centuries they accordingly developed fairly complex social, religious and political systems. Their culture began to take on the aspect of what one might call a proto-civilization.

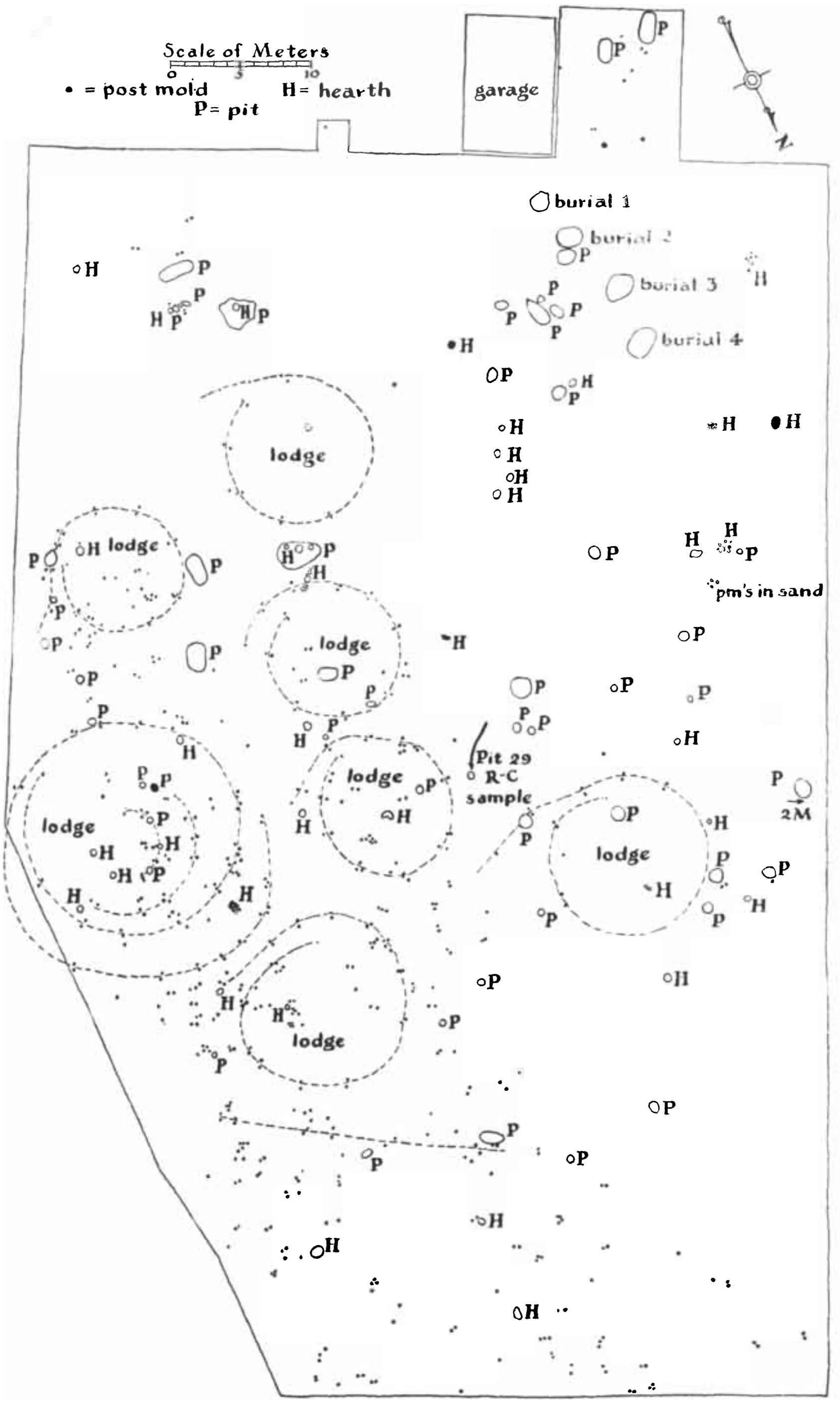
"Early explorers from Europe arrived in Massachusetts during the final stages of the Woodland period. Thus we have excellent descriptions of the lodges in which the Woodland people lived, and we know the meaning of at least part of their expressive language. Unfortunately, from the point of view of the archaeologist, the camp and village sites that appealed to the Woodland people were precisely those selected by their predecessors. Accordingly it is quite the usual thing to find a Woodland site superimposed upon one of the Archaic period. The tools left by both groups are often mixed, particularly at sites that show the mark of the Colonial plow. However, by the methods of typology—by analyzing artifacts according to types known to be the product of each culture—the archaeologist can recognize the presence of more than one assemblage of tools and can for the most part separate them into groups according to their time of origin. For example, the preference of Archaic Indians for projectile points with stems is well known; grooved axes and certain types of gouge are also characteristic of the period. Moreover, the Archaic Indians developed a special technique for sawing, grinding and polishing stone, by which they fashioned knives of a characteristic crescent shape and vessels of soapstone. These are positive clues to Archaic occupation.

"Until recently the nonmaterial aspects of the Archaic culture were practically unknown and the subject of much speculation. Because agriculture was not practiced during this period, the Archaic Indians were entirely dependent upon wild plants and animals. Any appreciable concentration of people living in such an economy would have resulted in a rapid depletion of the necessities of life, or so it was thought. In consequence the discovery of an Archaic village was considered most unlikely. Stone tools from this early period had been found in rock shelters and at open sites; it was assumed that the shelters built by the Archaic people must have been flimsy affairs of which no vestige could possibly remain. This conclusion seemed reasonable because the Archaic people were so preoccupied with the eternal quest for food and so dispersed by the environment in which they lived that they would have neither the time nor the opportunity for any but the most rudimentary social, political or religious concepts. How wrong the work of the amateurs at Wapanucket No. 6 has shown these conclusions to be!

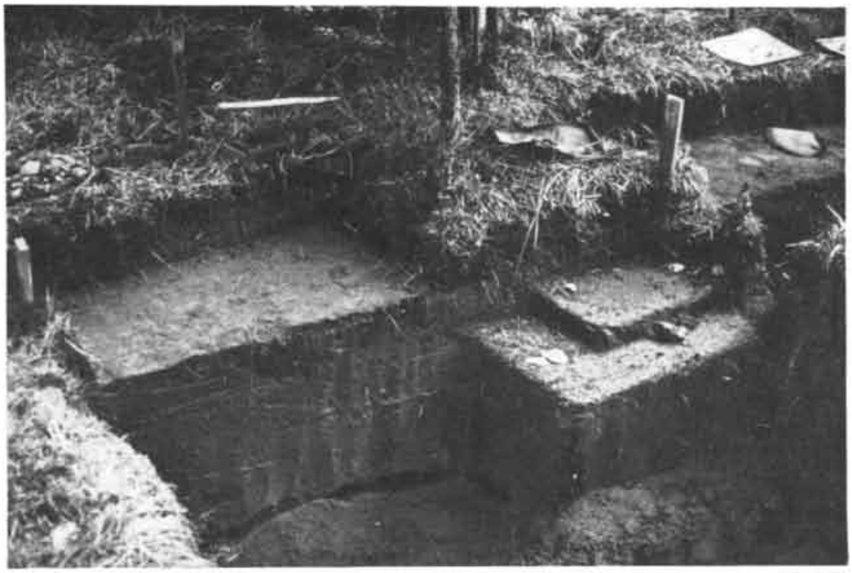
"The site lies on the northern shore of Assawompsett Pond. Originally this area was a part of the old mother colony of Plymouth. Assawompsett is the largest natural body of fresh water in Massachusetts, covering some 2,200 acres. It forms a part of the drainage system of the Taunton River, which together with its many tributaries provided the aboriginal inhabitants with an easy means of travel. A few hours in their dugout canoes would take them to the seacoast or to interior forests.

"The northern shore of the lake is formed by a sand dune flanked by swamps and small streams. Its wave-cut front rises steeply out of the water to a height of 24 feet, and its top offers several acres of level, well-drained land. This area has been the site of aboriginal occupation since the advent of man into New England.

"In the spring of 1956 a reconnaissance party from the Cohannet Chapter



Map of Wapanucket No. 6, the site of an Indian village dating back to 2300 B.C.



Part of the site, showing the method of excavation

excavated several random test-squares in the wooded area just back from the lake front. The appearance of Indian refuse pits, fire-cracked stone, and chips remaining from the manufacture of stone implements quickly confirmed our hope that the area had once served as an aboriginal campsite.

"The prerequisites of a controlled archaeological 'dig' are a careful survey of the area to be examined, the determination of levels in relation to some permanent object (such as a large rock or a survey marker) and the establishment of an excavation grid or checkerboard pattern of carefully measured lines for subsequent use in charting the precise location of all objects discovered. These were the first order of business. Numbered stakes were set at two-meter intervals to outline an area 52 meters long and roughly parallel to the shore. Next the group removed a thin layer of topsoil along the first line—the so-called base line. Then it began the heavy work of scraping away larger areas of topsoil an inch at a time and examining each freshly exposed surface for evidence of human occupation. Fragments of worked stone, artifacts, hearths, pits or any other indication of aboriginal habitation were located both horizontally and vertically with reference to the numbered stakes and were entered upon printed record cards prepared for the purpose. The data from these cards were

Remains of a platform for cremating the dead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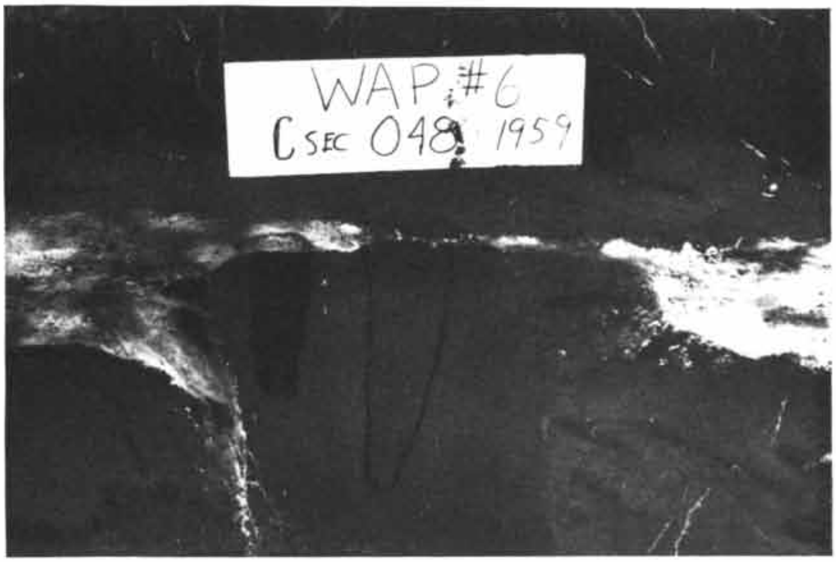


Molds of posts that supported the walls of a lodge at the site

entered upon a chart or progress plan of the area; notes were kept of the type of soil encountered, the content of hearths or pits and the position of post molds: discolorations in soil marking the location of posts which had decayed to dust centuries ago. (Post molds are easy to recognize. Upon removal of the topsoil, the tops of the molds appear as dark circular stains in the surrounding yellow soil. A vertical cut then reveals the cross section of that portion of the original post which was embedded in the earth. The majority of the molds found at Wapanucket No. 6 had smooth sides which curved to a sharp point at various depths.) Information of this sort, together with numerous photographs, constituted the field notes upon which the group based its final conclusions.

"As digging progressed and artifacts began to accumulate, the group became aware that none of the material was characteristic of the Woodland period; it was wholly Archaic in appearance. The trend could not be taken seriously at this early stage of excavation, but it was sufficiently pronounced to stimulate interest. The molds of posts began to form new and unfamiliar patterns in the records. As the weeks passed and the artifacts maintained their Archaic character, the group began almost unconsciously to speak of this as an Archaic

Stakes mark the position of post molds at the entrance of a lodge

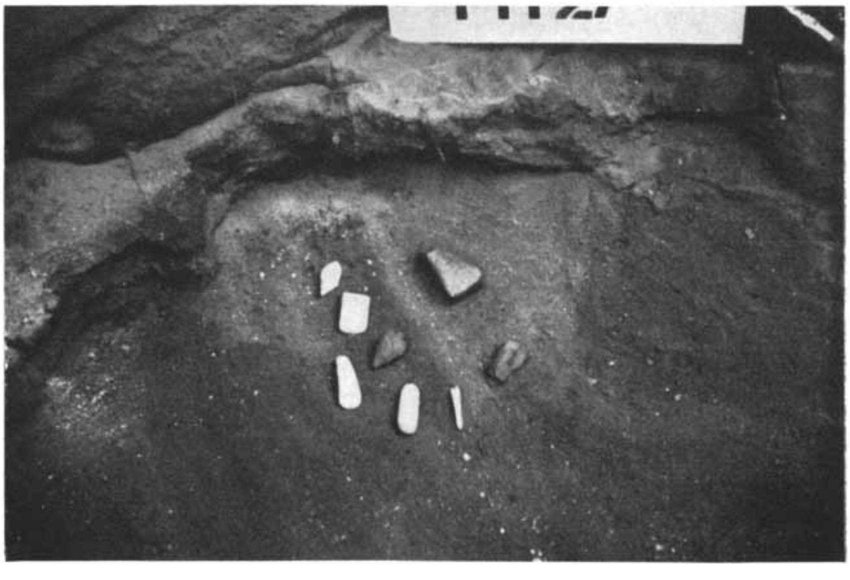
site. In our more conservative moments, however, we still doubted our diagnosis. The majority of the artifacts—the tops of the post molds and of pits and hearths—were appearing at about the same depth as that at which objects typical of the Woodland period had been found at other sites in the area.

"Several perplexing questions arose. How was it possible for these evidences of occupation to have been preserved with so little disturbance since Archaic times? Why was so favorable a location free from all indication of a Woodland occupation? Were we to abandon the concepts concerning the limitations of a hunting, fishing and food-gathering economy, so firmly established by many authorities? Could we justify the existence not only of a permanent abode but also of a whole Archaic village? On the basis of our findings the answers to all of these questions had to be yes. Our charts showed undeniable evidence of at least three lodges—structures larger than any known from the Woodland period—and a floor plan that had never, so far as we could determine, been uncovered before. The implements were without exception those of a late Archaic culture. Although a respectably large area had been excavated at this stage of the work, not a single incongruous artifact had appeared.

"During the following two seasons four additional lodge floors of the same unique pattern were found. By this time a total of 556 post molds had been charted, and the excavations had been extended a reasonable distance in all directions without uncovering another floor. We agreed that the complete village had been exposed.

"The pattern of the mold array established the existence of an entirely new type of floor plan that was repeated in seven instances. In the construction of these seven houses, pairs of posts had been driven into the earth in two concentric circles. The pairs of posts were placed on radial lines from the center of the structure and driven vertically into the earth. The pointed vertical section of the molds indicated that the posts were driven rather than set in a previously prepared hole. This suggested in turn that the height of the wall was no greater than that of a post which could have been driven by a man standing on the ground. At one point in each structure the walls bypassed each other to form a short protected entranceway. Six of the structures, apparently dwellings, averaged about 31 feet in diameter. The seventh, believed to have a ceremonial function, was 66 feet in diameter and possessed internal posts not found in the smaller lodges. The accompanying plan [*page 159*] shows the arrangement of this unique Archaic village, the first to be located in the Northeast.

"During the excavation of an Indian site certain features are encountered that in the final report are called pits or hearths, depending upon their appearance, content and vertical position in the ground. Basin-like depressions at or near the surface that contain charcoal, particularly those surrounded by hard, reddened soil, are usually called hearths. Thirty-nine such hearths are recorded at Wapanucket No. 6. Comparable but



Grave goods lie where they were uncovered at Wapanucket No. 6

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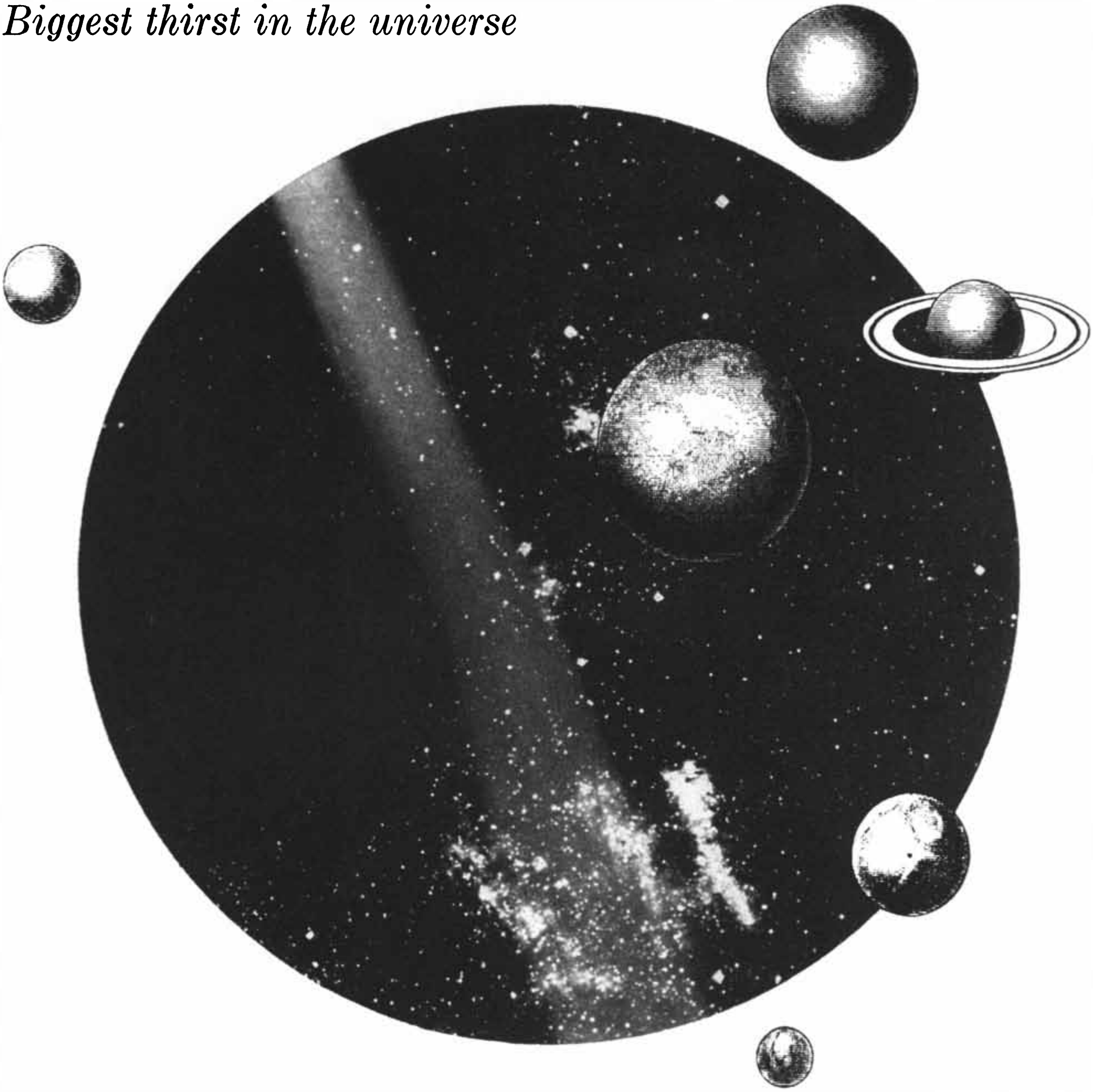

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Age of charcoal in this hearth was determined to be 4,250 ± 300 years

somewhat larger basins are commonly called pits. Many of these pits contain carbonized material and burned stone and are assumed to have served the final purpose of a receptacle for camp refuse. A pit numbered 29 is of particular importance at this site. The age of a sample of carbon taken from it was established by the geochronometric laboratory at the University of Michigan at 4,250 ± 300 years (approximately 2300 B.C.).

"The burials at Wapanucket No. 6 were found a few yards south and west of Lodge Floor No. 1. These consisted of four deposits in large oval pits. The cremated remains of human skeletons had been placed in the southwestern quadrant of each pit. In two instances grave goods had also been included, and in one instance a considerable quantity of red paint in the form of iron oxide was also present. Burial No. 2 contained a deposit of four stone gouges, a stone plummet (thought to be a fishing weight) and two sharpening stones, surrounded by a mass of red paint. In burial No. 3 a large crescent-shaped knife of ground slate (called a semilunar knife) and a sharpening stone were found. Sharpening stones of this type were made only by late Archaic Indians.

"Prior to the discovery of the burials two large features had been found nearby to which our group was unable to assign a satisfactory function. They consisted of carefully laid stone platforms some 10 feet in diameter. The flat stone slabs were reddened and cracked by the intense heat, and a large amount of charcoal had accumulated about and upon the platforms. The platforms are too large to be classed as hearths, and we were at a loss to account for them. With the discovery of the cremation burials their purpose became clear. These were the crematory pits where the initial phase of the funeral rite was conducted.

"The group recovered a total of 1,167 stone artifacts from the village area, including one or more implements of each type in the basic tool kit of the inhabitants. The chipped tools included projectile points, lance or spear points, knives, drills, scrapers and assorted woodworking tools. These accounted for more than 80 per cent of the stone objects recovered. The balance of the implements were those made by the sawing, grinding and polishing techniques typical of the late Archaic period.

"Much of the information represented by the material dug up at Wapanucket No. 6 is in direct conflict with earlier ideas concerning the culture and manner of life in Archaic times. It is evident that the occupants of Wapanucket No. 6 led a semisedentary existence. That they chose this location for convenience rather than defense seems obvious. Living atop the highest ground on the shore of the lake, they would have been a conspicuous part of the landscape. The very size of these lodges creates an impression of permanence and security. They could easily have accommodated at least 100 individuals.

"The explanation doubtless lies in the size of the lake. Here at Assawompsett, with its tidal streams, was an abundant supply of food that we, in our ignorance of wilderness life, had failed to take

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SUBMARINE SIGNAL | AIRBORNE ELECTRONIC | SYSTEMS MANAGEMENT | HEAVY ELECTRONIC | SANTA BARBARA into account. In spring the annual run of shad, and probably salmon and trout, would have provided an abundant food supply. Here migratory birds might be expected to congregate, and in the swamps surrounding the site there must have been considerable game. After a winter spent in ranging the forests to the north and west in small family groups, an ancient people would turn quite naturally to this favored site by the lake. Here could be found a welcome change from the red-meat diet of the winter. A plentiful store of smoked fish could also be prepared against a time when game was scarce. In their great ceremonial lodge the villagers could celebrate the rites required by their religious beliefs, and here those who had departed during the winter could be laid to rest.

"Thanks to the initiative and dedicated efforts of a small group of amateurs, a chapter from the ancient book has been carefully preserved and, with the help of specialists, translated. Much new knowledge has been added to our meager understanding of the northeastern Archaic occupation, and more may result from detailed study of the group's records. A full report is now in preparation and will be published shortly by the Society. In addition, the group is now constructing a complete reproduction of the village in miniature at the Bronson Museum, so that all may see how the citizens of Wapanucket village lived centuries before Tutankhamen was laid to rest in his tomb at Thebes."

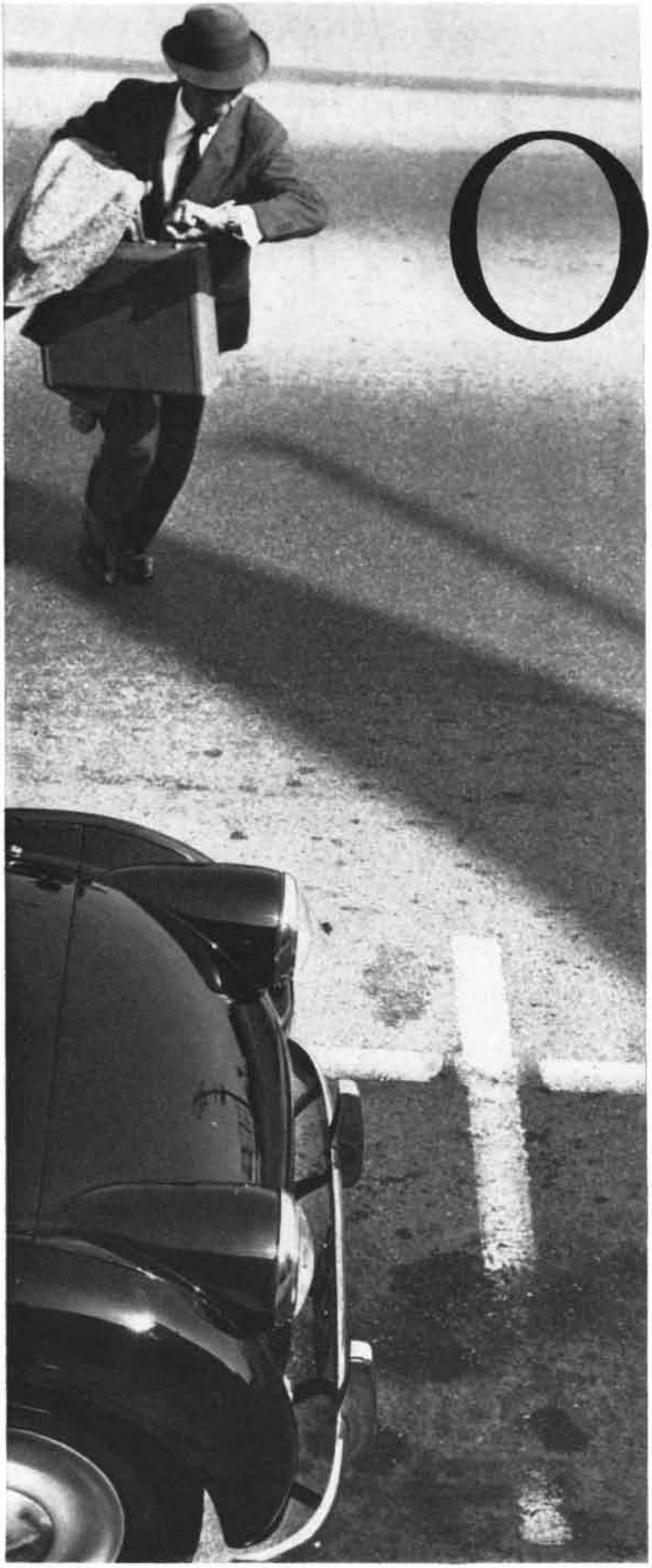
The experiments in color vision described by Edwin H. Land in the May, 1959, issue of this magazine have excited considerable interest among both professional investigators and amateurs. The experiments are particularly attractive to the amateur because they can be performed with relatively simple equipment, and because they make it possible to examine certain theories of color vision. For example, what do the experiments show about the idea that color vision is mediated by specific color receptors in the retina? Nicholas J. Pastore, who teaches psychology at Queens College in New York City, has devised a technique for investigating this question which has the attractive feature that it does not require two slide projectors (or a special two-lensed projector).

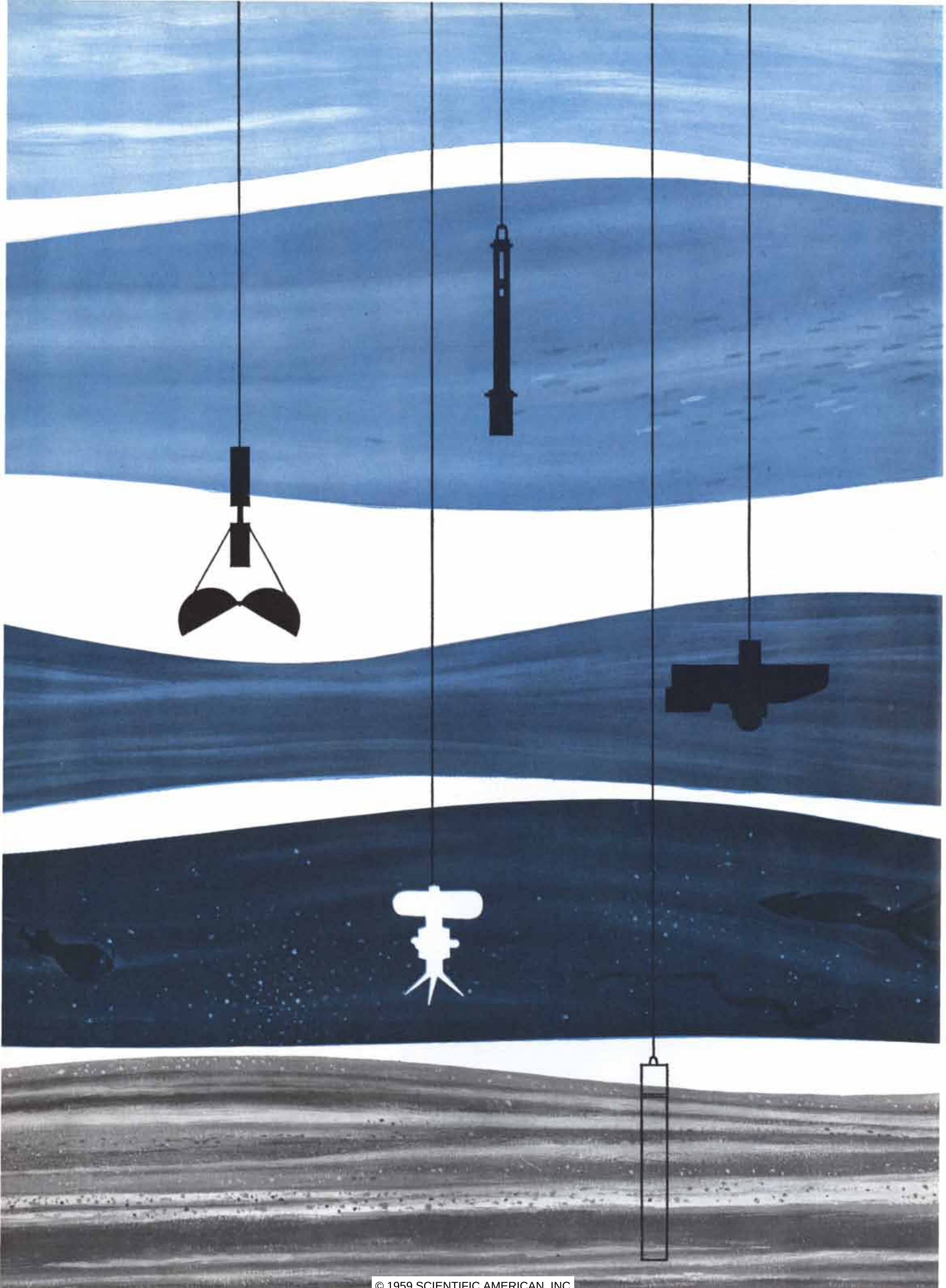
"The exciting observations reported by Land," Pastore writes, "apparently imply that specific retinal color-receptors do not exist. Or, if they do exist, it would seem that they are not essential for the perception of color. It should follow that Land's results would be repeated when one eye receives stimulation through the 'long record' (with the red filter) and the other eye through the 'short record' (with the green filter).

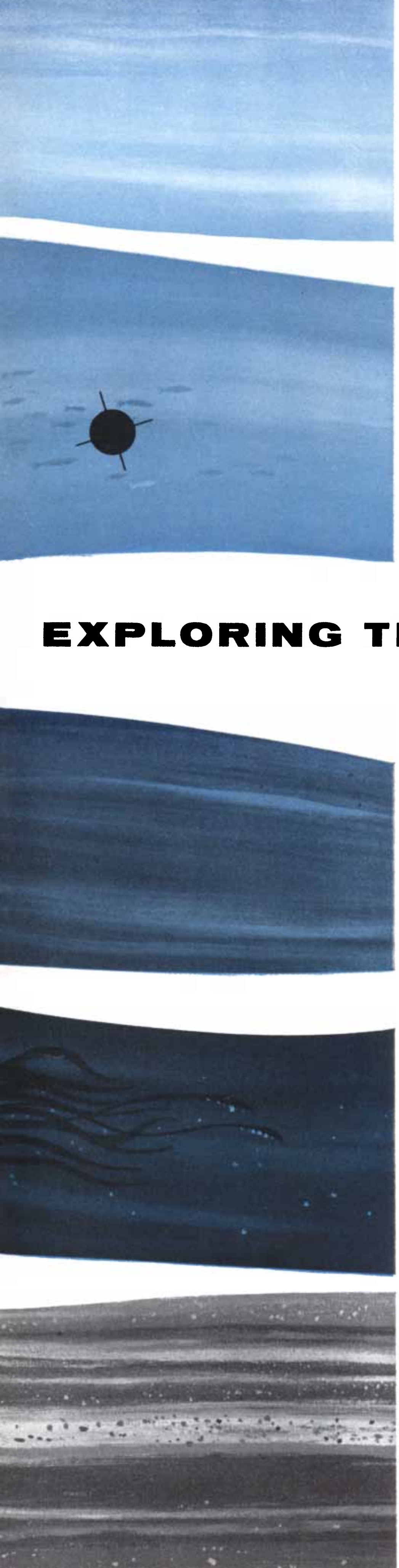
"To investigate this assumption, experimenters can photograph a colored scene first through a red photographic filter (Wratten 25-A) and then through a green filter (Wratten 58-B). He can then insert the resulting positive transparencies, with their respective filters, in a stereoscope. When I tried this, the reds and greens were somewhat more saturated than the colors of the original scene, but the yellows and oranges were so attenuated that many subjects who were invited to look through the stereoscope could not see them. It is interesting to replace the green filter in the stereoscope with one of neutral density (Wratten 96.20 neutral density). The full range of colors, including blues, greens and yellows, is still perceived by some subjects.

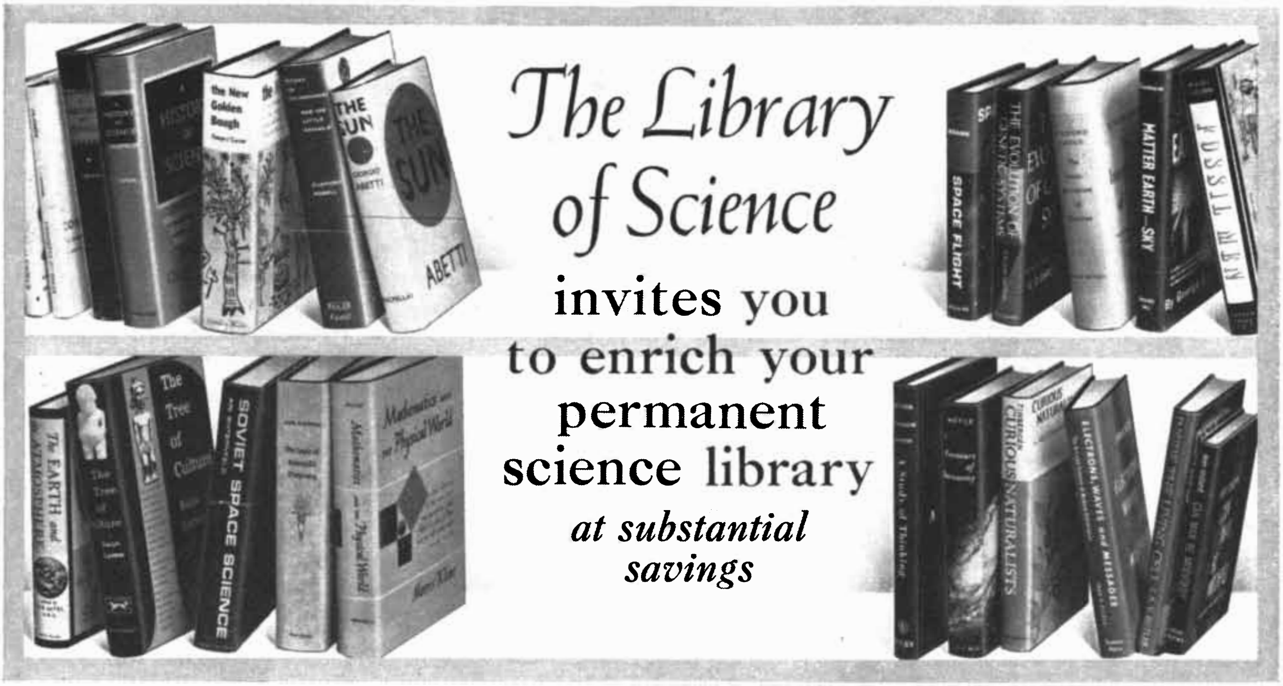
"The fact that a wide array of colors can be perceived through stereoscopic fusion, even though they may not faithfully represent the object colors, would seem to indicate that the interaction of long and short wavelengths which results in the perception of color occurs in the brain, and not in the eye. Incidentally, it was observed that changes in the intensity of light produced substantial alterations in color values. This may account for differences among subjects in reporting colors. Each observer should adjust the over-all intensity of the light until the best color-balance is achieved. Individual differences have also been observed in the interval required by the eye to perceive the Land colors. Most subjects see them at once. One subject, however, reported that all scenes appeared initially in monochrome and that perception of the full range of color developed gradually over an interval of several minutes.

"The fact that Land's major results can be obtained stereoscopically simplifies the problem of repeating his experiments. Those who have mastered the knack of fusing stereoscopic pictures by crossing their eyes report that they see the colors as vividly in this way as when they use the stereoscope. It is not even necessary to use positive transparencies; contact prints serve as well. Photographs made with a stereocamera appear to be superior to those made with a conventional camera because the fusion of the images is made easier. A stereocamera is essential, of course, in the photography of live subjects or of moving objects."









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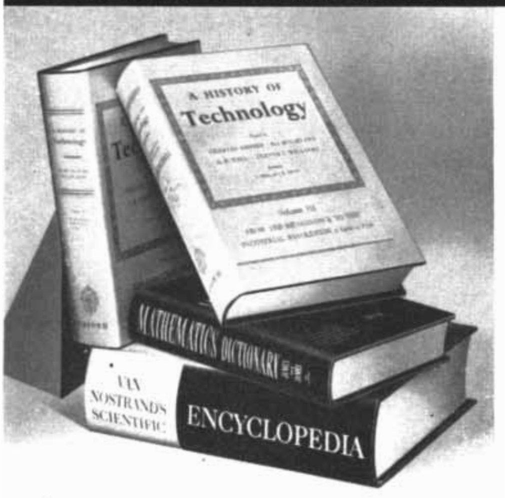

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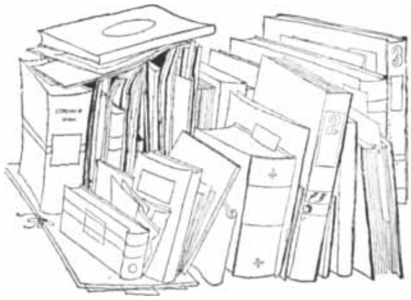

BOOKS

The first volume of a complete collection of Newton's letters

by Sir George Clark

THE CORRESPONDENCE OF ISAAC NEWTON: VOL. I, edited by H. W. Turnbull. Published for the Royal Society by the Cambridge University Press ($25).

From his own lifetime to the present day it has never been questioned that Sir Isaac Newton was one of the most remarkable men who ever lived. Biographical writers have, however, adjusted his reputation to the changing standards of their times. In the 17th century he was seen as a supreme discoverer in mathematics and physics; the late 18th endowed him with the attributes of a benevolent sage of the Enlightenment; the 19th century emphasized the valuable public services of his later years and slurred over his unorthodoxy in religion; 20th-century writers have represented him as tormented by psychological conflicts. Many scholars have recently been busy in disentangling the truth about his personality and also in tracing, step by step, the development of his thought. They have contended with formidable difficulties. Newton was one of those people who think on paper. Even when he was not engaged in calculations, he pressed his thought forward by revising and correcting what he had written. It is typical of him that, as his contemporary William Whiston tells us concerning his book *The Chronology of Ancient Kingdoms Amended* (1728), "he wrote out eighteen copies of its first and principal chapter with his own hand, but little different one from another." In addition to his books he left behind him manuscripts comprising millions of words, and after his death these were dispersed. Large and small portions of them have been published, some in orderly fashion, others almost haphazardly as they came to hand. The principal masses of manuscript are still largely unexplored. The Royal Society decided more than 20 years ago to provide a much-needed key to all this material, an edition of Newton's correspondence worthy to rank with the great sets of volumes in which the correspondence of Galileo, Descartes and Huygens stands collected.

The first volume has now appeared, and a second is to follow shortly. Professor H. W. Turnbull, the author of the compact little book *Mathematical Discoveries of Newton,* took over the editorship at an early stage from the late Professor H. C. Plummer, whose health was failing. As to how he has executed the task, it is enough to say that he has more than fulfilled its exacting demands. The volume presents all the traceable letters to and from Newton down to the end of the year 1675 in the Old Style calendar. Extracts are added from letters between third parties in which Newton's work is mentioned, and there are a few relevant memoranda of Newton's which cannot be classed as letters. Everything is done—by giving translations where the text is in Latin and by elaborate historical, mathematical and scientific annotation—to make the volume useful and convenient for the different kinds of reader who will want to resort to it.

Needless to say, the publication is an important literary event. Not that it is important in the sense of bringing surprises. It tells us very little about Newton's personal history that is new. There is one short and fragmentary letter written by Newton's mother when he was 22; there is another letter from which we learn that Newton wished the drinking of cider to be propagated in England; but nearly the whole of the correspondence is about Newton's work. Even here only a small proportion is absolutely new. Out of 156 items only 19 have not been published before, and out of the 64 written by Newton himself only four (two letters and two memoranda) are printed for the first time. But until now anyone who wanted to use all the previously printed texts in conjunction had to assemble more than a dozen books and periodicals, some of them difficult to find. Many of the texts gain in significance now that they are between the same covers. Taken together they do much to bring into focus two interrelated processes: how Newton made his discoveries, and how, why and to whom he imparted them.

The period covered by the scientific correspondence in this volume runs from February 23, 1669, to February 29, 1676, seven years during which Newton's powers were at their height. At the beginning he was 27 years old and he had already been a member of Trinity College, Cambridge, for nearly eight years. By this time he was a Fellow of the College, living as a bachelor in his rooms in the Great Court. During these years he seldom left Cambridge and never for long. He was in close contact with the admirable Isaac Barrow, 12 years older than himself and the leading mathematician in the university. Up to this time Newton had published nothing, and there is no evidence that he had engaged in scientific correspondence.

The momentous change had already come about by which scientists were given a third means of communicating their work in writing, in addition to publishing books and exchanging letters with other scientists: the first scientific periodicals were beginning to appear. Newton was in due time to avail himself of this new medium, but his first contribution to the *Philosophical Transactions* of the Royal Society did not appear until 1672. For the time being correspondence remained as important as ever, and it had its own organization that was still essential to the progress of thought. There were active intermediaries who made it their business to bring scientists in touch with one another, so that science might benefit from the exchange of letters between them. Newton had to do with two such men. One was John Collins, a Fellow of the Royal Society who was especially interested in mathematics. He made himself useful as a volunteer, for instance by bringing Newton's work to the notice of the Scottish mathematician David Gregory and by forwarding letters of each of them to the other—they do not seem to have corresponded directly. The other was the German Henry Oldenburg, the Society's Secretary. His official position and his knowledge of languages fitted him to act as a link with the Continent. It was through him that Newton's work became known to the great Dutch mathematician and scientist Huygens and to the universal genius Leibniz. Unfortunately the intermediaries, Oldenburg in particular, did not do all they could have done to prevent the exchanges of ideas from developing into altercations. They were tempted almost to take up the position of boxing promoters. This was not the best way to handle Newton.

The scientific correspondence begins quite suddenly with a copy made by Collins of a letter from Newton to an unidentified friend about his success in a "small attempt" he had undertaken as a by-product of some experiments in optics. People were trying to make refracting telescopes more effective, but Newton satisfied himself (on inadequate grounds, it later turned out) that it could not be done either by geometrical contrivance or by technical perfection in the making of lenses. Accordingly he had invented the reflecting telescope, and he had made such a telescope himself. Although it was only six inches long, and the materials were bad and the polish on the metal reflector not good, with it he had seen Jupiter distinctly round and Venus horned. This was the sort of invention that appeals to everyone. Afterward Newton made another telescope and sent it up to the Royal Society. The Society ordered one four feet long to be copied from it, and elected Newton a Fellow.

No one could doubt that he was an ingenious scientist and a first-rate artificer. But he was already known as more than that. Another branch of the correspondence had begun, quietly enough, when Barrow wrote from Trinity to Collins, promising to send him some papers by "a friend of mine here, that hath a very excellent genius to those things." They contained generalized methods for calculating the dimensions of magnitudes, and methods of resolving equations. Collins was soon copying for further transmission a manuscript entitled "De Analysi per Æquationes," and when Barrow disclosed the name of his friend, Newton was launched as a mathematician.

Newton often showed himself a willing and friendly correspondent. He took the trouble to help one unimportant person who was preparing a book of tables of square roots and logarithms, and another who submitted a professional problem about gauging the quantity of liquid in a partly filled cask. But there is nothing to show that he derived any pleasure from the demands that his growing reputation began to make on his time. He seems, at least in the years covered by this volume, never to have initiated the commerce of letters with anyone. It is fairly clear that in these early years he did not keep copies of his own outgoing letters. In the beginning he showed no inclination to keep his thoughts to himself, even on the subject of alchemy, on which he was beginning to experiment and on which he touched in one early letter. He lectured on optics, as Professor in succession to Barrow, and he told Collins that he gave his lectures yearly to the university library.

But early in the year 1670 there were signs that he found intellectual contact with other people disturbing. Sending to Collins a solution of a problem about annuities, he wrote: "You have my leave to insert it into the *Philosophical Transactions* soe it be wthout my name to it. For I see not what there is desirable in publick esteeme, were I able to acquire & maintaine it. It would perhaps increase my acquaintance, ye thing wch I cheifly study to decline." There is no reason to suspect any insincerity in this. After Newton was elected a Fellow of the Royal Society he allowed three years to go by before he went up to be admitted at a meeting. Fourteen months later he wanted to resign: Cambridge was a long way from London and he had met with some unrecorded rudeness. However, he stayed on. Hard-working men of genius are often more concerned to pursue their investigations than to make them public, but even when they are proud and sensitive, they mostly manage to reconcile steady productiveness with the requirements of social life. Newton, however, was not so fortunate.

He frequently stated his aversion to controversies, disputes, contentions, "feuding and warring in print"; but whenever he made an announcement, he found himself committed not only to laborious hours with his quill-pen in explaining it to courteous inquirers, but also to something much more distasteful. It began when he followed up the delivery of the telescope by describing his conclusions about the prismatic decomposition of light. This brought him into unhappy relations with several other scientists. Robert Hooke, the Curator of the Royal Society, who had charge of its experiments, was a man of brilliant gifts, but jealous, touchy and sometimes worse. He put forward criticisms, some of which were justified, but he seemed to underrate Newton's work in comparison with his own. After some ominous preliminaries he and Newton were reconciled; they exchanged forgiving letters that do honor to them both. But the great Huygens also was critical, and he seemed to be at cross-purposes with Newton. In answering both Hooke and Huygens, Newton had to deal with questions that he had not intended to raise. He had not claimed the certainty of mathematical proofs for his propositions about color; they depended on experiments and on physical principles as well as on mathematical demonstrations. He had not offered any theory or hypothesis about the nature of colors, but only what he derived from his experiments and calculated positively and directly. It was wearisome to repeat himself and elaborate his explanations.

The most irritating of the critics was Francis Hall, known as Line or Linus to the learned world. He was Professor of Hebrew and Mathematics in the College of English Jesuits at Liège, and he had made useful contributions to optics. Since one of his friends thought that he deserved canonization, we may be sure he was a meritorious character; but the unsolicited letter that he addressed to Oldenburg expressed disagreement with Newton in what appeared to be a casual and patronizing manner. In a later letter he made it worse. He really had a point to make, but he would neither accept the result of Newton's crucial experiment nor repeat it. He died but his friends maintained the argument.

At first Newton was reasonable except for moments of impatience, but then a different mood settled upon him. He changed his mind about publishing his Cambridge lectures on optics. He declined Collins's offer, made through Barrow, to arrange for it, "finding already," as he wrote, "by that little use I have made of the Presse, that I shall not enjoy my former serene liberty till I have done with it." In 1673 he told Oldenburg, not for the first time, that he intended "to be no further sollicitous about matters of Philosophy" (*i.e.*, physics), and that he hoped Oldenburg would favor him in that determination by "preventing," so far as he conveniently could, any other philosophical letters that might concern him. After that there was a period when he was chiefly occupied with chemical experiments. His inhibition against publication was not limited to physics. For some years Newton had intended to issue, with the addition of his own new work, an edition of a book on algebra published in 1661 by

the Dutchman Gerard Kinckhuysen. There were difficulties about the plan, which was never a very good one. It was not finally abandoned until 1676, but before that Newton was undecided whether to publish his own work, or to complete his paper about "invention or the way of bringing problems to an Æquation." Such difficulties caused his works to be published only after many delays, and then often piecemeal and imperfectly. The treatise *De Analysi* appeared in 1711; the optical lectures only after his death.

Later in his long life, when his fame was higher, Newton was still harassed by controversy. His further exploration of optics started a division of opinion that lasted long after his time, and there was the famous and odious dispute about his share in the discovery of the calculus. In defending his claims he reviewed this earlier period and indicated what mathematical devices he had used then and even before, from about the time when he took his degree at Cambridge. These considered statements from memory are of great value in showing the connections of his thought, but they are not accurate as to dates and sequences. They therefore set problems that the correspondence helps to solve, as it does of course many lesser problems. When Newton wrote a mathematical letter, he did not show all his workings; he thought it would be a not-unpleasing exercise for the recipient to supply the missing steps. Modern readers will be the better able to do so with help that Professor Turnbull supplies. Newton stated each result in a form suitable for his reader, but it was left for the editor to show the depth and richness of the underlying analytic theory.

More than pleasure can be derived from following Newton's mind at work. It was exact, tenacious, critical of others (though generous in recognizing their successes), and from time to time it was open to sudden illumination. An impulse from outside might start Newton off on a train of thought, but once started he was not easily diverted from his own course, and as a correspondent he learned far less from others than he taught them. James Gregory dropped his work on the quadrature of the circle when he heard from Collins that Newton was ahead of him, but there was no one whose work had any such effect on Newton in this period. On the whole it may be doubted that he gained by engaging in organized correspondence as a means for the cooperation of minds.

This is not necessarily a melancholy reflection. If we read only the letters, we are bound to make too much of the checks and *contretemps*. They sink down to their proper level when we remember the splendor of Newton's discoveries. He grew up at a time when able men in half a dozen European countries were working at mathematics and physics, using the same books and studying one another's results as they became available. At Cambridge he came into the main stream of contemporary thought. He was equally interested in a wide variety of subjects, and while he worked up some of them to the point of making his conclusions public, he had others in mind that he mentioned only when something called them out. His later work followed from optical experiments, astronomical observations and mathematical reasoning, but in a sense it was all implicitly present from the beginning. Occasionally some stimulus led him to write down something outside his immediate program of work. When Oldenburg passed on to him Huygens's book on the pendulum, he wrote in answer two paragraphs about gravitation. Except for these, his letters in this volume are silent on this subject, although it is the one with which Newton's name came later to be chiefly associated. But the volume also gives, with facsimile reproductions, a manuscript of several years earlier in which Newton dealt with it for his own satisfaction. This may well be the manuscript that he showed to David Gregory long afterward, and of which Gregory wrote that in it all the foundations of Newton's interpretation of the solar system were laid. It shows that the two paragraphs came from a store of thought of which the extent can scarcely be known.

Newton drew so much from this store that he revolutionized the treatment of every branch of mathematics and established a system of astronomical mechanics that endured for three centuries. These great advances in knowledge enriched the content of liberal education, most markedly at Cambridge, but to some extent throughout the Western world. They were assimilated into the beliefs about the nature of the universe, some of them remote from Newton's own, which have long been enthroned in Western thought. Now that a new era has succeeded the age of Newton, the interest of tracing how his choice of questions and his conclusions came to this dominance has lost something of its relevance. The minutiae of Newtonian scholarship may seem to have nothing to do with nuclear physics or with the newest cosmologies. On the other hand, these advances are themselves

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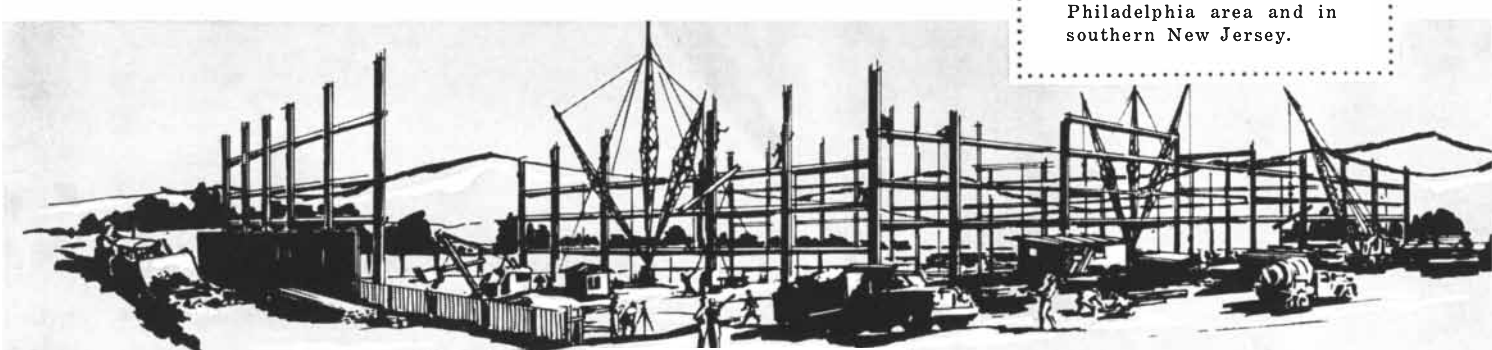


part of the history of science. If this history is to be studied to any real advantage, it must conform to scientific standards of thoroughness. This volume is an example of how it ought to be done.

Short Reviews

DARWIN'S CENTURY, by Loren Eiseley. Doubleday & Company, Inc. ($5). FORERUNNERS OF DARWIN: 1745-1859, edited by Bentley Glass, Owsei Temkin, William L. Straus, Jr. Johns Hopkins Press ($6.50). THE AGE OF THE WORLD: MOSES TO DARWIN, by Francis C. Haber. Johns Hopkins Press ($5). The festivities, Allah be praised, are coming to a close; there can be too much of a good thing, especially when most of it is not so good. The Darwin centenary has had a mixed complexion. Himmelfarbian revisionists have discovered not only that he was a plagiarist but also that he was wrong; sundry specialists have assembled historical minutiae and irrelevancies, less in Darwin's honor than in their own. Fortunately a few good books have appeared, among which Eiseley's must be numbered. Neither falling into a coma of veneration, nor depreciating what cannot be depreciated, he has written an enlightening study, worthy of its subject. He shows us what Darwin did and fairly examines his debt to his predecessors and contemporaries. Of considerable interest is the evaluation of the work of William Wells, who in 1813 read to the Royal Society a paper that afforded a remarkable preview of the principle of natural selection, and of the great influence on Darwin of Charles Lyell. Altogether, in its rounded, literate, well-tempered appraisal of Darwin's achievements, in its account of the obstacles to the theory of evolution set by physicists, theologians and other pundits, and in its perceptive analysis of the confluence of thought that the *Origin of Species* represents, Eiseley's book is the most satisfactory and sensible of the commemorative expressions. *Forerunners of Darwin*, engineered by no less than three editors, consists of 15 essays by various scholars, six of which are reprints of papers by the late Arthur O. Lovejoy. The contributions deal with Maupertuis, Buffon, Diderot, Kant, Herder, Lamarck and Schopenhauer, seen as Darwinian precursors. The contents are on the whole pretty special and not entrancing; one must not fail to mention a paper by Charles Coulston Gillispie, which informs the reader that Darwin was a dull but diligent chap, the "classic illustration of what Duhem meant when he described the English mind in science as weak and comprehensive." One recalls sadly the weak and comprehensive minds of Harvey, Boyle, Newton, Faraday, Maxwell and other English ninnies. Haber's study, an "extension of his doctoral dissertation," is a sound academic exercise, but it takes him a long time to show what is now well known: that the theory of evolution rests on the concept of the earth's great age, and that until this was proved Darwin did not have enough room to lay out his edifice. Let the curtain be lowered for another century, and until then may the great man sleep in peace.

THE ORIGIN OF SPECIES BY CHARLES DARWIN: A VARIORUM TEXT, edited by Morse Peckham. University of Pennsylvania Press ($15). Six editions of the *Origin* were published between 1859 and 1872; each had revisions, some very substantial; Darwin rewrote many of his sentences four or five times, and the book grew by almost a third. The editor, professor of English at the University of Pennsylvania, has undertaken the almost incredible drudgery of preparing a variorum text, which gives no version completely but records all major additions, deletions and changes in style and punctuation. A seventh wonder of academic pyramid-building.

DIARY AND LETTERS OF JOSIAH GREGG, edited by Maurice Garland Fulton. University of Oklahoma Press ($17.50). The publishers have reissued this collection comprising the diary and letters of the Santa Fe trader, scholar, explorer and scientist who wrote the classic work on the West, *Commerce of the Prairies*. The first volume covers Gregg's Southwestern movements and enterprises from 1840 to 1847; the second is a narrative of his excursions in Mexico and California from 1847 to 1850, the year of his death. This is an enjoyable and valuable work (containing the substance from which Gregg hoped to write a sequel to his earlier volume), presented in an attractive, handsomely illustrated format characteristic of the publications of the University of Oklahoma Press.

A HISTORY OF EMBRYOLOGY, by Joseph Needham. Abelard-Schuman ($7.50). Needham's noted treatise *Chemical Embryology*, published in 1931, began with four chapters on the history of embryology. These were later amplified and appeared as a separate book. The treatise and the book are out of print, and now a second edition of the history is issued, which Needham has revised with the assistance of Arthur

Hughes. The work spans the growth of the subject from antiquity through the 18th century; a companion volume by a group of specialists is promised that will continue the story through the 19th century under a number of separate headings. The extraordinary amplitude of Needham's learning, his literary skill and characteristically lively and provocative approach to problems of science and society make this a very attractive book. Excellent illustrations.

PILLOW PROBLEMS AND A TANGLED TALE, by Lewis Carroll. SYMBOLIC LOGIC AND THE GAME OF LOGIC, by Lewis Carroll. Dover Publications, Inc. ($1.50 each). These two volumes, each comprising two books, contain mathematical and logical recreations by the author of *Alice's Adventures in Wonderland*. The "pillow problems," so called because they were "solved in the head, while lying awake at night," are algebraic, geometric, trigonometric or related to probability. They are not profound, but they will not put you to sleep; indeed, they may help to explain Carroll's growing insomnia and his need to invent a "nyctograph," a device for writing in bed in the dark without having the pen run off the paper. *A Tangled Tale* consists of puzzles embedded in a story of 10 "knots," *i.e.*, chapters. *Symbolic Logic* deals with the ways of expressing classical logic by means of symbols. It contains more than 380 problems and such famous premises for soriteses as: Babies are illogical; nobody is despised who can manage a crocodile; illogical persons are despised. (Answer: Babies cannot manage crocodiles.) *The Game of Logic*, a scarce little book, describes a logic game to be played on a board with counters. The inside back cover of this edition can be cut apart to provide the equipment.

ANIMAL CAMOUFLAGE, by Adolf Portmann. University of Michigan Press ($4.50). An engagingly written, well-illustrated, elegant little book about the "sorcery of nature"—a phrase of Karl von Frisch—by which faces and forms are changed so as to deceive, conceal, lure, warn and frighten. A butterfly becomes a folded leaf; the curlew presses to the ground to shorten its shadow; the flashing clownfish hides its brilliant colors in the tentacles of a sea anemone; a South American hopper has an "eye" on its wing to mislead its enemies; the Indo-Malayan relative of the praying mantis looks as if it had been squashed and is therefore not worth eating; the measuring worm uses combined features of rigid posture, concealing colors and shadow-disguising tubercles to masquerade as a tiny twig; the crab *Pisa* covers itself with sponges and corals and thus merges into its natural background; the sponge crab cuts out a sponge mask and holds it in place over its back by a specially modified last pair of legs (if given a large piece of wet paper, the crab will at once cut out a piece just the right size and don it); the moth *Oxidia* has a "midrib" running across all four wings which increases its resemblance to a leaf; the Amazon Valley fish *Monocirrhus polyacanthus* hangs head-downward beneath the surface of the water and is almost indistinguishable from a dead leaf; the Malagasy tree snake has a head so modified that the tip looks astonishingly like a twig; certain African butterflies give the effect of a complete flowering plant; wasp stripes are copied by many insects, among them beetles; shrimps, fiddler crabs, prawns, flounder and flatfish undergo remarkable changes of color, the flatfish even changing its pattern to blend into different backgrounds. The survival value of these various forms of camouflage is described in a final chapter of this delightful volume.

SCIENCE AND HUMAN VALUES, by J. Bronowski (95 cents); ALBERT EINSTEIN, edited by Paul Arthur Schilpp ($3.90); SCIENCE SINCE 1500, by H. T. Pledge ($1.85); ANCIENT SCIENCE AND MODERN CIVILIZATION, by George Sarton (95 cents); THE STRUCTURE AND EVOLUTION OF THE UNIVERSE, by G. J. Whitrow ($1.45). Harper Torchbooks. This first venture of Harper into the field of paper-back reprints in science is admirable. The titles are excellent, the volumes are attractive, suitably illustrated, clearly printed and not overpriced. Bronowski's essay, though highly praised by discriminating readers, did not have much of a run in the hard-cover edition, and deserves the wider circulation it is now sure to get. The Einstein book, which originally appeared in the Library of Living Philosophers, offers a searching examination by Max Born, Arnold Sommerfeld, Kurt Gödel, Niels Bohr, Max von Laue, Louis de Broglie, Wolfgang Pauli, Philipp Frank, Hans Reichenbach, P. W. Bridgman and others of his scientific work and its philosophical consequences; also included are his autobiography, his "reply to criticisms" of the contributors and an invaluable bibliography of his writings. Pledge's short history of modern mathematics, physics, chemistry and biology is outstanding as a one-volume survey; it is authoritative and rich in information. Sarton's essays are informed by his vast erudition and exhibit his sensibility as to the influence of Greek science and culture on modern thought. Whitrow's introduction to cosmology is a revised and updated version of his *The Structure of the Universe*, first published in 1949. It does not call for specialized knowledge, and will appeal to serious students of the subject.

THE AXIOMATIC METHOD, edited by Leon Henkin, Patrick Suppes and Alfred Tarski. North-Holland Publishing Company ($12). Proceedings of a symposium held at the University of California in 1957 and 1958. One of the central aims of the symposium was to examine the markedly different pattern of axiomatic development in mathematics and physics. The vitality and range of axiomatics are illustrated by the spectrum of topics discussed: elementary geometry, plane affine geometry, geodesics, topology, rigor in physics, classical mechanics, the axiomatization of mechanics, relativistic kinematics, the axiomatic foundations of quantum mechanics, axioms for cosmology, physicological problems, axiomatic theory of functions, axiomatics and genetics. Among the contributors are Paul Bernays, Alfred Tarski, Paul Szasz, Friedrich Bachmann, A. Heyting, Adolf Grünbaum, P. W. Bridgman, Patrick Suppes, Alfred Landé, Pascual Jordan, J. H. Woodger, R. B. Braithwaite, Karl Menger and R. L. Wilder. Philosophers, mathematicians and physicists will find much in these pages to engage their attention.

HANDBOOK OF PHYSIOLOGY: SECTION I, NEUROPHYSIOLOGY, VOL. I, edited by John Field; section edited by H. W. Magoun. The Williams & Wilkins Company ($22). The American Physiological Society has undertaken the publication of a multi-volume handbook of physiology to constitute a repository for the body of physiological knowledge, the discoveries and formulations of past as well as contemporary times. Physiologists of many nations have contributed as editors and authors, and when complete the work promises to be the most encompassing and authoritative in its field. The first three volumes of the *Handbook*, of which this is one, constitute the section on neurophysiology, a branch of study that has been completely transformed by the developments of the past 25 years. Among the 80 contributors to this section are Sir John

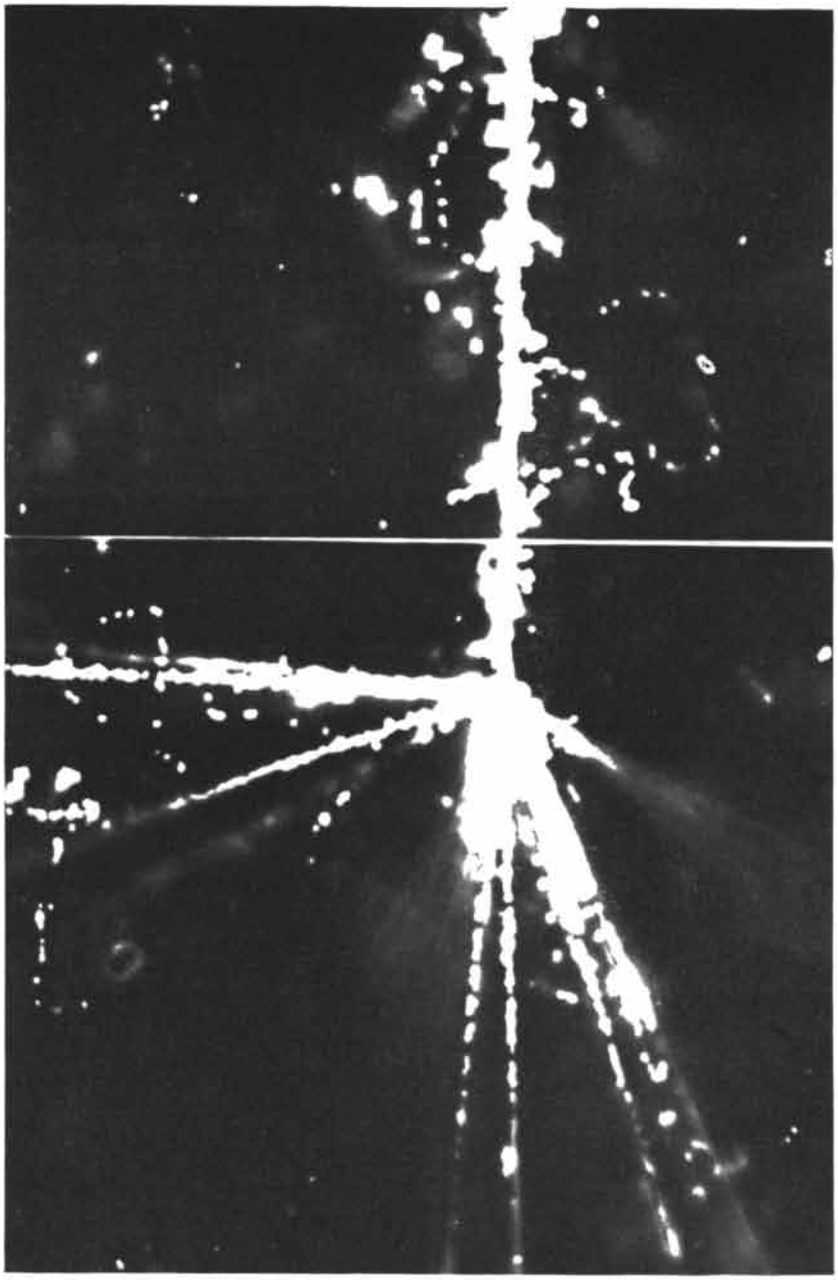
Eccles, Alfred Fessard, Lord Adrian, H. K. Hartline, Derek Denny-Brown, Frédéric Bremer, Wilder Penfield, C. F. Schmidt and Sir Rudolph Peters.

SPACE TECHNOLOGY, edited by Howard S. Seifert. John Wiley & Sons, Inc. ($22.50). A collection of 30-odd papers on all phases of the physical principles of space exploration. The series of lectures on which this volume is based, though highly technical and on a graduate level, was attended by no less than 4,500 students at the various branches of the University of California, was televised and was made into kinescope films reaching an audience of 100,000. Five main categories comprise the treatment: flight dynamics, propulsion and structures, communications, guidance and control, man in space. Impressive.

MATHEMATICS DICTIONARY, edited by Glenn James and Robert C. James. D. Van Nostrand Company, Inc. ($15). A second, revised and substantially enlarged edition of a useful reference book. Additions include basic terms in modern algebra, number theory, topology, vector spaces, theory of games, linear programming, numerical analysis and computing machines. Another feature is a multilingual index giving English equivalents of mathematical terms in French, German, Russian and Spanish.

A SHORT INTRODUCTION TO ANATOMY, by Jacopo Berengario da Carpi. University of Chicago Press ($5). A translation, with an introduction and historical notes, by L. R. Lind of an important 16th-century anatomical treatise by a forerunner of Vesalius. This is a foundation work, Berengario having been the first, according to F. H. Garrison, to substitute drawings from nature for traditional schemata. It is of special concern to the historian of science because it corrects the common notion that Vesalius and da Vinci "appeared suddenly out of a dark and unproductive void known as the Middle Ages." Illustrations.

THE INDIVIDUAL AND THE UNIVERSE, by A. C. B. Lovell. Harper & Brothers ($3). Lovell's brilliant Reith Lectures for the British Broadcasting Corporation, in which he describes the universe we can study with our telescopes—optical and radio—and discusses various theories of the origin of the universe. That a good book need not be a big book is once again demonstrated; in a little over 100 pages the author gives an account of the new



astronomical learning, imparting a sense of its marvelous beauty and complexity, and a respect for how much and yet how little we know. No other popular book on this subject, regardless of size and scope, has so much treasure. Recommended without reserve to anyone with a capacity for wonder.

A Social and Religious History of the Jews, by Salo Wittmayer Baron. Columbia University Press ($45). Second, revised and enlarged edition of a distinguished eight-volume survey of the political, economic, social and cultural history of the Jews from ancient times to the close of the Middle Ages. Volume VIII covers the contributions of Jewish scholars, from 500 A.D. to 1200, to mathematics, astronomy, alchemy, medical science and philosophy. Through their writings, it should be noted, much of the science of the Greeks was preserved, later to be transmitted by Latin writers to the West.

Notes

The North American Deserts, by Edmund C. Jaeger. Stanford University Press ($5.95). A readable guide by an ecologist with 40 years of field experience to the five great deserts of the North American continent, describing their physical appearance, weather and climate, geologic history, plant and animal life and human cultures.

The Theory of Heat Radiation, by Max Planck. Dover Publications, Inc. ($1.50). A translation of the second edition of Planck's *Wärmestrahlung* (1913), an introduction to the theory of radiant heat in terms of his principle of quantum action.

Walter Bagehot, by Norman St. John-Stevas. Indiana University Press ($7.50). A study of the life and thought, together with a selection from his political writings, of one of Victorian England's most versatile and gifted men.

The Myth of the Birth of the Hero and Other Writings by Otto Rank, edited by Philip Freund. Vintage Book ($1.25). A collection of writings by one of Sigmund Freud's best-known pupils, who, after a close relationship lasting two decades, broke away and founded his own psychology.

Relativity for the Layman, by James A. Coleman. The Macmillan Company ($3.50). This book has had several

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incarnations. It was published in 1954 in hard covers, then appeared as a paperback, and is now reissued by a different publisher. It presents a simplified account, which was praised by Albert Einstein, of the history, theory and proofs of relativity.

The Scientific American Book of Mathematical Puzzles & Diversions, by Martin Gardner. Simon and Schuster ($3.50). A collection based on the author's department in this magazine: his writings, addenda from readers, bibliographies, solutions.

Vikings of the Pacific, by Peter H. Buck. University of Chicago Press ($1.95). A paper-back reprint of *Vikings of the Sunrise*, which, though published 20 years ago, has not been equaled as a story of Polynesian life.

Atomic Age Physics, by Henry Semat and Harvey E. White. Rinehart & Company, Inc. ($2). This paperback follows closely the second half of the National Broadcasting Company television course on physics given in 1958 and 1959. It covers the atom and atomic structure, the nucleus and nuclear structure. Good illustrations.

A History of Mechanical Inventions, by Abbott Payson Usher. Beacon Press ($2.25). A paper-back reprint of a standard history that was revised in 1954.

The Heavenly City of the Eighteenth-Century Philosophers, by Carl L. Becker. Yale University Press (95 cents). Soft-cover reprint of a brilliant group of historical essays that discloses the fallacy of believing "that the eighteenth century was essentially modern in its temper," *i.e.*, that the Age of Reason was reasonable.

The Actinomycetes: Vol. I, by Selman A. Waksman. The Williams & Wilkins Company ($12.50). The author has spent 45 years in study of these soil microorganisms. In this treatise, the first volume of which considers the nature, occurrence and activities of the actinomycetes, he summarizes his investigations and those of other students.

Embryos and Ancestors, by Sir Gavin de Beer. Oxford University Press ($4). The third edition of this excellent book on embryology and evolution picks up fresh data that have been gathered in the last decade.

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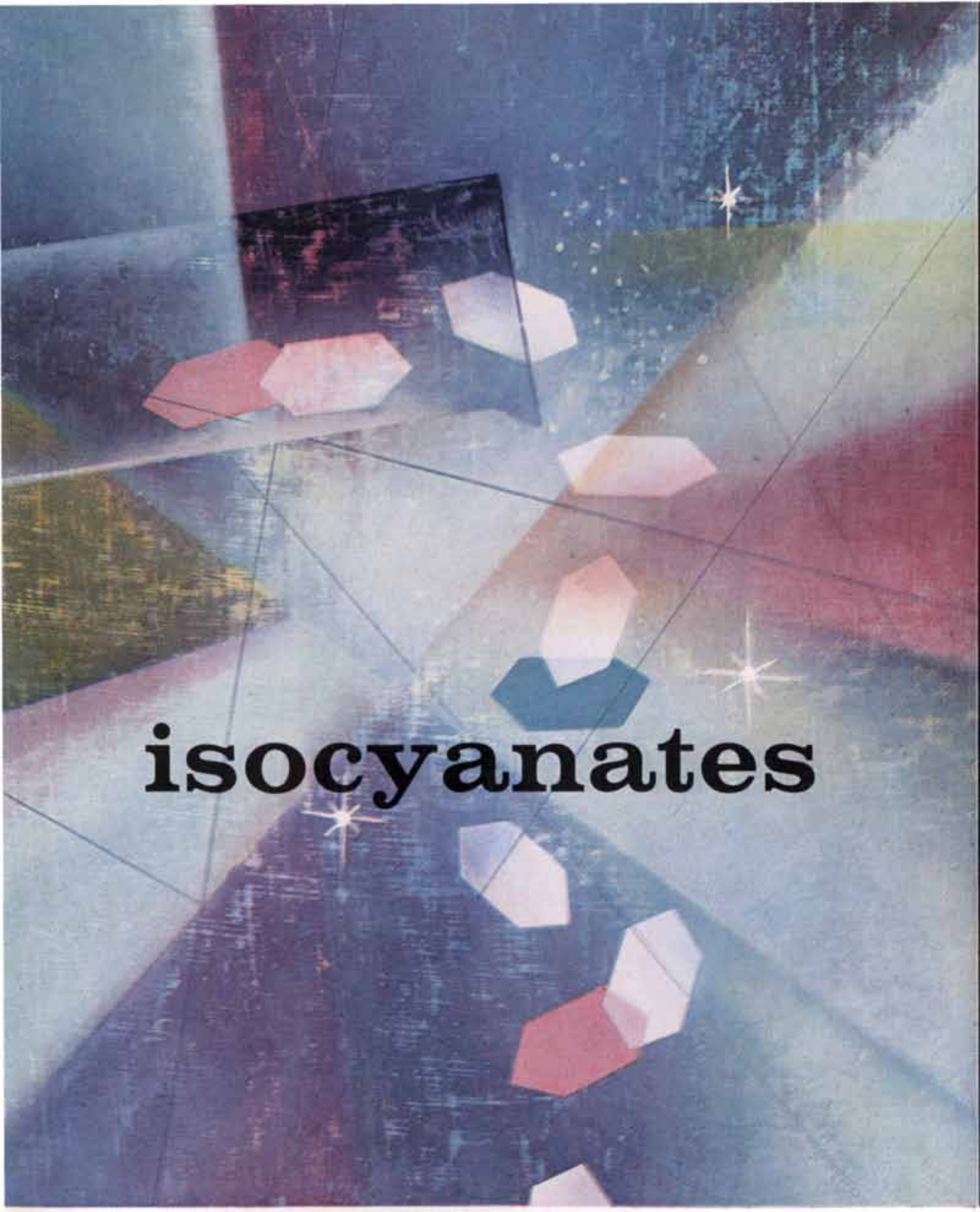

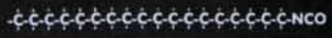

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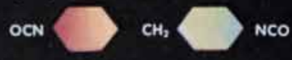

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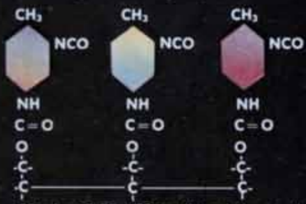

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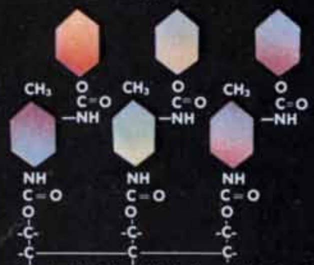

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