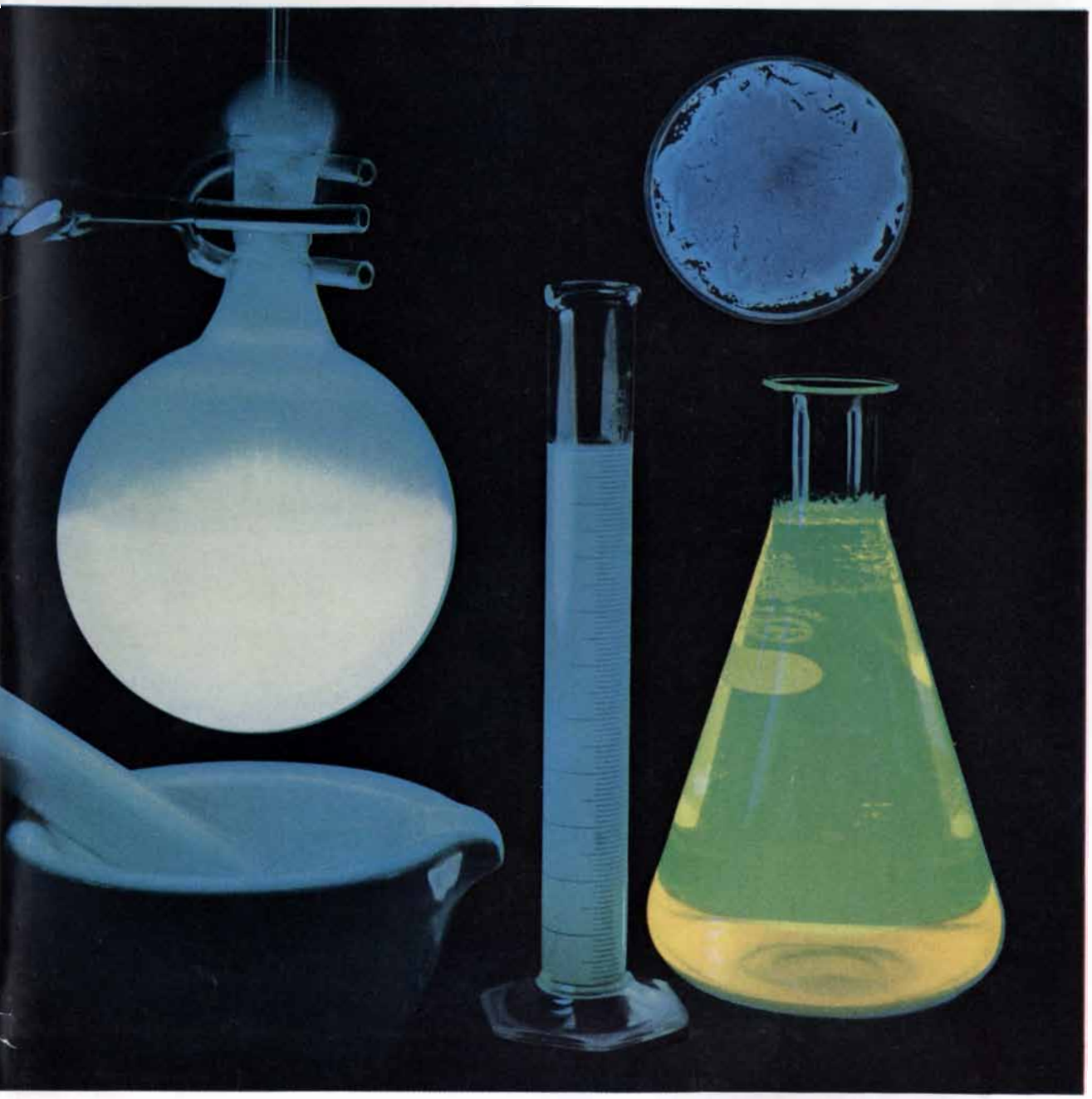
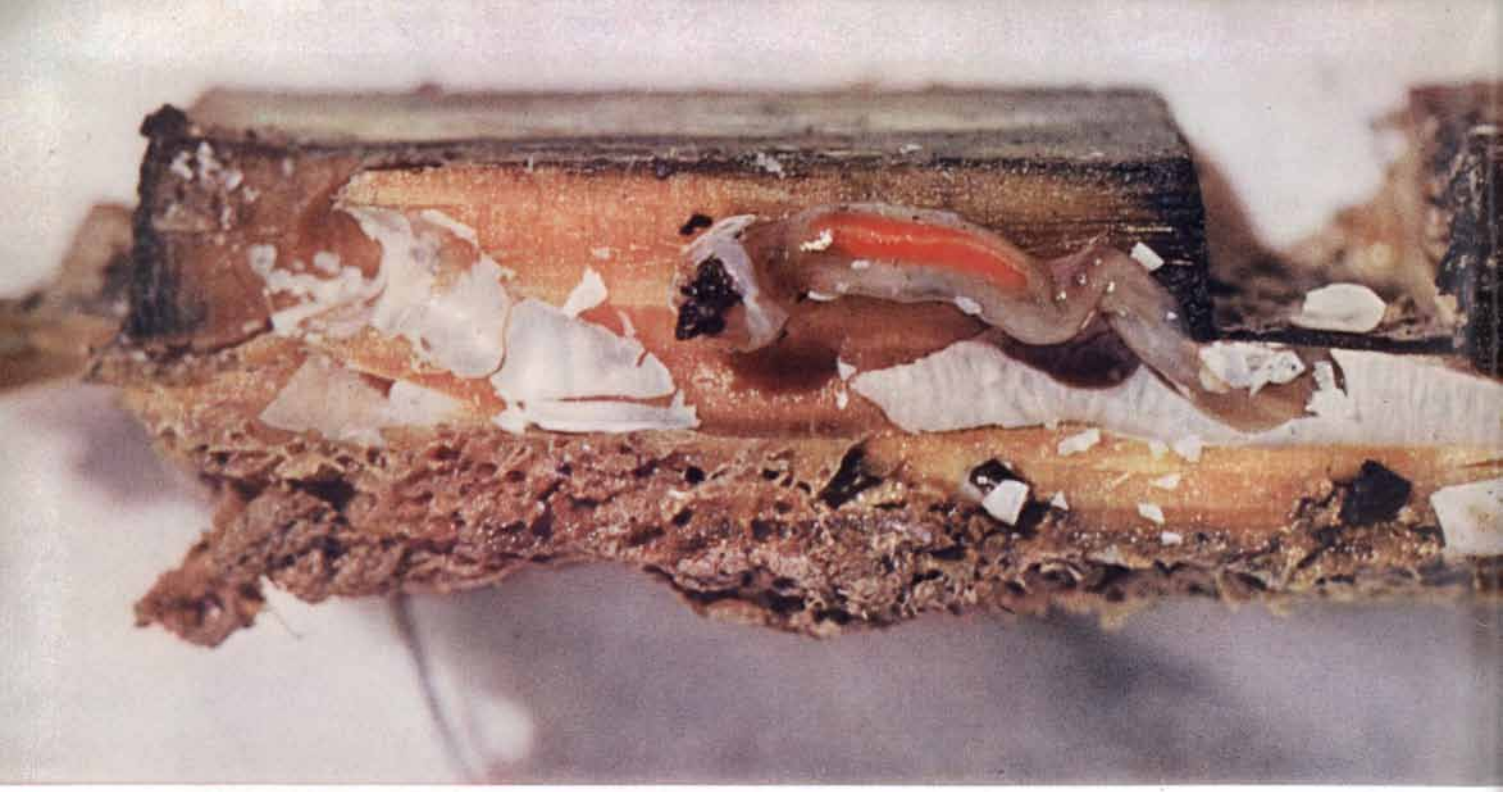
SCIENTIFIC AMERICAN



BIOLOGICAL LUMINESCENCE

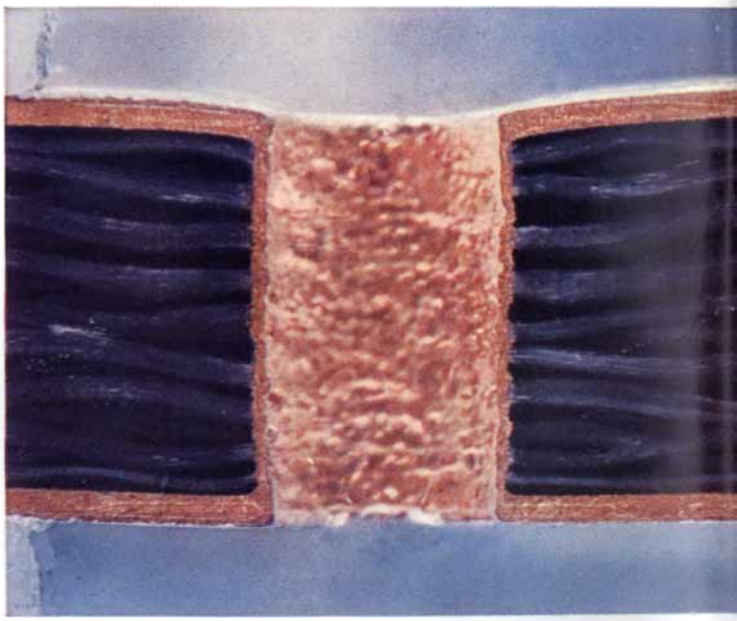
FIFTY CENTS

December 1962



HOW TO KILL TEREDOS' APPETITE FOR WOOD: Now there is a highly effective answer to this destruction in salt water: bioMeT* TBTO*, one of the many M&T organotins. Applied easily to boats by brush or dip, its colorless appearance will not affect paintability. Long-term tests of protection of marine piling are under way. Other uses: water treatment, anti-fouling paints, textile purification, terrestrial wood protection. *Trademarks of Metal & Thermit Corporation

MILD STEEL TURNS TO STAINLESS IN THE ARC: A welder becomes a veritable alchemist with M&T's "Ferro-core" electrodes. A new addition to the wide M&T welding line, this type has a mild steel core wire, with alloying elements in the coating. The deposit turns to stainless steel in the arc. Advantages: substantially lower electrode cost; more metal deposited per electrode.



HOW TO PLATE THE SIDES OF A 1/32-INCH HOLE: Minuteman, Hound Dog, F-104, Polaris—all have high reliability systems using printed circuit boards plated by the M&T Pyrophosphate Copper Process. The deposit is smooth, has fine grain. It's just as uniform in every hole as on each side of board—assuring good, soldered connections. Electroplating chemicals are an M&T specialty.

Uniting imagination in chemicals with know-how in metals, M&T contributes scientific advances to many fields: marine protection, welding versatility, electronic reliability. With this background, M&T offers you new methods, unique materials, proven capabilities—for creative approaches to old and new problems. **METAL & THERMIT CORPORATION**

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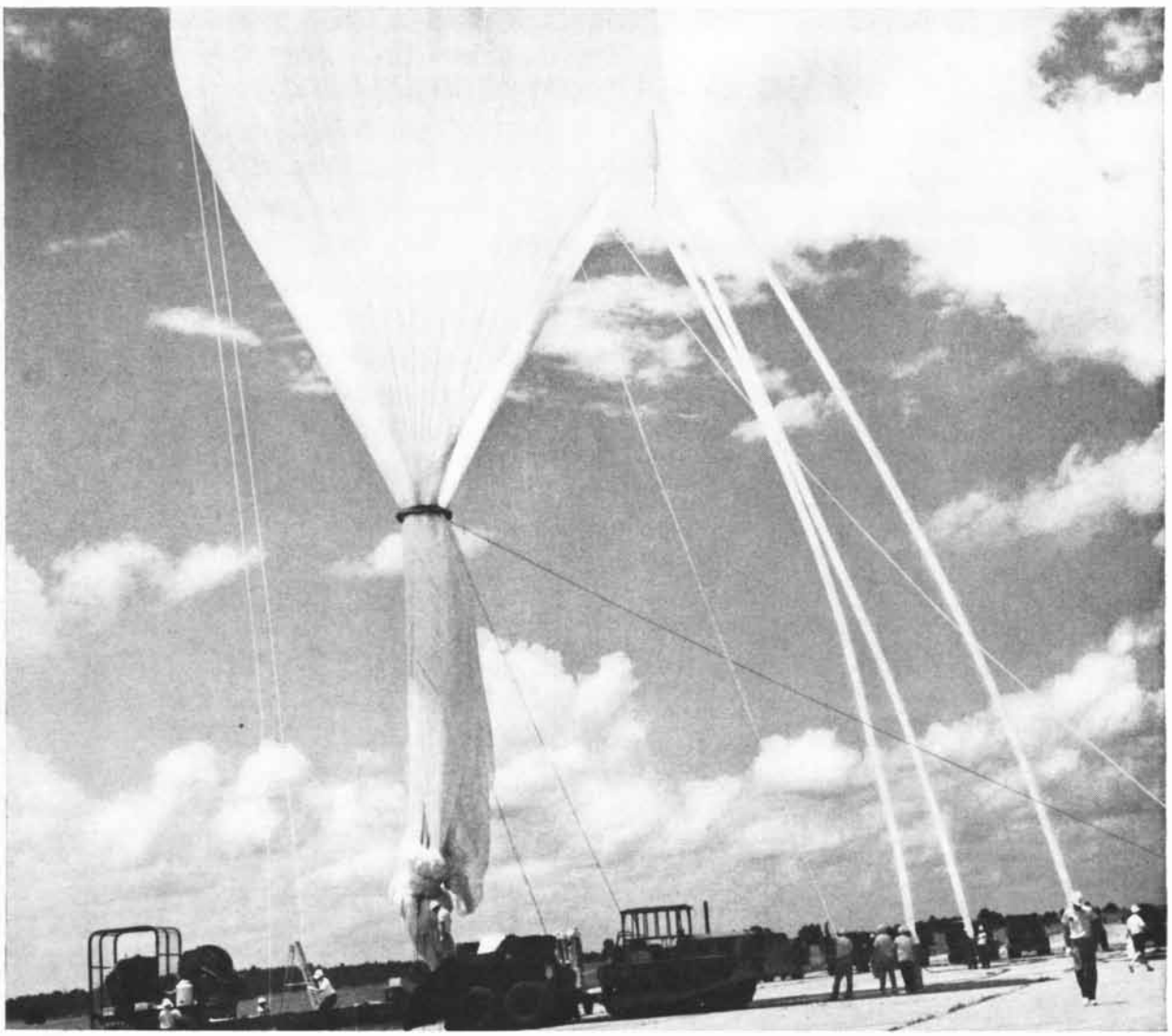
the 80,000 foot TRIPOD

Mysterious cloud patterns that stay the same for weeks on end blanket the face of Venus. What are they and what's behind them? What is the 30,000 mile long "Red Spot" that drifts longitudinally in Jupiter's cloud system? Saturn's nine moons? To answer these and a host of other questions, Princeton University will send Stratascope II aloft to 80,000 feet, above 96% of the earth's atmosphere. It will carry a radio-controlled photo-telescope that has an optical system capable of distinguishing two objects 30 inches apart at 1,000 miles.



Hundreds of scientists from many companies and many specializations worked together through the Project Program Manager, Vitro Laboratories, to create this exciting astronomical adventure. As Program Manager for *balloon system development, planning and flight operation,* Vitro acts as conference leader, interpreter, problem identifier, and coordinator. Vitro Laboratories has the longest successful history of interface engineering.

VITRO CORPORATION OF AMERICA • 261 MADISON AVENUE • NEW YORK 16, NEW YORK Vitro

WHO SAYS YOU CAN'T CARRY WATER IN A SIEVE?

You can now, thanks to a startling new product called AM-9. It actually turns water solid in seconds.

Remember those wonderful childhood days at the beach? You scooped a hole in the sand. You watched, fascinated, as the hole filled with water. Then you bailed... and it filled ... and you bailed... and it filled. Until you gave up and went for a swim.

Now picture this very same underground seepage on a giant scale and you have the problem that has faced many a harassed construction engineer.

Yes, although man may decide to sink a bridge footing here or dig a mine shaft there, Mother Nature quite often has other ideas. And she gets her way through *water*.

How? By the typically feminine maneuver of going underground. Beneath the topsoil lie layers and layers of substances, all of which have different properties. In tunneling through it, man has often, to his dismay, come upon layers of porous, sandy soil or fissured rock through which water flows easily. Trouble!

A problem like this is often solved by a technique called *grouting*. Grouting simply means that materials are pumped in to fill the voids in the sand or rock—like sticking thousands of tiny fingers in thousands of tiny dikes. In the past almost any inexpensive filler material was used. Cement. Clays. Even oatmeal. You pumped... and you hoped.

Then came AM-9* chemical grout.

It all began when a Cyanamid scientist synthesized a new compound named, with typical scientific brevity, *methylenebisacrylamide*. Step number two came when a group of other chemists, while exploring new uses for acrylics, uncovered a weird phenomenon. They found that when they mixed methylenebisacrylamide with another acrylic compound and certain catalysts in a glass of water—*the water turned solid!* So solid that it had to be cut from the glass with a knife.

At the time these first gels were being formed in the laboratory, an urgent, practical need had already been isolated. Water flowing through soil or rock formations caused costly problems and delays in construction and mining. Could this mysterious gel be the answer? It could—it was.

After refinement in Cyanamid laboratories came the big tests—exhaustive field trials. What emerged was AM-9—a grouting material that could literally work wonders.

It transforms porous soil into impervious matter instantaneously. It halts cave-ins and underground seepages. It permits man to tunnel and excavate to his heart's content.

And AM-9 has still another string to its bow. So thin it flows wherever water can flow, it *waterproofs* just as well as it grouts. AM-9 halts chronic water infiltration in sewers and mines, was used to permanently waterproof the utility tunnels at the Plattsburgh Missile Complex.

With the development of this remarkable product, Cyanamid entered an entirely new field. Chemicals had long been known to improve the *agricultural* properties of the soil, but they had been thought to have little power over the soil's *engineering* properties.

Truly, AM-9 marks a breakthrough for the entire chemical industry.

And that is precisely what is so exciting about being in the *business* of science.

Cyanamid's twelve divisions are staffed with thousands of scientists, virtually all working toward the solution of some pressing problem. Yet the full realization exists that minds must be allowed to "putter." To stare aimlessly into space. To explore with no apparent direction.

Out of this "puttering" comes a variety of things. You get solutions to problems that do not yet exist, weird and seemingly worthless substances—that really work—like AM-9.

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Plastics and Resins/Cyanamid of Canada Limited/Cyanamid International

Established 1845 **SCIENTIFIC AMERICAN** December 1962 Volume 207 Number 6

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows two different kinds of biological luminescence (see "Biological Luminescence," by William D. McElroy and Howard H. Seliger, page 76). All the light for the photograph is provided by the luminescent reactions themselves. At top right, standing on edge, is a Petri dish containing a solid culture of the luminescent marine bacterium *Achromobacter fischeri*. At top left is a spherical flask containing a mutant form of *A. fischeri;* the mutant is glowing brilliantly because the nitrogen needed for growth is being supplied by a meat extract. When nitrogen is supplied only by inorganic nitrates, the luminescence is much fainter, as shown in the tall graduate. The flask at bottom right contains a luminescent system incorporating extracts from the lanterns of the firefly *Photinus pyralis*. In the flask are (1) luciferin from *P. pyralis,* (2) the enzyme luciferase from *P. pyralis,* (3) adenosine triphosphate, (4) magnesium ions and (5) a glycyl-glycine buffer solution. At bottom left are a mortar and pestle used to grind the firefly lanterns, which provide luciferin and luciferase.

THE ILLUSTRATIONS

Cover photograph by William Vandivert

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THE REAL DIFFERENCE IS INSIDE

That's right — we cut the can away . . .

You are looking at the most critical area of Motorola's PNP germanium epitaxial mesa transistor — the die itself. Magnified over 50 times, this unretouched photograph enables you to see clearly the emitter and base stripes and their lead wires.

Most engineers have never seen the inside of a Motorola transistor. Clean, isn't it? Critical controls must be maintained in order to produce such units . . . controls that have a significant effect on the ultimate reliability of a transistor.

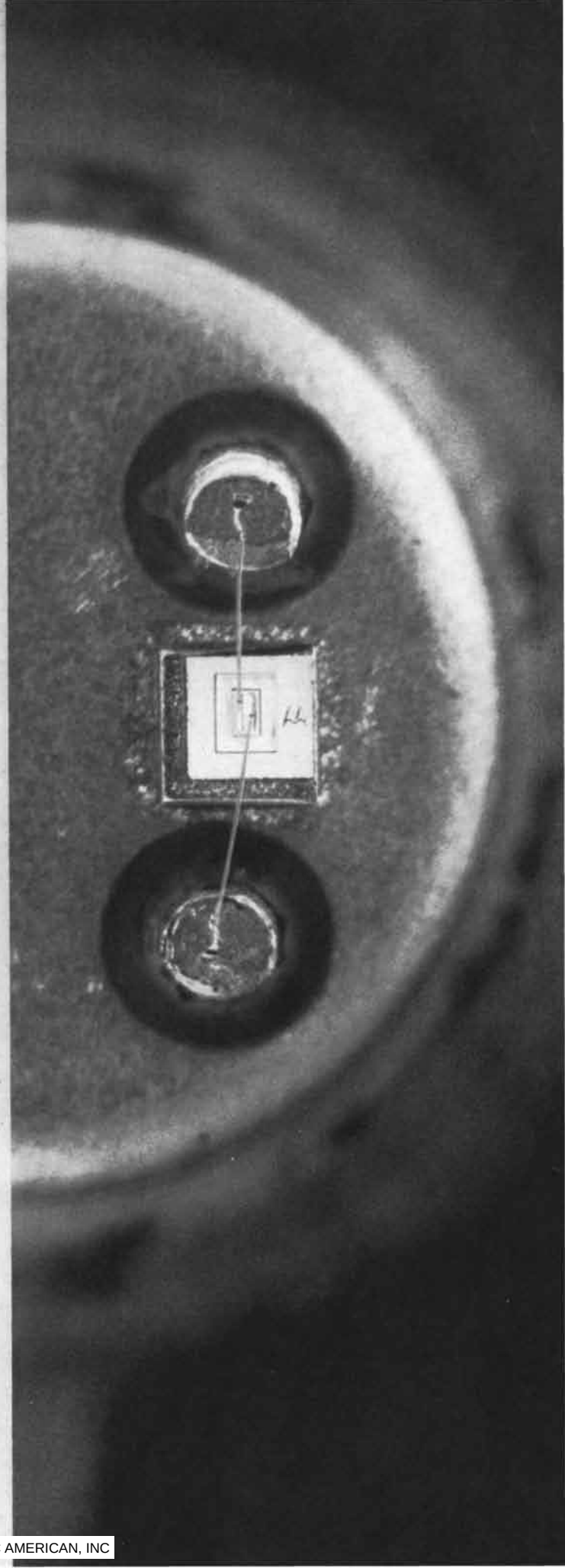
Notice the sharp, uniform metallic deposition of stripes . . . the precise control of stripe area, definition, and spacing. Motorola controls these dimensions to within one ten-thousandths of an inch. This care and skill is indicative of that taken throughout all phases of Motorola mesa transistor production, from the growth of epitaxial layers controlled to millionths of an inch to literally controlling the number of molecules of surface moisture necessary for optimum transistor performance.

Such precision may not be required to build a transistor that merely meets minimum performance standards. However, it is essential for the production of devices that will provide the continued reliable operation that has become synonymous with the name Motorola Mesa.

But, don't take our word for it . . . the next time your Motorola representative calls, have him open one of these mesa devices for you. Compare its obvious mechanical perfection with that of any other transistor on the market today.

You'll discover for yourself why Motorola high-frequency germanium mesa transistors were chosen to meet the highest reliability level of any transistor used in the critical Minuteman missile program . . . and are currently specified in applications demanding the most stringent reliability and performance requirements to date.

Compare it with others . . .
THE REAL DIFFERENCE IS INSIDE!



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P122-001

MERCURY JOURNAL

29 July 1958 . . . . . . President Eisenhower signed bill creating the National Aeronautics & Space Administration (NASA).

1 October 1958 . . . . NASA began official operation.

21 October 1958 . . . NASA announced a competition for a manned spacecraft, to be launched by an Atlas, placed in orbit around the earth and returned safely. A McDonnell study team, which had been working on manned orbital spacecraft for 11 months under company research budget, was assigned to prepare the proposal.

12 January 1959 . . . NASA announced selection of McDonnell to build Mercury Spacecraft.

13 February 1959 . . . Contract was signed with McDonnell for the design and construction of 12 manned orbital Mercury spacecraft. As the program expanded, subsequent orders were received for eight additional spacecraft, two procedural trainers, an environmental trainer, seven check-out trailers and much of the prelaunch operation at Cape Canaveral, including the mating of the spacecraft to the launch vehicle, check-out and countdown.

9 April 1959 . . . . . . NASA announced names of the seven Mercury Astronauts.

9 September 1959 . . NASA-produced "Big Joe" R & D spacecraft launched to test basic Mercury design concept. Spacecraft survived high heat and airload and was recovered.

4 October 1959 . . . . Little Joe 1 fired at NASA's Wallops Station, Va., checked matching of launch vehicle and NASA-produced spacecraft. The Little Joe test series enabled early evaluation to the spacecraft in the high aerodynamic pressures encountered at low altitudes.

4 November 1959 . . . Little Joe 2 fired from Wallops. Evaluated low-altitude abort conditions.

4 December 1959 . . . Little Joe 3 fired at Wallops Station to check high altitude performance of the escape system under high airloads. Rhesus monkey "Sam" used in successful flight.

21 January 1960 . . . Little Joe 4 fired at Wallops to evaluate escape system under high airloads. "Miss Sam", another Rhesus monkey, served as test subject.

25 January 1960 . . . Less than a year after signing of contract, McDonnell delivered first production spacecraft (#4).

2 April 1960 . . . . . . First instrumented spacecraft (#1), with escape tower, delivered to NASA by McDonnell.

9 May 1960 . . . . . . Spacecraft #1 fired in an off-the-pad abort escape rocket test.

29 July 1960 . . . . . . Mercury-Atlas 1. The first Atlas-launched flight was aimed at qualifying the production spacecraft under maximum airloads and afterbody heating rate during re-entry conditions. Spacecraft (#4) carried no escape system or test subject. Test objectives were not achieved due to launch system malfunction.

NASA's First Administrator T. Keith Glennan, and Pres. J. S. McDonnell Disclose Mercury Configuration 12 January 1959

McDonnell Project Engineers Establish Production Plans

Astronauts Visit McDonnell 12 May 1959

Big Joe R & D Capsule 9 September 1959

Little Joe Tests 1959-61

Hypervelocity Impulse Tunnel Tests

Paradrop Tests

#1 Spacecraft Delivery 2 April 1960

Manufacturing and Assembly

Final Manufacturing and Testing in White Room

McDonnell Engineers Perform on Site Checkout

Abort Rocket Test 9 May 1960

First Mercury-Redstone Flight 21 November 1960

Ham—the Astro-Chimp

Procedures Practice in Simulator

Launch—Checkout Trailer

Freedom 7 Spacecraft Hoisted Aboard Redstone

A-OK for Astronaut Shepard 5 May 1961

Launch Preparation for Astronaut Grissom

Mercury Orbits with "Mechanical Man" 13 September 1961

Friendship 7 and John Glenn

Liftoff for Astronaut Carpenter 24 May 1962

They Safely Return

. . Days of achievement follow months and years of creative engineering and planning.

8 November 1960 . . . Little Joe 5 fired from Wallops to check production spacecraft (#3) in an abort simulating the most severe Little Joe launch vehicle airload. Premature spacecraft separation signals resulted in early firing of the escape tower and loss of test objectives.

21 November 1960 . . Mercury-Redstone 1 was the first scheduled unmanned Redstone-launched flight. Premature engine cutoff at launch terminated the test. The emergency escape system was jettisoned. Spacecraft (#2) was not damaged and test was rescheduled.

19 December 1960 . . Mercury-Redstone 1A was a repeat of November attempt. Successful flight reached a peak altitude of 135 statute miles and covered a horizontal distance of 236 statute miles. Spacecraft (#2) was recovered.

31 January 1961 . . . "Ham", the 37-pound Astro-Chimp, was rocketed into space history aboard Mercury-Redstone 2. "Ham" and spacecraft (#5) were recovered after reaching an altitude of 155 miles and landing 420 miles downrange. Flight demonstrated ability of primate to react normally in prolonged weightless flight. "Ham" was recovered safe and well.

21 February 1961 . . . Mercury-Atlas 2 reached an altitude of 108 miles and speed of 13,000 mph. Flight checked maximum heating during worst possible re-entry conditions. Spacecraft (#6) was recovered 1,425 miles downrange.

18 March 1961 . . . . . Little Joe 5A at Wallops Station repeated Little Joe 5 test. Spacecraft (#14) was recovered but all test objectives were not met and shot was rescheduled.

25 April 1961 . . . . . . Mercury-Atlas 3 was an attempt to orbit spacecraft (#8) with a "mechanical man" aboard. Forty seconds after launching, the launch vehicle was destroyed by radio command. Spacecraft escape system functioned perfectly and spacecraft was recovered for reuse.

28 April 1961 . . . . . . Little Joe 5B completed the spacecraft escape system flight qualification tests. Spacecraft (#14) was reconditioned by McDonnell after previous flight and reused in this successful maximum dynamic pressure escape test.

5 May 1961 . . . . . . Astronaut Alan B. Shepard, Jr. rode Mercury-Redstone 3 into history with his ballistic flight seen by the world. The flight reached a peak altitude of 116 statute miles and was recovered 302 miles downrange. Spacecraft (#7) is now on public display in the Smithsonian Institute.

21 July 1961 . . . . . . Mercury-Redstone 4 was a successful downrange flight by Astronaut Virgil I. "Gus" Grissom. This was the first flight with the large window, greatly improving astronaut observation capability. Premature loss of the escape hatch caused spacecraft (#11) to take on water and sink despite determined helicopter recovery efforts. Astronaut Grissom was recovered from the water by helicopter.

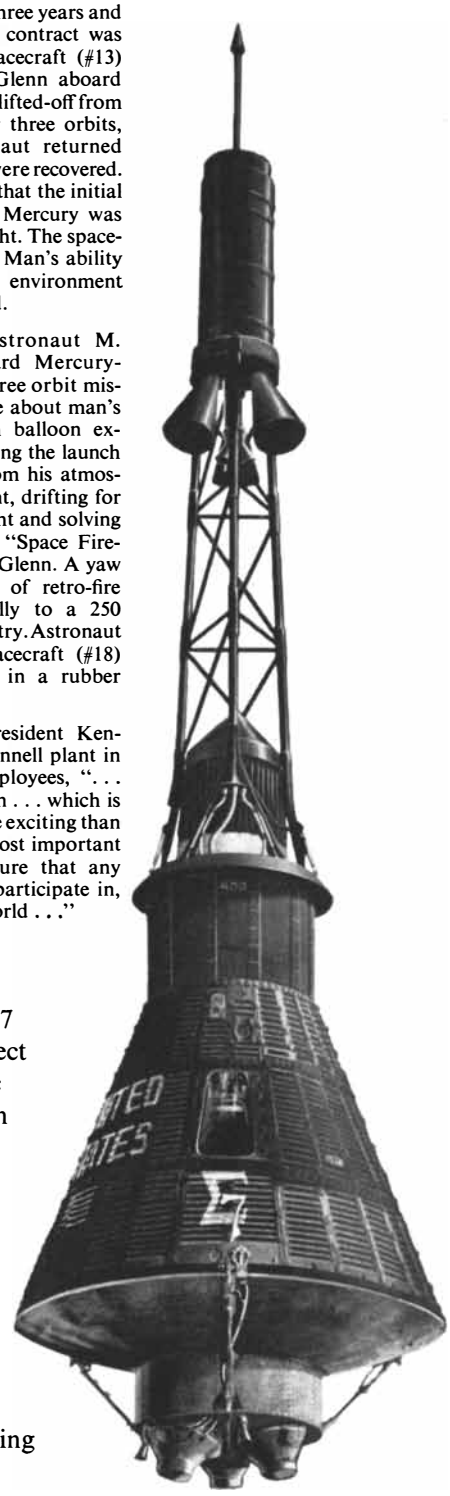
13 September 1961 . . Mercury-Atlas 4 placed the McDonnell Mercury Spacecraft in orbit for the first time. The spacecraft (#8) carried a McDonnell-developed "mechanical man" designed to use oxygen and add moisture to the cabin at the same rate as a man. The spacecraft was recovered after one orbit 160 miles east of Bermuda.

29 November 1961 . . Space-Chimp "Enos" twice orbited the earth in Mercury-Atlas 5. Spacecraft (#9) was recovered about 260 miles south of Bermuda.

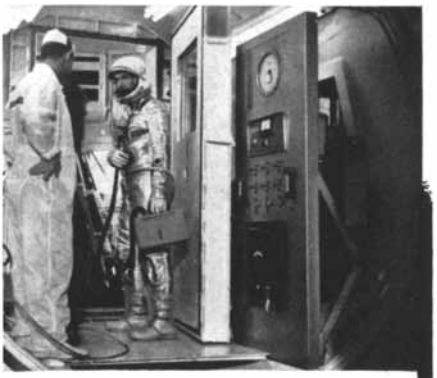
20 February 1962 . . . Three years and 39 days after Mercury contract was awarded, Mercury Spacecraft (#13) and Astronaut John Glenn aboard an Atlas launch vehicle lifted-off from Cape Canaveral. After three orbits, spacecraft and astronaut returned safely to the earth and were recovered. It is significant to note that the initial assignment of Project Mercury was completed with this flight. The spacecraft had been proven. Man's ability to adapt to the space environment had been demonstrated.

24 May 1962 . . . . . . Astronaut M. Scott Carpenter aboard Mercury-Atlas 7 completed a three orbit mission, adding knowledge about man's visual perception with balloon experiments, photographing the launch vehicle and the sun from his atmosphere-free vantage point, drifting for long periods in free flight and solving the phenomena of the "Space Fireflies" first observed by Glenn. A yaw condition at the time of retro-fire contributed substantially to a 250 mile overshoot on re-entry. Astronaut Carpenter left the spacecraft (#18) and awaited recovery in a rubber raft alongside.

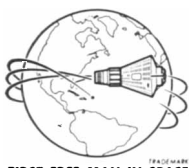
12 September 1962 . . President Kennedy visited the McDonnell plant in St. Louis and told employees, ". . . I can imagine no action . . . which is more essential and more exciting than to be involved in the most important and significant adventure that any man has been able to participate in, in the history of the world . . ."



3 October 1962 . . . Astronaut Walter M. Schirra, Jr., in his Sigma 7 Mercury Spacecraft (#16), completed a near-perfect six-orbit flight by landing on target in the Pacific Ocean off Midway Island. Much of the mission was accomplished in drifting flight by the United States' fifth man to go into space. The mission contributed additional knowledge about spacecraft control, space vision, and man's ability to work effectively in a prolonged weightless condition. The successful performance of Astronaut Schirra and Sigma 7 prepared the way for the planned one-day Mercury flight, and later 2-man McDonnell Gemini Spacecraft rendezvous flights. The flight was part of continuing U. S. space exploration programs.



Astronaut Schirra



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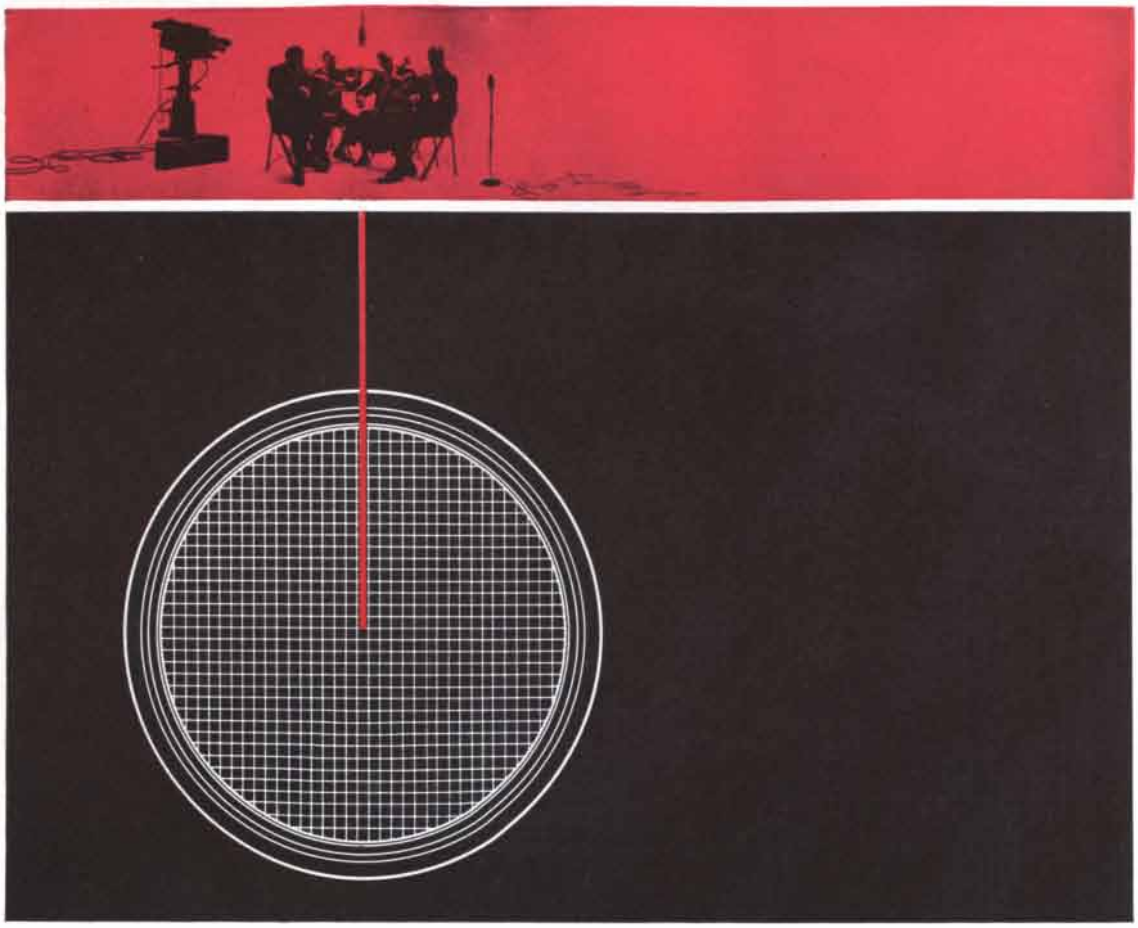

AN EAR TO HEAR A BEAM OF LIGHT

Light rays brighter than the center of the sun may someday carry the sound of music around the world. As communications specialists the scientists and engineers of ITT are vitally interested in this revolutionary use of light waves. In Europe one of our companies is deep in the development of laser tubes which will emit the intense beam of light capable of carrying millions of messages simultaneously. One of our U.S. divisions is adapting a unique ITT-developed phototube, now used to detect nuclear radiation, for reception of these laser-beamed messages. This amazing tube is but one of thousands of components or "electronic building blocks" made throughout the free world by ITT System companies. The list runs from sub-miniature diodes which must be assembled under microscopes, to electronic tubes of immense size and power. Many of these components are standardized for production by ITT companies in 24 countries . . . an example of how our worldwide organization benefits ITT customers everywhere. / International Telephone and Telegraph Corporation, World Headquarters: 320 Park Avenue, New York 22, New York.

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LETTERS

Sirs:

Readers of a scientific periodical expect a book reviewer to exercise his critical function with balance and to carry out his responsibility with the fidelity to fact that is demanded of the book itself. In the service of your readers we are compelled to correct a number of inaccuracies in Ernest M. Gruenberg's review of our book *Mental Health in the Metropolis: The Midtown Manhattan Study* [SCIENTIFIC AMERICAN, October]. Page numbers hereinafter refer to points in our book where evidence for our corrections will be found.

1. The review states: "The area selected for study by the investigators of the Midtown Manhattan Study had a population of some 110,000." The figure is 175,000 (pages 14 and 72).

2. Discussing the symptoms covered in the Midtown sample interviews, the reviewer asserts: "The possibility that some of the symptoms... occur in the absence of mental disorder is not considered." This possibility was in fact *not* overlooked. As one illustration, Thomas A. C. Rennie, the Study's late director, gave "free of significant symptoms" as his definition of the "well" category of mental health (pages 135, 138, 342, 396, 399 and 400), indicating that certain symptoms appearing in an otherwise well-functioning person were not held to be incompatible with sound mental health.

3. The reviewer reproduces the book's table of mental health distributions by socioeconomic-origin groups and reports that these groups had been classified only according to the criterion of occupation. Actually this classification was based on *both* education and occupation (pages 202, 204 and 212).

4. In discussing the inclusion of the Marked symptom formation class within the Impaired category of mental health, Gruenberg suggests that the Study sociologists effected this inclusion and did so "without making any reference to the data on rater reliability." The fact is that the Study psychiatrists exclusively made this and all other decisions bearing on mental health matters; and in this particular instance they did not overlook the issue of "rater reliability" but concluded that other considerations, principally clinical in nature, were more important in supporting the decision taken. The several kinds of evidence are too lengthy and technical to be discussed here, but they can be found on pages 135, 136, 154, 342, 399 and 400.

5. On the issue of taking account of age differences among the various population subgroups studied for their mental health composition, the reviewer charges the Midtown investigators with "general failure to handle age in a satisfactory manner." The fact is that we systematically carried analytical control or standardization for age differences *as far as statistical limits allowed*, in every one of our relevant data chapters (pages 177, 178, 184, 185, 216, 219, 258, 262, 267, 276, 294 and 305).

6. We turn to what seems to have engaged Gruenberg the most, namely the time framework of the symptom questions asked in interviewing the Midtown sample respondents. This issue is pivotal to the entire Study and cannot be passed over as briefly as we would like. In this one instance we must set down the details, in spite of their technicality, instead of referring the reader to appropriate pages in the Midtown book.

Reflecting psychiatry's life-history emphasis, the interview with our sample adults included 28 "selected signs of [somatic or emotional] disturbance during childhood, of course reported retrospectively." Needless to say, these were *not* regarded as current symptoms.

In addition to these, 74 symptom questions had a clear current time reference, e.g., "Are you ever bothered by nervousness? Would you say [you are bothered]: often, sometimes, never?"

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The flame of creativity has always burned bright in Massachusetts . . . and never brighter than today. Come see for yourself!

Another 18 potentially symptomatic questions offhand seem to have a temporally nonspecific, "Have you ever in your life had..." connotation. However, in 13 of the 18 a "Yes" reply was followed by several time-clarifying questions, including: "Do you still have it now?"

Three other symptom questions, seemingly unanchored in time, are typified by one: "Have you ever been bothered by 'cold sweats'? Would you say often, sometimes, never?" The only answer given weight by the Study psychiatrists was "Often," and this response tends to bring the symptom down into the present.

The final pair in this series of questions referred to frequency of (1) spells of dizziness and (2) fainting spells. Although chronologically nonspecific, they were adopted, wording unchanged, because several previous validation tests had established that affirmative answers to these (and others of the above) questions are closely associated with and highly predictive of *current* psychopathology. Nevertheless, these symptoms by themselves carried no weight in the Study psychiatrists' judgments of respondent mental health except in conjunction with the total constellation of his current symptoms.

Having defined the time framework and rationale for all the symptom items put to our Midtown respondents, let us now examine how accurately Gruenberg handles the very same facts in four consecutive statements of his review.

In the first statement the reviewer sees "confusion... compounded because the book is not clear as to the time dimension [of the symptoms covered]." In light of the fact that only two in the entire series of Midtown symptom items *seem* to be chronologically unanchored, it appears that the "confusion compounded" characterization is something akin to the proverbial molehill elevated to the stature of a mountain.

In the second statement the reviewer says: "Whether or not the raters [the Study psychiatrists] made any explicit effort to distinguish present from past symptom patterns is not clear." On pages 52 and 65 the book indicates that such a distinction *was* made. But even if it had not been, to the reviewer the omission is ground for entertaining this as a reasonable possibility: while evaluating the Midtown respondent's mental health, Rennie, a Cornell professor of psychiatry, and his associated psychiatrists did not differentiate the past from the present phase of the life history. A rough parallel would be to take an eminent biologist author's silence on the distinction between extinct and extant forms of life as warrant for suspecting that he does not apply the distinction in his work.

The reviewer directly follows his second statement with a third: "As a result they [the Midtown investigators] end up by measuring something called 'lifetime prevalence,' which presumably means the proportion of the population studied that has at any time displayed any of the symptoms being counted."

A point that in the statement immediately preceding was merely "not clear" here acquires a "they end up" certainty, apparently based on newly derived clarity that the psychiatrists had *not* distinguished present from past symptoms. Moreover, the reviewer's quotation marks around "lifetime prevalence," within the context of his discussion, suggest that it is a term we applied to the Impaired mental health category. Actually that term is not so applied, and it appears to be contrived entirely out of the presumption that the Study's psychiatrists had *in fact* been chronologically undiscriminating.

With a straw man in hand, the fourth statement proceeds to put it firmly in its place: "This particular measure [i.e., "lifetime prevalence"] is one of the new gimmicks that are being introduced these days into a field of mensuration that has enough real troubles without being further burdened by unhelpful tricks. Lifetime prevalence measures are of no visible usefulness.... When data regarding past and present are fused, it becomes almost impossible to handle the data in a productive fashion."

If past and present *had been* "fused" in the Midtown Study, and if its mental health data were "impossible to handle" productively, then by implication *all* its findings would predictably be unreliable and "of no visible usefulness." If so, the trend of these findings would probably be discordant with previous studies that *had* distinguished present from past symptoms.

Gruenberg himself is witness to the contrary. In spite of the presumed temporal fusion of symptoms, which by his reasoning must apply with greatest force to the most symptomatic of the mental health levels, he gives "most credence" to the Midtown mental health grades of Incapacitated and Severe symptom formation. He goes further: "Both of these categories were also reported in the Syracuse survey [conducted by Gruenberg], and it is interesting to graph the two sets of data together, as I have done in the illustration on page 162. These two curves show a marked rise with age in the [*current*] prevalence of extremely sick people in two U.S. populations."

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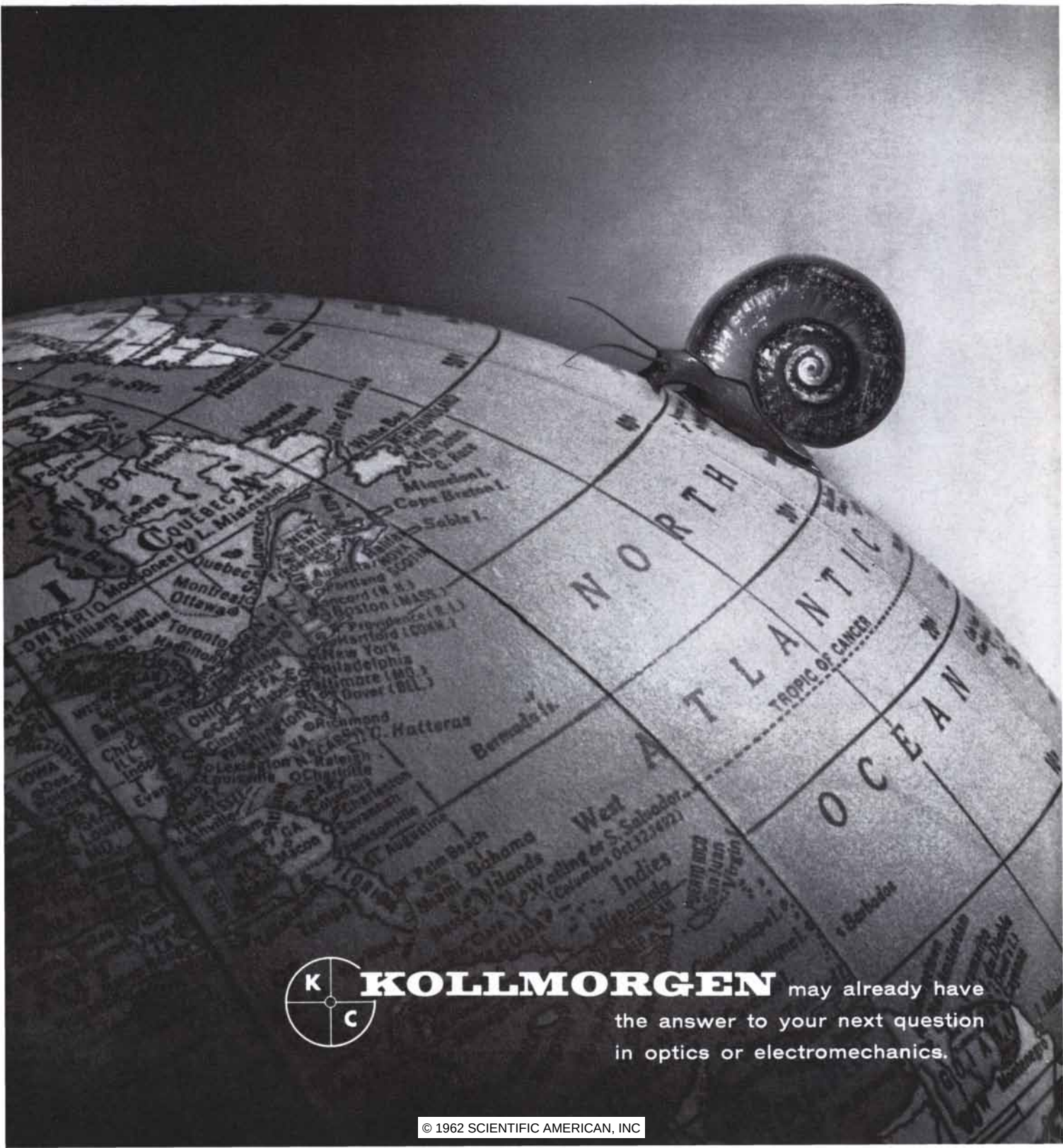
Q.

Who has the facts about controlling speeds as slow as one revolution per day?



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Gruenberg gives special emphasis to this convergence of his data and ours: "This appears to be a reliable finding supported by data found elsewhere in similar morbidity surveys and its importance cannot be overemphasized."

Gruenberg also reports that the age convergence in the two studies is accompanied by similarity in the sex findings as well: "Neither the Midtown nor the Syracuse study shows a significant variation between the sexes in these [morbidity] rates...."

On the evidence of these double parallels, we can infer that the Midtown findings in reliability and usefulness may be comparable to those from Gruenberg's own Syracuse survey, where we can in professional courtesy credit him with our confidence that the distinction between past and present symptoms was competently drawn.

Gruenberg notes but does not identify other investigations that support the Midtown age trends. Our book cites still other surveys of general populations that have yielded close approximations of Midtown's frequencies of certain current symptoms and direct parallels to Midtown's twin combination of highly significant age and socioeconomic links with mental morbidity.

These *multiple* convergences with a series of *independent* investigations of *present* mental disorder can be read as suggesting that perhaps the psychiatrists in the Midtown and the other studies referred to may have judged mental morbidity by roughly similar criteria, with the same chronological discrimination and with generally comparable reliability.

What place, in the end, does the reviewer give this evidence, whose "importance," he states, "cannot be overemphasized"? Appearing near the middle of the review, it is followed by the pages (already discussed above) of extended elaborations of our sociologists' presumed neglect of intergroup age differences and our psychiatrists' presumed failure to make the elementary distinction between past and present symptoms. The latter allegations are very near the review's last words and their cumulative effect can be read as a challenge to the Study's foundation of scientific credibility. Largely buried under this blanketing implication is the testimony of other investigations, Gruenberg's included, offering multiple independent support for the credibility and perhaps the relative solidity of the Midtown findings.

The surprising number of inaccuracies corrected above by no means represents all the errors of fact or interpretation appearing in the review. Most of all we regret that it does not give the reader a coherent account of the large goals the Midtown Study set out to reach in a great metropolis, nor of the many new findings uncovered—some for the first time in an American city—nor of the windows opened by the data on crucial areas of "unfinished business" in our affluent, democratic society. These are omissions in reporting that are not for the authors to redress here.

The review, however, also contains one error in prediction, and setting it right accords us the only satisfaction derived in writing this letter. Gruenberg asserts that "for some reason [the Midtown book] has not been presented as a technical monograph but as a hardcover, commercial book offered... to both the specialist and the interested reading public." In effect he predicts that by attempting to address both audiences the book will succeed in attracting neither. Actually during the eight-year period of research and writing that preceded publication of *Mental Health in the Metropolis,* we had grounds to conclude that the book's contents would be highly relevant to the concerns of professionals in psychiatry, psychology, public health, social work, sociology and anthropology. Accordingly, in preparing the book, we had to address it not to one but to *all* of these diverse specialists, and of course the only element common to all is that they are educated people deeply committed to the mental health field.

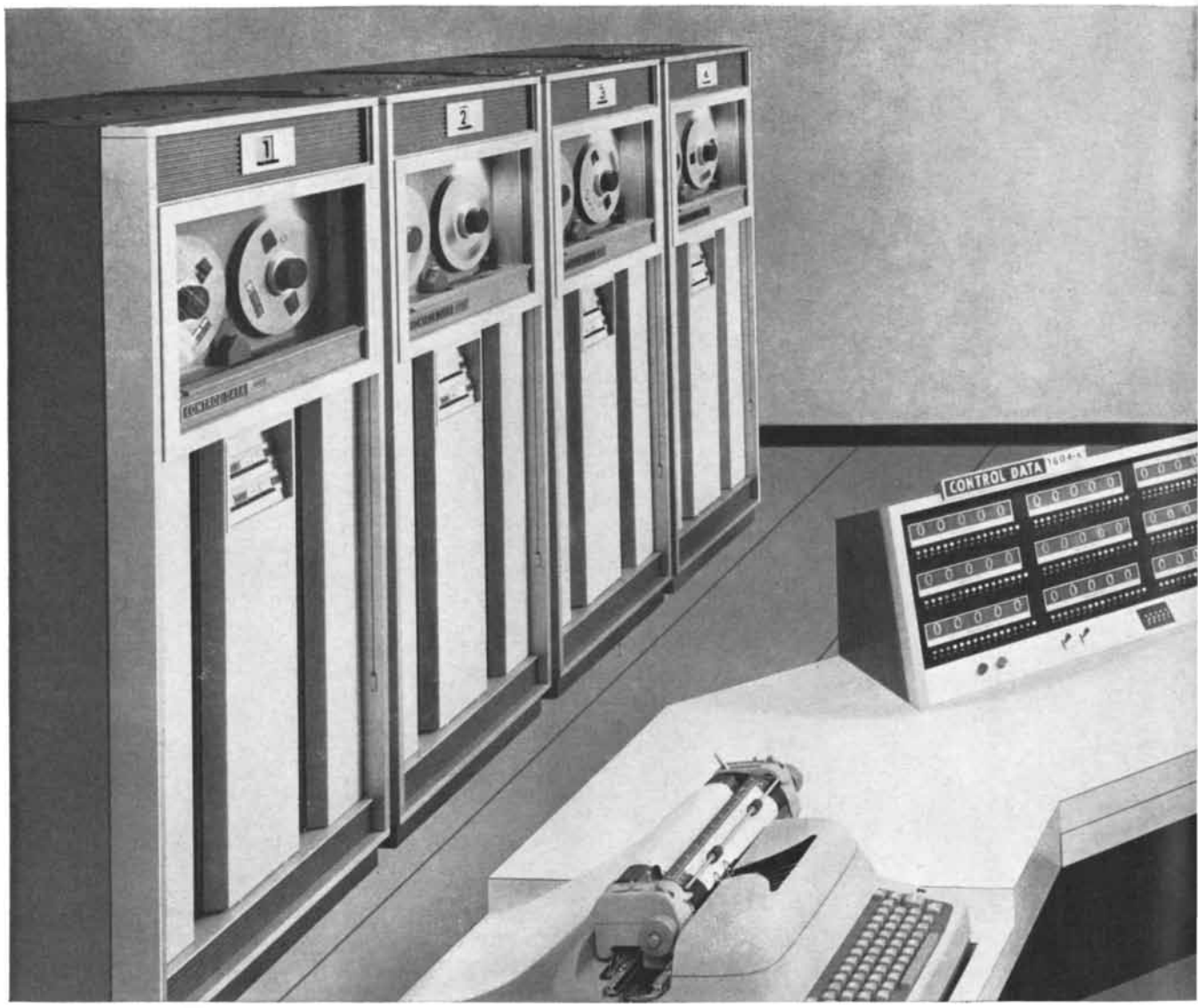
As a result, the educated, interested layman became for us the archetype of our potential audience. On the other hand, we had to discharge our responsibility to render a full accounting of our methods, and we also had to avoid the deceptive façade and the condescending stance of most popular science prose. These posed exceedingly difficult writing problems that we did not completely resolve. That the book does not altogether miss its mark, however, can be inferred from the fact that it is now into its second printing, with mounting evidence that it is drawing both general and professional readers.

The Gruenberg review carries the editor's headline: "A survey of mental health in New York raises important issues of methodology." We suggest that the review raises important issues of accurate reporting and responsible criticism.

LEO SROLE, PH.D.

THOMAS S. LANGNER, PH.D.

STANLEY T. MICHAEL, M.D.



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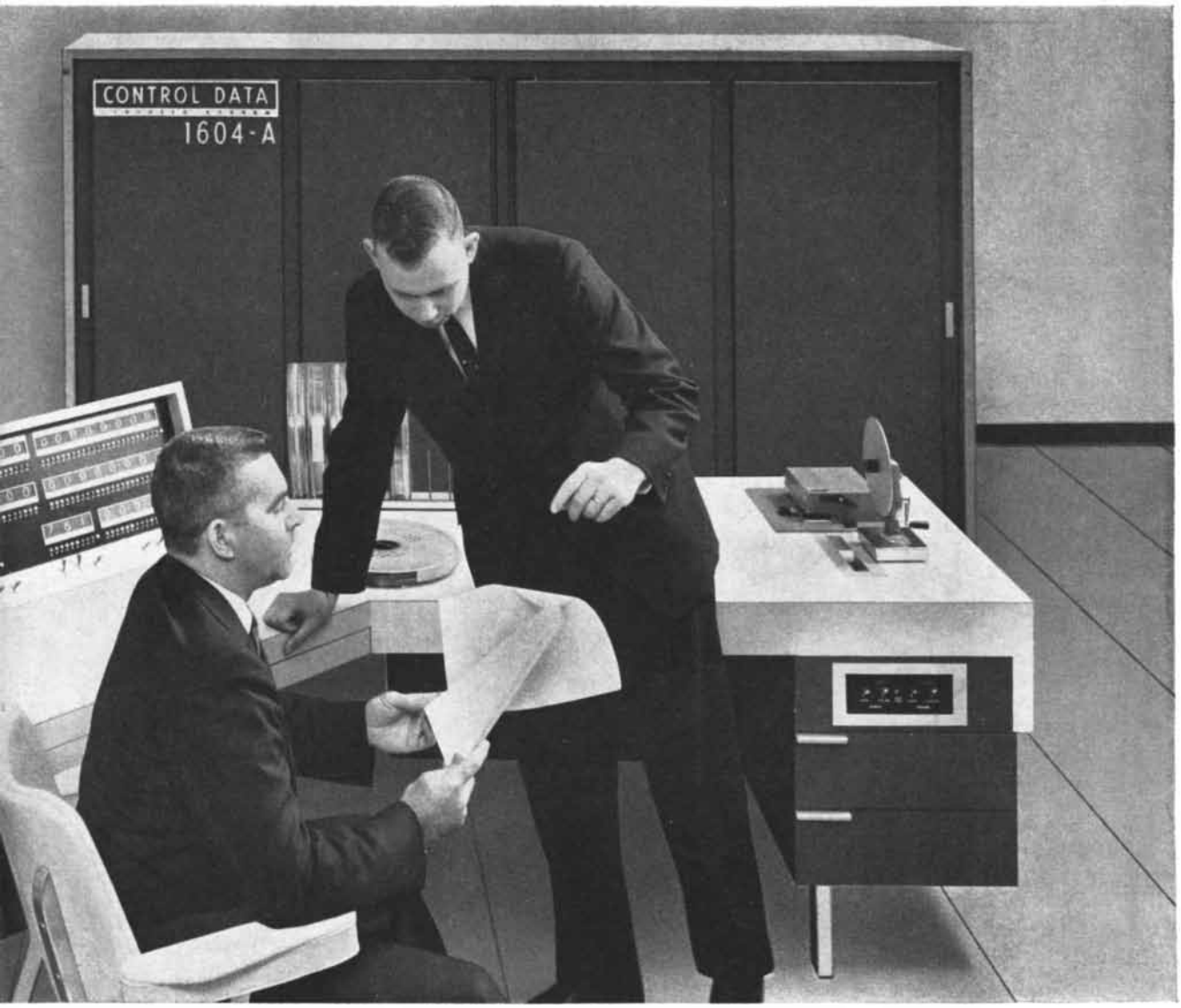

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Basic Research at Honeywell
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Studies of the Visual Processes Underlying Color Perception

Precise psycho-physical measurement techniques appear to clarify conflicting theories on the color receptor system of the human eye, possibly confirming an additive four-component receptor system as underlying color and brightness perception.

Scientists have been trying to understand how the eye sees color and to duplicate this process ever since the time of Sir Isaac Newton, who proposed that there were as many neural processes as there were discriminable colors. Thomas Young in 1801 recognized that if three primary colors, when mixed in different proportions, can be made to match any color of the spectrum, then a system of three independent receptors would be adequate. Von Helmholtz amplified the Young theory by suggesting that the brightness of colors was the sum of the responses of the three classes of color receptors. This has been termed an "additive" theory.

An alternate theory is the "opponents" theory proposed by Hering and based largely on psycho-physical data. He proposed that two antagonistic (or opposed) pairs of receptor mechanisms provide "color aspect" of color vision. These pairs are blue-yellow and red-green. Brightness in this theory is independent of the color mechanism but is dependent on a third black-white process.

The conflict in theories is sharpest on two empirical questions: (1) Is yellow the combined response of the red and green mechanisms (additive) or does it have an independent response mechanism (opponents)? (2) Is brightness the summed response of the color receptors or an independent mechanism?

Honeywell psychologists are using a very sensitive technique utilizing psycho-physical responses of human subjects. By refining techniques of chromatic adaptation in combination with threshold measurement they have succeeded in isolating microstructure in the human foveal spectral sensitivity curve.

There now appears to be evidence that there are sensitivity peaks corresponding to red, yellow, green and perhaps blue. By adapting the eye to very narrow wave bands in the red, yellow and green parts of the spectrum it is possible to reduce these sensitivity peaks selectively supporting an additive theory but with at least four components.

In the Honeywell experiments, a seated subject fixates a small circle in a large surround field which carries the adaptive light. After adapting the eye to the surround field the subject fixates the small center circle where a narrow band stimulus from the various bands of the spectrum is flashed. The threshold energy for detecting this flash is measured. Measurements indicate (see fig. 1-a) that when the eye is neutrally adapted, there is a main peak in the green at 550mμ and sub maxima at 570mμ (yellow) and at 600mμ through 690mμ in the red.

When the eye is adapted to red (fig. 1-b) the red shoulder or sub maximum at 600mμ to 690mμ is greatly reduced.

When adapting the eye to yellow (fig. 1-c) the 570mμ peak is almost eliminated.

Using a green adaptation (fig. 1-d) the main peak at 550mμ appears somewhat reduced.

It is important to note that in each case the adjacent shoulder is unaffected.

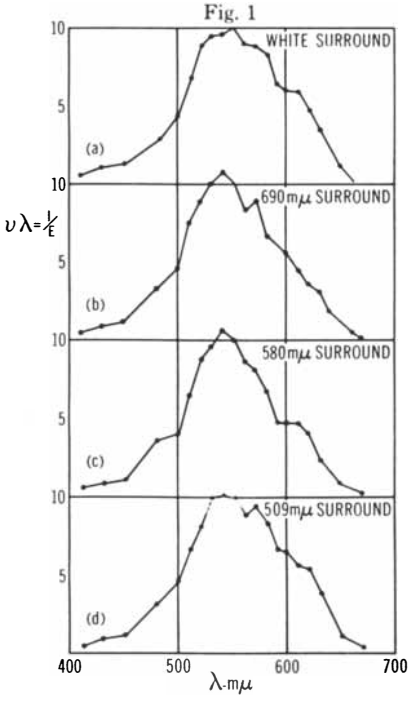
These techniques demonstrate that spectral sensitivity may be a composite of several underlying chromatic mechanisms which above 500mμ have three independent components with peak sensitivities to green, yellow and red light.

Further work is underway at Honeywell's Research Center to relate these findings to brightness perception and to explore more intensely the nature of the yellow response mechanism. Of obvious interest and concern to the medical and human factors field, a deeper understanding will also make possible significant advances in the technology of color measurement leading to mechanical simulation of color reception.

If you are engaged in scientific work in color perception and wish to know more about Honeywell's research in this area, you are invited to correspond with Dr. Harry Sperling, Honeywell Research Center, Hopkins, Minnesota.

If you are interested in a career at Honeywell's Research Center and hold an advanced degree you are invited to write Dr. John Dempsey, Director of Research at this same address.

Fig. 1



THRESHOLD ENERGY REQUIRED TO DETECT COLOR STIMULI

The men and women who built this airline

When you read this headline, if you are a veteran traveler, you could think of many United people you may have known.

—The early pilots whose hard school had been flying the mail with only bonfires to guide them at night.

—Thorp Hiscock, who made two-way radio work for aviators.

—Ellen Church, the world's first stewardess.

—Jack Herlihy, the great pilot-engineer. And many, many others.

But important as their contributions have been, these and other famous United people are not the men and women who really built the airline.

You did—and the millions of others who have traveled with us over the years. By staying close to you and finding out what you thought of us, we have learned more about running an airline than we have from any other source.

We have been delighted with your compliments, but also appreciative of complaints leading to improvement.

Many of our advances in reservations, scheduling, ground handling, food, design and interiors of aircraft, and a hundred other aspects of our service have come from simply talking with air travelers.

Talking with people and suiting our service to their needs is all part of an attitude which is at the core of United's employment, training and operation.

It's an attitude we look for in everyone we hire at United Air Lines. It guides our training. It comes first in whatever we do.

This attitude is spelled out by four simple words: extra care—for *people*. With the great human responsibilities involved, there can be no better basis for running—or choosing—an airline.

UNITED

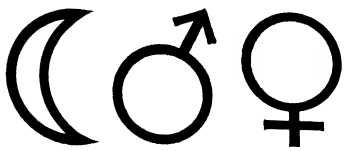
THE EXTRA CARE AIRLINE

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1912: "The brilliant Russian physiologist Pawlow has for some years been conducting an exhaustive investigation by scientific laboratory methods of the reflex action of animals. Certain results of his latest studies are interestingly résuméed by Prof. Lüthje in the *Deutsche Revue,* from which we quote: 'Pawlow now no longer speaks of psycho-reflexes but of conditioned and unconditioned reflexes. The latter are those that invariably occur when the appropriate stimulus finds a sensory path, as when food is put in the mouth and a flow of saliva follows. A conditioned reflex, on the other hand, is one that occurs only under certain given circumstances: if food is frequently shown to a dog and afterward given him to eat, after a certain number of experiments a flow of saliva will occur at the mere sight of the article (a "natural conditioned stimulus"). "Artificial conditioned stimuli" have the same effect. If a given musical note is repeatedly sounded at the same time that a given article of food is offered to a dog, after a certain lapse of time the mere sounding of the note will produce a corresponding flow of saliva. Similarly other external conditioned stimuli (optical, thermal, etc.) can be formed, if the same stimulus is repeated a number of times synchronously with an unconditioned stimulus, such as the taking of food.' "

"From many points in America and Europe come reports of an unusual turbidity of the atmosphere, which began early last summer and still continues. This is manifested in a marked diminution of the intensity of solar radiation, as measured with the pyrheliometer, abnormal displacement of the neutral points of atmosphere polarization, a hazy appearance of the sky, and the presence of Bishop's ring around the sun. Sir John Moore wrote from Dublin last August: 'The sky is constantly covered with a thin film of uniform cloud in which no halos develop and through which the sun, moon and stars shine with a subdued, sickly brightness.' Observers in



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☾♂♀ Left to right, above, astronomical symbols for the Moon, Mars, and Venus.

Russia, Switzerland, Sweden and Germany, as well as America, report an unusual lack of blueness in the sky. There seems to be every reason to attribute these phenomena to the presence in the upper atmosphere of an immense pall of dust arising from the explosive eruption of Katmai volcano in Alaska last June. Similar effects were observed after the eruptions of Krakatoa and Mount Pelée and in those cases lasted for some years."

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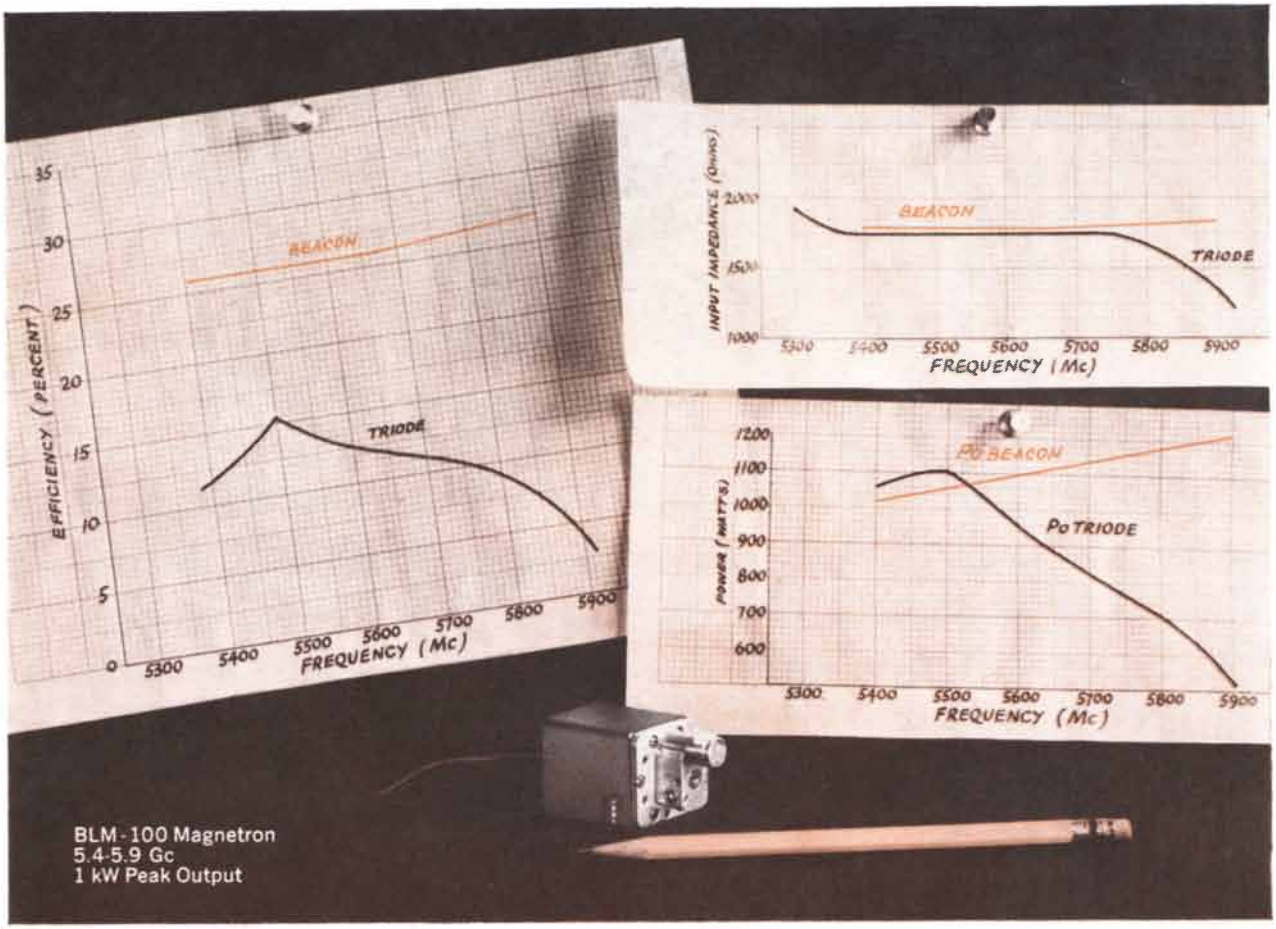
Scientific American.

DECEMBER, 1862: "Subscriptions to the fund for the relief of the working-classes thrown out of employment in Great Britain by the failure of the cotton supply are coming into the committee very rapidly. The sum of $100,000 has already been subscribed for this noble object, and Messrs. N. L. & G. Griswold have generously tendered a new ship of large capacity to carry abroad such provisions as may be contributed or purchased with the money collected toward relieving the suffering poor of Lancashire and other manufacturing districts in England. Many of the railroad companies whose lines lead into New York have consented to transport over their respective roads corn, flour and other provisions from the West to this city free of charge; and it is expected that most of the Western roads will not be behind the Eastern lines in carrying forward this humane work."

"The scientific doctrine is now very generally inculcated and believed that heat is the result of motion and that light is also due to an undulatory motion. Some confusion of ideas has been experienced by many persons with respect to a correct understanding of this subject. It should be understood, when the



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5.4-5.9	1.0	1.00	0.0015	2.4-2.7	1.7	8.5	BLM-125
5.4-5.9	1.4	0.70	0.0007	3.0-3.2	2.0	8.5	BLM-110
5.55-5.75	25.0	0.75	0.001	10.0	8.5	56.0	BLM-109

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By JIM HELFRICH
Garden City, N.Y., Regional Office
Non-Linear Systems, Inc.

Inherent Digital Voltmeter Ability Unravels Antibiotic Assay Problem

How would you measure, record, and store test data on an antibiotic's effectiveness in bacterial cultures when hundreds of samples are involved?

This was the problem faced by Chas. Pfizer & Co., Inc., at its biological assay department in Brooklyn, N.Y. — and strangely enough, it doesn't differ greatly from those encountered in measuring and logging data in industrial processing, missile checkout, and dozens of other applications.

To solve the problem, Pfizer developed an electronic assay system to measure the clarity of a bacterial culture solution, this being directly related to potency of antibiotic samples introduced into the culture. Then, measurements are converted to digital form for automatic recording and storage.

Here's how the system works:

Step 1 — A beam of light passing through a bacterial culture is measured at a dual reading station. The laboratory technician is shown pouring test solution into one of two cuvettes which are automatically emptied once turbidity is recorded. An NLS digital voltmeter (center) converts the voltage signals of a spectrophotometer both to easily read numerical readings for the operator and to electrical contact closures for operation of a card punch.

Step 2 — The NLS digital voltmeter operates a card punch. Each card is punched to identify the antibiotic sample, punched with the digital voltmeter reading indicating potency, and stored for evaluation. The evaluation is done by an IBM 650 computer at Pfizer and this information is used to prepare various laboratory and accounting reports related to turbidimetric assay work.

The result is a direct and automatic method to collect data on a great number of samples with a minimum of human tedium and human error. Further, it is another example of the wide range of problems that can be solved with ingenuity and a digital voltmeter. Wherever physical parameters are convertible to voltage — from simple production testing to highly complex data logging — the digital voltmeter is a highly useful tool because of its inherent ability to convert electrical signals representing temperature, pressure, speed, flow, etc., into information that can be accepted and acted upon by card or tape punches, digital data printers, and electronic computers.

For more information on how digital voltmeters and other digital measuring instruments might be of assistance to you, please contact one of the 19 NLS factory offices or write to Non-Linear Systems, Inc., Del Mar, California.

non-linear systems, inc.
originator of the digital voltmeter

statement is made, that heat is caused by motion or is developed by motion, that these are simply expressions to convey an idea of the operations of nature. Motion means the relative change in place, position or condition of bodies. The expression, 'Force is the cause of motion,' is also frequently used. But this is also a simple statement for the operations of matter and is equivalent to saying, 'An apple falls by gravitation.' In this use of the term, gravity is the understood cause of the motion; it is a force of nature, but the great First Cause is beyond the comprehension of man's limited intellect."

"The *Great Eastern* has now been lying in Flushing Bay, near this city, for several months, undergoing repairs necessitated by her striking a rock not laid down in the chart, when she was 'hove to' for a pilot off Montauk Point. It was stated at the time this took place that the amount of damage was small, but on thorough examination it was found that 85 feet in length of the plating was fractured, and in some places it was four feet in width. This accident has demonstrated her superiority of construction. Now, although the outside plating was so much injured, the inside skin was untouched, and she carried 1,000 passengers and 2,000 tuns of merchandise to their destination without damage. The last two voyages of this noble steamship between Liverpool and New York were quite successful and remunerative, and they were the most regular ever accomplished by any one steamer."

"The art of cutting and polishing diamonds (says the Boston *Transcript*), although of remote antiquity in Asia, has only recently been introduced into this country. It is now practiced here by one house, and only one, we believe, namely that of Messrs. Crosby, Hunnewell & Morse of Boston, and we need no longer send as heretofore to Amsterdam or London to have diamonds repaired or re-cut. These dealers have on exhibition at their store a native diamond that they have cut in the highest style of the art. It is the largest diamond ever found in the United States, perhaps the largest now in the country. The weight of the gem before cutting was nearly 24 carats; after cutting it was about one-half its original weight. It was found near New London in southern Virginia, in the vicinity of a quarry of elastic-jointed sandstone. No exact value has been put on the gem, but it is estimated as being worth from $10,000 to $15,000."

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THE AUTHORS

ASA E. SNYDER ("Desalting Water by Freezing") is vice-president of research for the Pratt & Whitney Company and research co-ordinator for the Fairbanks Whitney Company. On graduation from high school in 1941 Snyder joined the Merchant Marine, attended the U.S. Merchant Marine Academy in 1942 and 1943 and served the next three years with the Navy. As a cadet engineer on a convoy to Murmansk (a port well north of the Arctic Circle), Snyder saw his first sea ice; he was impressed with the fact that open sea water could freeze at sufficiently low temperatures, and he says that his present interest in the freezing process probably dates from that observation. Snyder studied mechanical engineering at Swarthmore College and Princeton University, receiving an M.S. degree from the latter in 1952. Before he joined Pratt & Whitney in 1960 he had held supervisory and executive positions at the International Harvester Company, the General Electric Company and U.S. Industries, Inc. Snyder is also an amateur oceanographer and an associate of the Woods Hole Oceanographic Institution.

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WILLIAM D. McELROY and HOWARD H. SELIGER ("Biological Luminescence") are respectively director of the McCollum-Pratt Institute at Johns Hopkins University and research associate at the Institute. McElroy, also chairman of the department of biology at Johns Hopkins, acquired a Ph.D. in biochemistry from Princeton University in 1943 and from 1942 to 1945 was engaged in research on various war projects for the Office of Scientific Research and Development. Following a year of postdoctoral work with George W. Beadle at Stanford University, McElroy went to Johns Hopkins in 1945. At the McCollum-Pratt Institute, which he has directed since 1949, McElroy has been concerned primarily with the mechanism of light emission from chemical reactions, particularly those of biological origin. In addition to this work McElroy serves in an editorial capacity with several journals and as executive editor of *Archives of Biochemistry and Biophysics*. He is the author of some half-dozen books and was coauthor (with C. P. Swanson) of "Trace Elements" in the January 1953 issue of SCIENTIFIC AMERICAN. Seliger, whose chief research interests are energy transfer in bioluminescent processes and the physics of light-producing chemical processes, was originally trained as a nuclear physicist and received his Ph.D. from the University of Maryland in 1954. Before taking his present job in 1958 he had been supervisory physicist of the Radioactivity Section of the National Bureau of Standards.

ROBERT L. SPROULL ("The Conduction of Heat in Solids") directs the Materials Science Center at Cornell University, where he is also professor of physics. After obtaining his B.A. at Cornell in 1940 and a Ph.D. in physics three years later, Sproull did research on microwave electronics from 1943 to 1946 as a research physicist with the Radio Corporation of America; he joined the Cornell faculty in 1946. Sproull spent 1952 at the Oak Ridge National Laboratory, served as editor of the *Journal of Applied Physics* from 1954 to 1957, and in 1958 and 1959 he was physicist with the Brussels firm European Research Associates. He became director of the Materials Science Center in 1960.

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sor and senior research mathematician at the Mental Health Research Institute of the University of Michigan. Rapoport was born in Russia, educated in Chicago's public schools and trained in music at the Vienna State Academy of Music, which gave him degrees in composition, piano and conducting. For the next four years he gave concerts in Europe, the U.S. and Mexico. In 1937 (at the age of 26) he enrolled as a freshman at the University of Chicago, and in 1941 he received his Ph.D. in mathematics. Following service in the Air Force as a liaison officer with the Soviet Air Force in Alaska during World War II, Rapoport taught mathematics for a year at the Illinois Institute of Technology, was research associate and later assistant professor of mathematical biophysics at the University of Chicago from 1947 to 1954, and spent a year at the Center for Advanced Study in the Behavioral Sciences. He went to Michigan in 1955.

JOHN A. CLEMENTS ("Surface Tension in the Lungs") is assistant chief of the Directorate of Medical Research, a division of the Army Chemical Center in Maryland. Clements' research on the physiology of respiration and his association with the Directorate of Medical Research both began with a tour of duty with the Army from 1949 to 1951. On assignment to the Applied Physiology Branch during his first year, Clements began studying the effects of carbon dioxide, exercise and heat on respiration. He was then assigned to the Clinical Investigation Branch and has remained there since his return to civilian status. He has done research at the Chemical Defence Experimental Establishment in England, the Roswell Park Memorial Institute in Buffalo and the University of California San Francisco Medical Center.

R. A. DEERING ("Ultraviolet Radiation and Nucleic Acid") is assistant professor of physics at the New Mexico Highlands University. Deering took a B.S. in engineering physics at the University of Maine in 1954 and a Ph.D. in biophysics at Yale University in 1958. After a year of teaching physics at Southern Illinois University, a year at the University of Oslo as a Fulbright research grantee and two years at Yale as a research associate in biophysics, Deering took his present job in 1961.

LAMONT C. COLE, who in this issue reviews Rachel Carson's *Silent Spring*, is professor of zoology at Cornell University.

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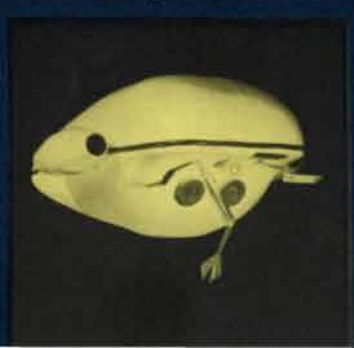

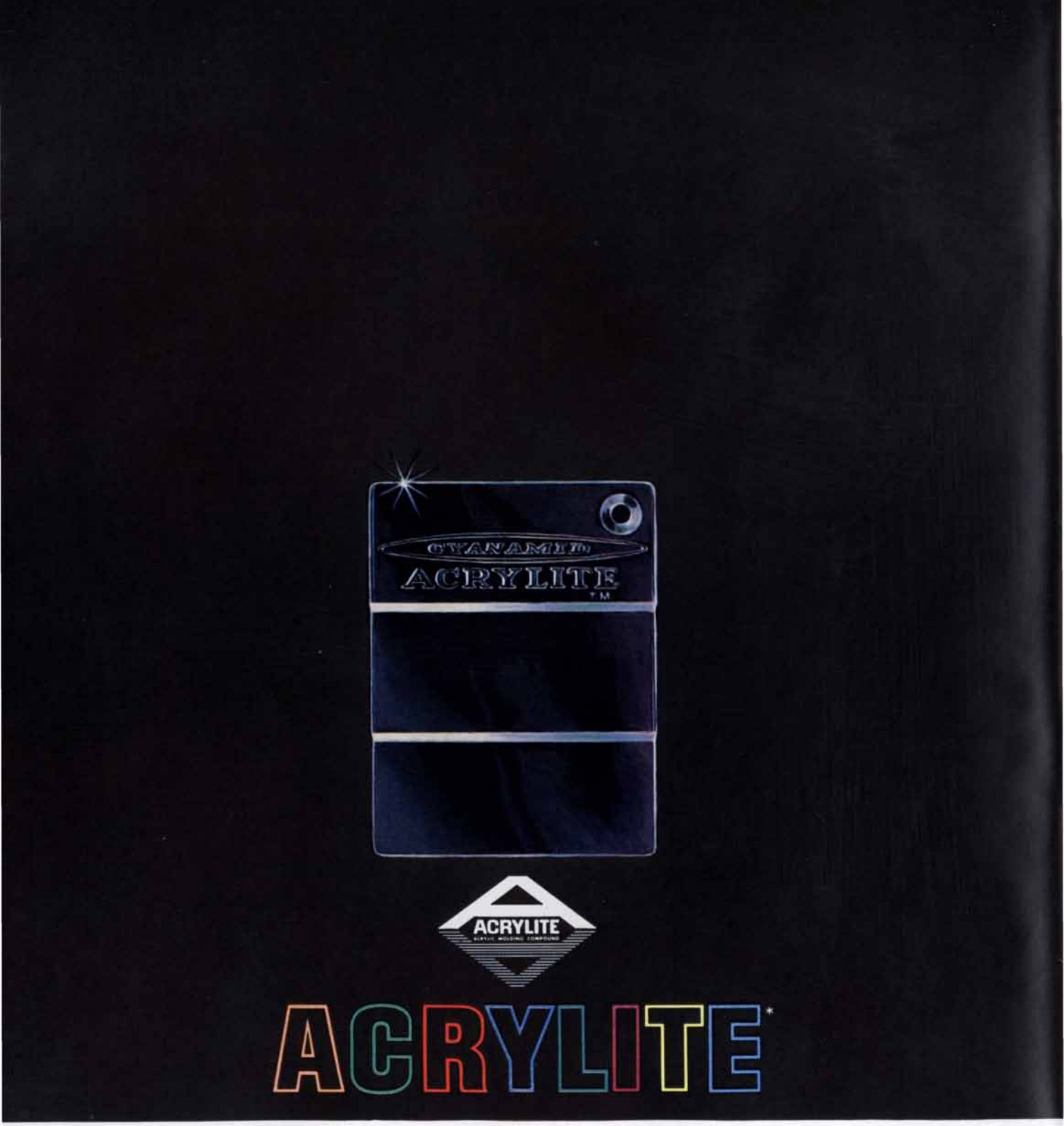

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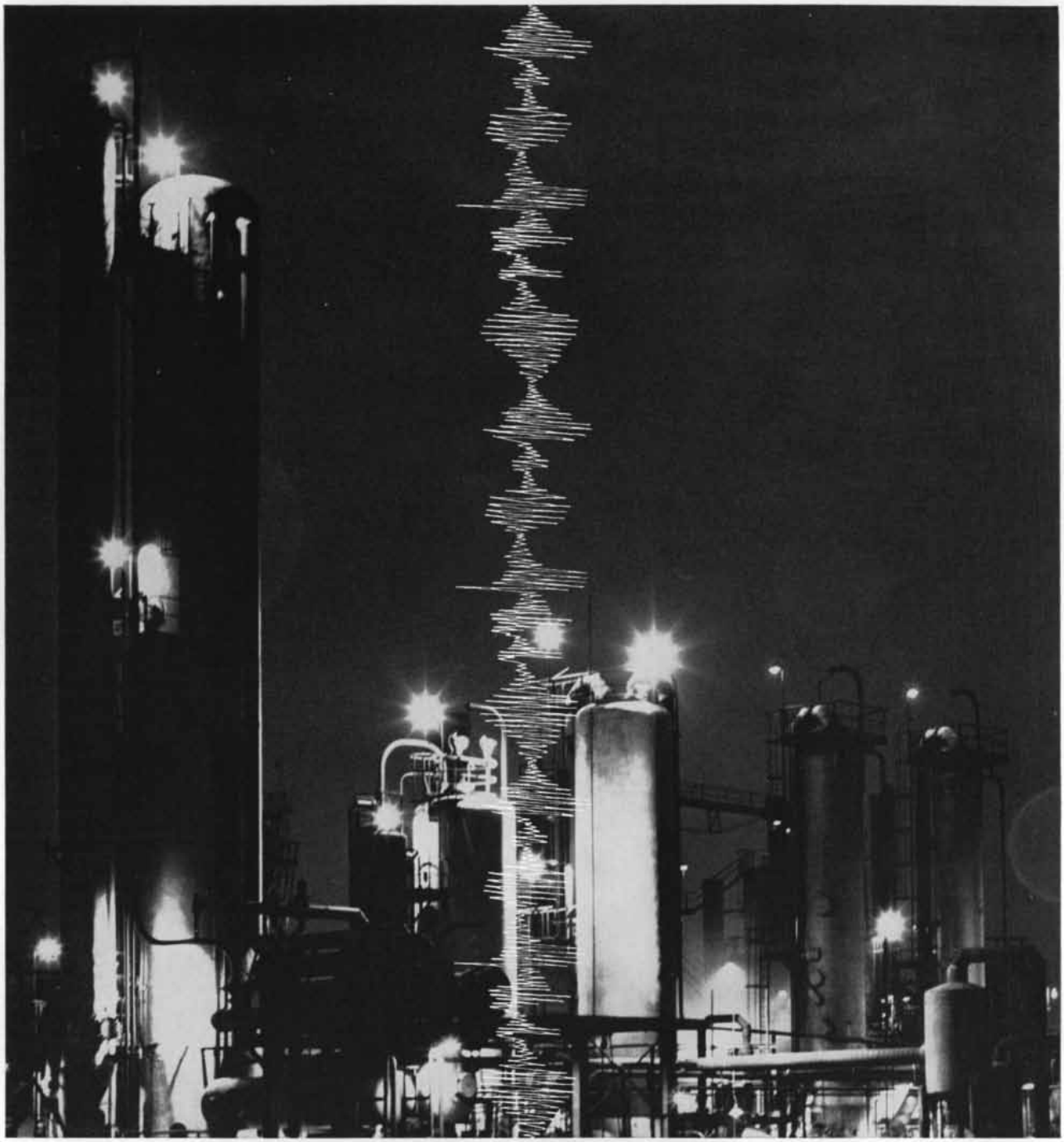

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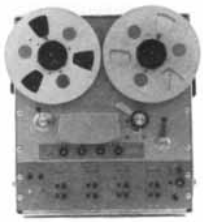

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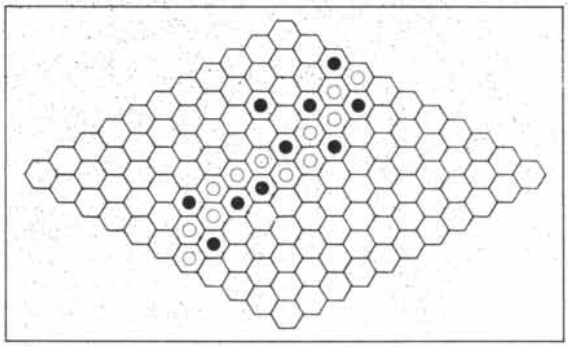

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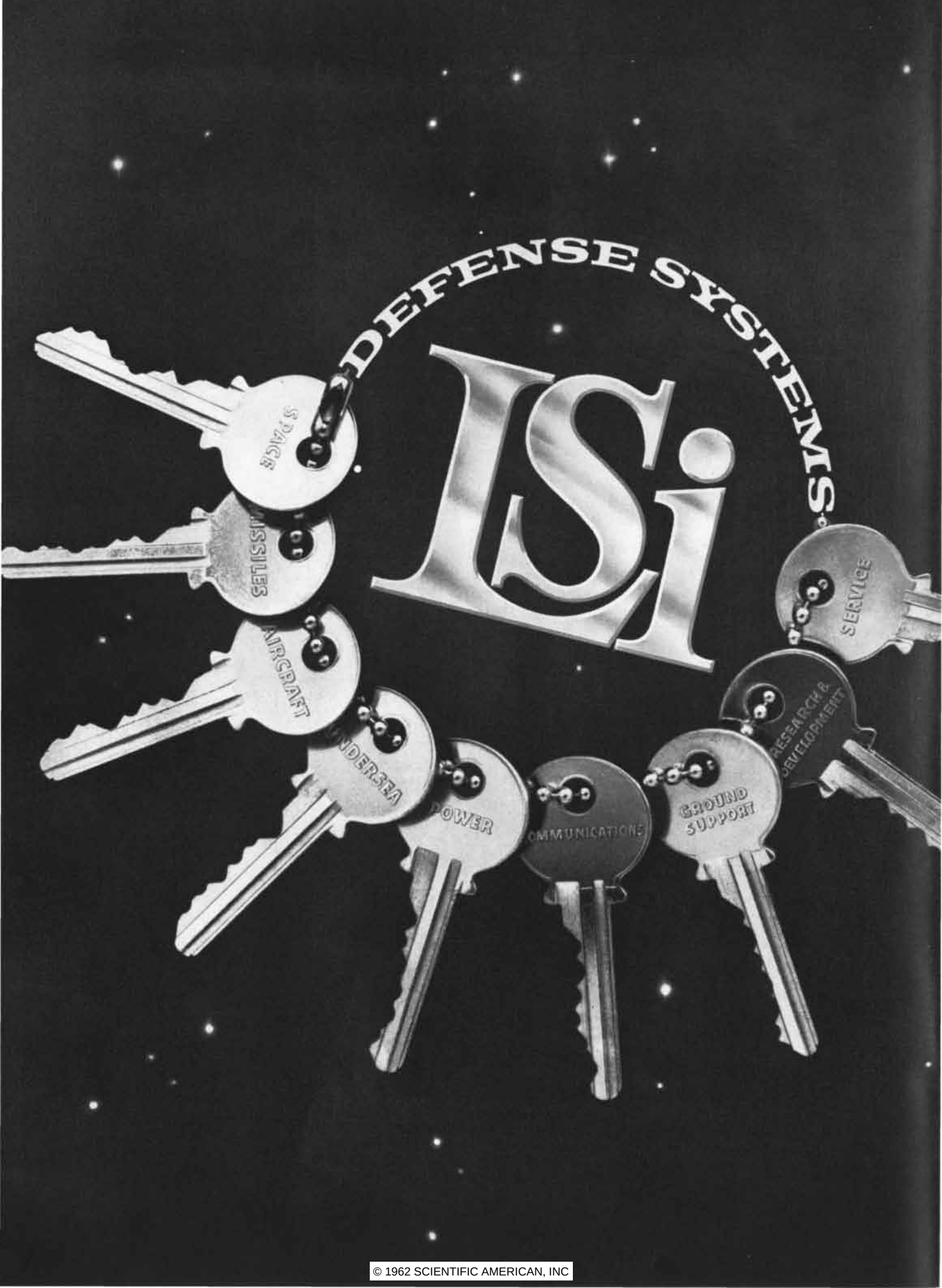

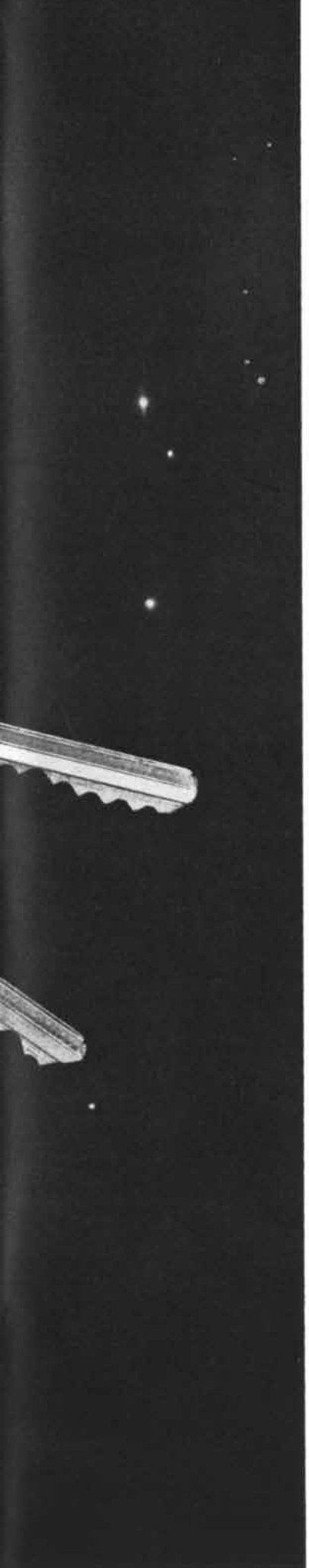

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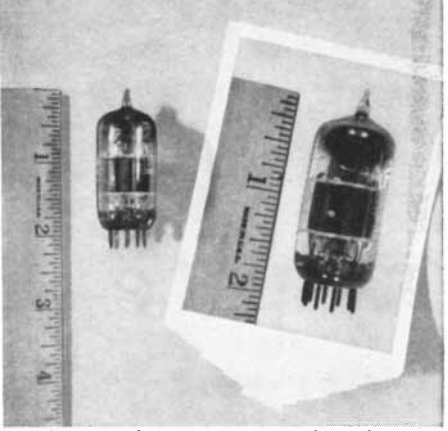

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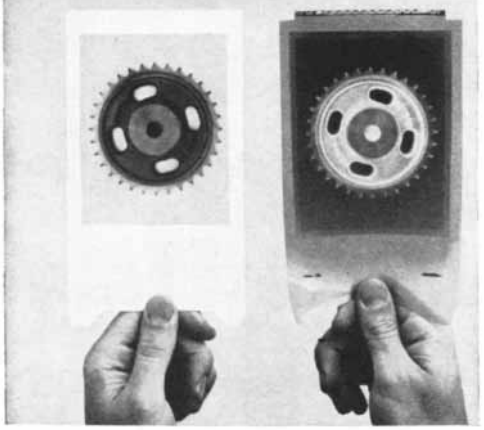

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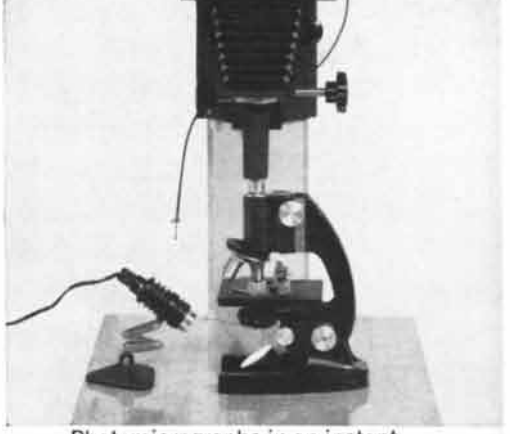

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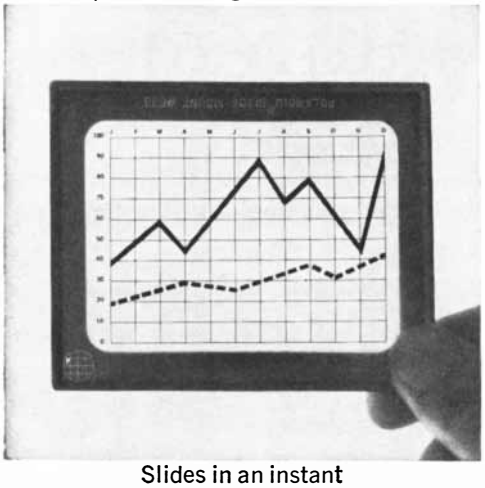

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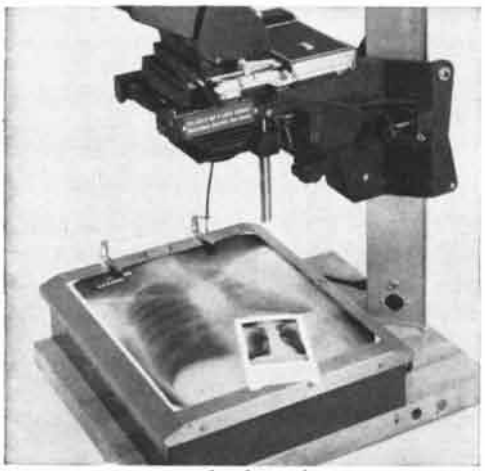

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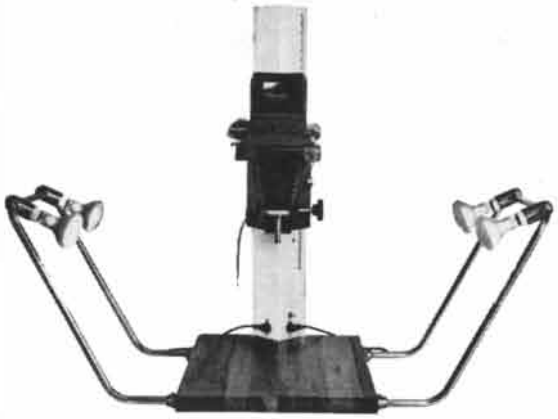

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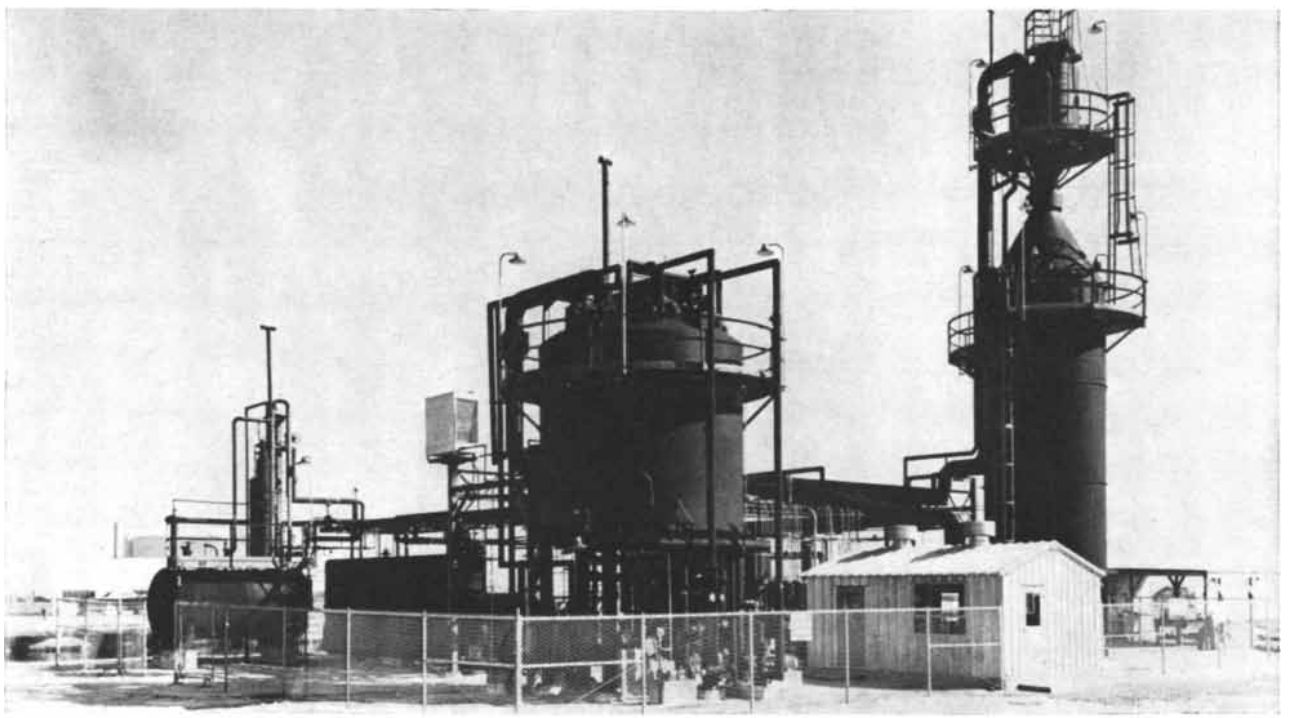
Desalting Water by Freezing

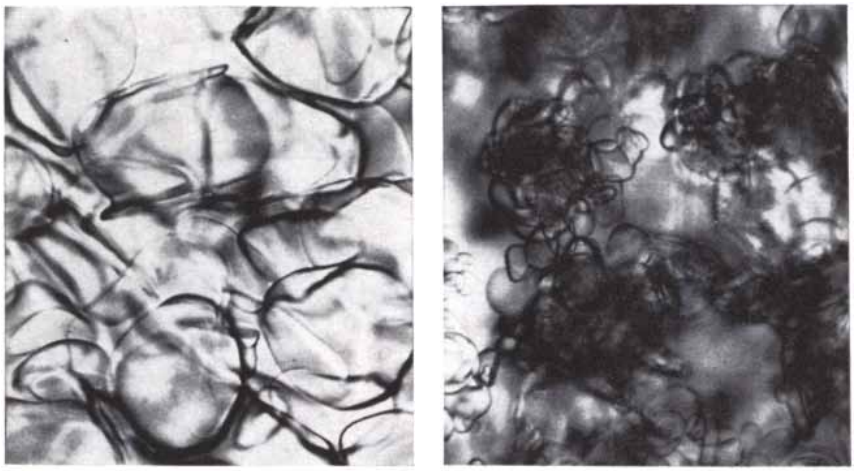
The alleviation of shortages of fresh water is often viewed in terms of distillation or the electrical removal of ions. Processes based on freezing crystals of fresh water out of salt may be more economical

by Asa E. Snyder

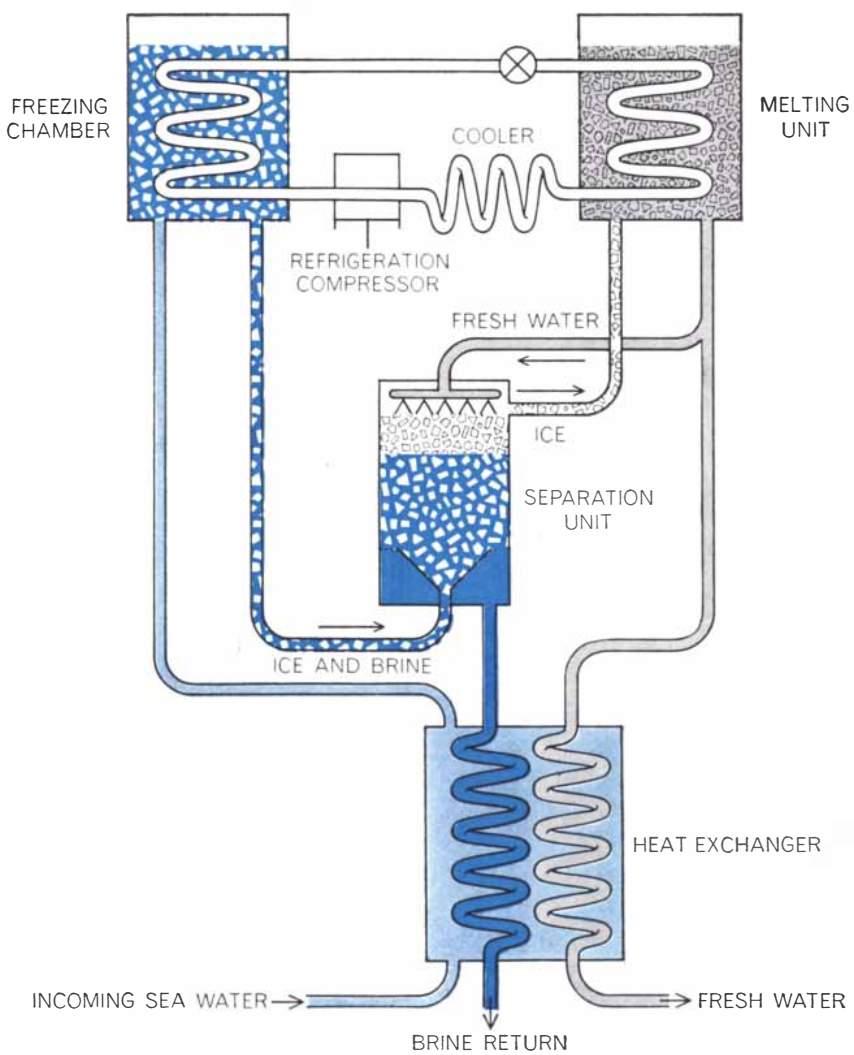
In 1952 the Congress of the United States authorized a major research and development effort to find a practical method for obtaining fresh water from salt water. About $25 million has now been spent on the effort. Four "demonstration" plants have been built or authorized to test the feasibility of alternative processes. Last spring the Office of Saline Water of the Department of the Interior invited bids from industry for the construction of a fifth plant, which will employ the freeze-separation process. This process exploits the fact that salt is excluded from the ice crystals formed when salt water is cooled to the freezing point. Ten years ago, when the U.S. desalting program was inaugurated, scarcely any thought was given to freeze-separation. Today many experts feel that freeze-separation may emerge the winner in the competition to find the most practical means for converting salt water to fresh.



PILOT PLANT at St. Petersburg, Fla., is operated by the Blaw-Knox Company for the Office of Saline Water. One of several built to test various methods of desalination by freezing, it uses isobutane as refrigerant and has a capacity of 35,000 gallons per day.



ICE CRYSTALS vary somewhat with freezing conditions. The crystals in the photomicrograph at left, magnified 100 diameters, were frozen at a large difference in temperature between the water and the coolant; those at right, magnified 40 diameters, formed at a small temperature difference. The micrographs were made by Applied Science Laboratories, Inc.



INDIRECT-REFRIGERATION method illustrates the principles of desalination by freezing. Sea water is partially cooled in a heat exchanger, then enters a freezing chamber, where a slurry of pure ice crystals in brine is formed by refrigeration. The brine is washed away from the crystals in a separation unit and the ice is then melted by heat originally removed from the sea water and stored in the refrigerant. Some of the fresh water is recycled to provide wash water for the separation unit. The indirect method is relatively inefficient.

The removal of salt from saline water may seem a minor technical problem in an age that gives priority to landing a man on the moon. The crux of the matter is of course that it can be just as difficult to do something simple at an acceptable cost as to do something complex with unlimited funds. In the U.S., and in most countries with adequate rainfall, fresh water costs less per gallon or ton than any other commodity on the market. It is also the commodity in greatest demand.

Each day farms, factories and homes in the U.S. withdraw approximately 300 billion gallons of water from wells, rivers and other sources. About 45 per cent of the total is for crop irrigation, another 45 per cent is for industry and slightly less than 10 per cent is for human and household use. This is just the water that must be paid for. Nearly 10 times as much water, or 2,500 billion gallons per day, falls free as rain on cultivated land and provides the moisture needed for raising most of the nation's crops.

A common price for municipal water is about 20 cents per 1,000 gallons, or about five cents per ton. Industry usually obtains water at a much lower price. Most of the water used in the West for irrigation costs only a fraction of a cent per ton. Ironically, it is the cheapest water that is actually consumed, in the sense that little is available for further use. About two-thirds of the irrigation water evaporates into the atmosphere, either directly from the surface of the ground or by transpiration through plants; thus it cannot be reused until it falls again as rain. Most of the water "consumed" in homes and in industry, on the other hand, is returned to streams and rivers, where it is available for further use.

Even in the U.S., where rainfall provides about 5,000 billion gallons of water per day, local water shortages have become increasingly common. In the Western states, where about a fourth of the water supply is pumped from wells, ground-water tables have been falling for many years. In other words, water is being mined: the underground reservoirs are not being replenished by rainfall. It was estimated in 1950 that the 17 Western states were then using about 70 per cent of all the water they could expect to develop at reasonable cost. The big difficulty in the West is that about two-thirds of the river runoff is concentrated in the Pacific Northwest and therefore is of no value to the arid Southwest. California, which is soon to become the nation's most populous

state, has long been the nation's biggest water consumer. It accounts for about 10 per cent of all the water used in the country, although it receives less than 5 per cent of the country's rainfall. It seems safe to prophesy that when an economical method for obtaining fresh water from the sea is developed, California will be the first state to use it.

The four demonstration plants so far constructed in the Government's water desalination program employ two general processes. Three of the plants use some form of evaporation, or distillation, to remove the salt. A fourth plant employs electric dialysis, in which an electric current drives ions of sodium and chlorine through a porous plastic membrane, leaving fresh water behind. The four plants have individual capacities of between 250,000 and one million gallons of fresh water per day.

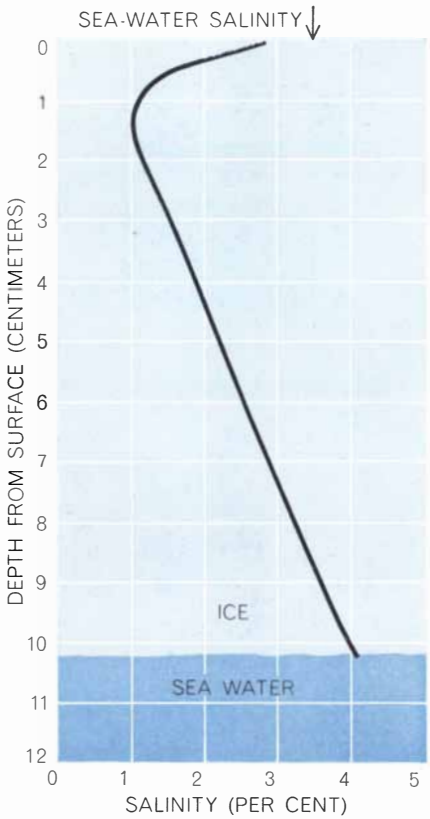
Several years ago the Office of Saline Water began studying the freezing process and financed construction of a 15,000-gallon-per-day pilot plant, which went into operation in 1959. The plant was designed by the Carrier Corporation. When the Government announced its intention last spring to finance a demonstration plant with a capacity of 250,000 gallons per day, using the freezing process, five firms submitted bids.

The conversion of salt water to fresh water by freezing is going on all the time in nature and has been known to man for thousands of years. Some inhabitants of Soviet Central Asia and western Siberia, for example, collect the ice formed when salt water freezes in ditches and use the ice, after it has melted, to water their cattle. Fishermen along the banks of the saline Aral Sea in the U.S.S.R. collect sea ice during the winter and store it for summer use. The individual crystals of ice formed when salt water freezes are entirely salt-free. Even in a layer of ice several inches thick floating on sea water most of the salt is excluded. The remaining salt is trapped as brine in the interstices between ice crystals. In a layer of sea ice 10 centimeters thick, frozen under simulated conditions, the lowest salinity occurs about 1.5 centimeters below the surface [*see upper illustration at right*].

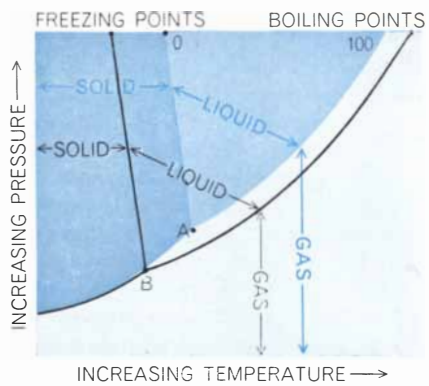
It is not difficult to build laboratory apparatus that will produce high-quality fresh water from salt water. The difficult task is to design a full-scale plant in which there is a fine balance between high thermodynamic efficiency, low capital cost and minimum maintenance. In principle freezing processes have several advantages over the various distillation processes, which are their obvious competitors. The biggest advantage is that the freezing process operates at temperatures at which corrosion and the formation of scale present only a negligible problem. This is in sharp contrast to the trouble caused by corrosion and scaling in the distillation process. At the relatively high temperatures needed for distillation, ions of sodium, chlorine, calcium, magnesium, bicarbonate and sulfate form complex precipitates that produce hard scale on the inside surface of the equipment. At elevated temperatures sea water is also highly corrosive to ordinary steels. Although various measures can be taken to minimize corrosion and scaling, they add to either capital or operating costs. If strong preventive measures are not taken, maintenance costs become prohibitive. At the low operating temperatures of the freezing process the scale-forming substances tend to stay in solution; and low-alloy steels, with ordinary protective coatings, resist corrosion nicely.

Sea water is a complex solution of organic and inorganic salts derived over the course of geologic time from the solution of rocks, the gaseous effusions of volcanoes, biological activity and, to a small extent, from meteoritic material entering the earth's atmosphere. Sea water is about 2,700 times more abundant on earth than fresh water is. The salinity of sea water is defined by oceanographers as "the total amount of solid material in grams contained in one kilogram of sea water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine and all organic material completely oxidized." The U.S. Public Health Service defines fresh water simply as "water containing less than 500 parts per million of dissolved salts." In discussing water desalination it is customary to speak of the number of parts per million (p.p.m.) of dissolved solids rather than the number of grams per kilogram.

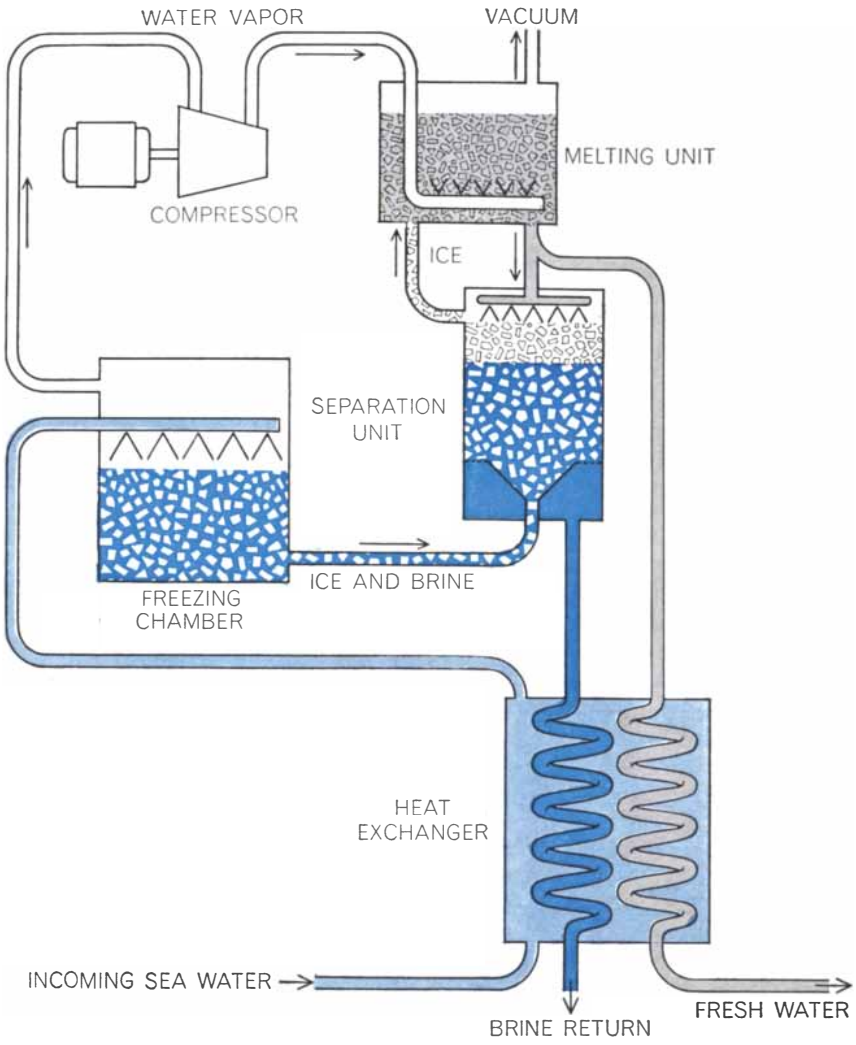
In the open ocean the total concentration of salinity varies between 33,000 and 38,000 p.p.m., depending on the geographical location. For example, precipitation, evaporation and the melting of ice in the polar regions all affect the salinity levels of sea water. In coastal areas where there is a considerable inflow of fresh water from rivers and ground water the salinity values are often below 30,000 p.p.m. Low salinities are also encountered in enclosed seas in high latitudes, where evaporation is low and precipitation and fresh-water inflow are high. The Baltic Sea, for example, has a salinity of only 7,000 p.p.m. On the other hand, the highest salinities are found in enclosed seas in subtropical zones, where there is little inflow of fresh water, little precipitation and high evaporation. The Red Sea and



SALTS tend to segregate when sea water freezes, as shown in this graph of the salinity distribution within a slab of ice.



PHASE DIAGRAM shows how freezing and boiling points, indicated at the top of the chart for atmospheric pressure, vary as the pressure decreases. Three phases are shown by colored areas for fresh water, by black lines for salt water. Below the "triple point" (*A and B*) there is no liquid phase.



DIRECT REFRIGERATION uses the cooling effect of vaporization. The sea water is sprayed into a freezing chamber kept at a pressure below the triple point. Some of it vaporizes. The flash evaporation produces ice crystals, which are washed and separated as in the indirect method. The vapor, which is also salt-free, is compressed. In the melting unit the ice melts and the compressed water vapor condenses to form the fresh-water product.

the Persian Gulf have salinities of as high as 43,000 p.p.m.

It is well known that dissolved salts lower the freezing point of water and raise the boiling point. For ordinary sea water the freezing point lies between − 1.8 and − 2 degrees centigrade. Under most conditions individual ice crystals never grow very large. Typical crystals are tiny plates with a diameter between .1 and .4 millimeter. The cubes of ice one sees in a refrigerator tray are made up of many such crystals densely packed together. The size of the crystals can be modified somewhat by altering the conditions under which the crystals are grown [*see top illustration on page 42*]. One problem in desalination by freezing is that a good deal of the original saline solution gets trapped in the interstices between the tiny crystals of pure ice. To remove this liquid the crystals must be washed with desalted water. If the ice crystals could be formed as very large pure crystals, the separation and subsequent washing operations would be simpler, cheaper and more effective. Much study is therefore being given to the problem of controlling crystal size.

The cost of energy is a major item of expense in any desalination process. Regardless of what form of energy is used in a particular system, a certain minimum amount is required to separate salt and water. When the salts in sea water go into solution, a fixed amount of heat is released. Any process designed to separate the salt from the water must restore the heat produced when the salt originally dissolved. For sea water of average salinity the energy of separation corresponds to an input of 2.8 kilowatt hours for each 1,000 gallons of fresh water produced. Since electric energy for a large-scale desalination plant in the U.S. can be obtained for about 1.6 cents per kilowatt hour, the bedrock energy cost for desalting sea water would be about 4.5 cents per 1,000 gallons. To achieve this minimum energy cost the process would have to operate at a thermodynamic-cycle efficiency of 100 per cent, and no energy could be expended for pumping water or any other auxiliary purpose.

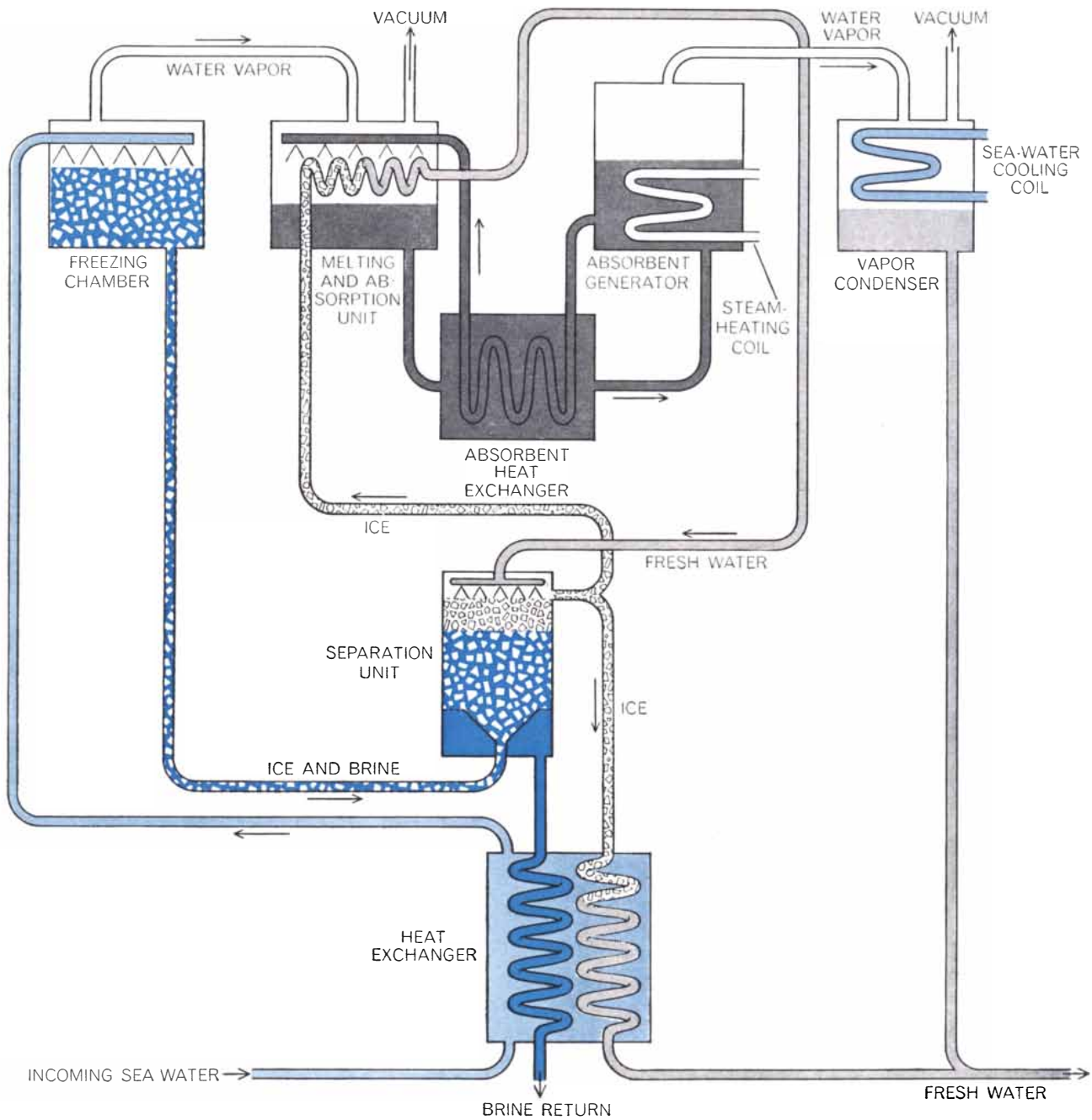
Obviously practical plants cannot come close to 100 per cent thermodynamic efficiency. In a plant using the distillation process 100 per cent thermodynamic-cycle efficiency would mean that every bit of the heat needed to evaporate the first gallon of sea water entering the plant could be recaptured and used to heat an endless succession of gallons. This would require perfect heat exchange in a perfectly insulated system. In practical plants, a thermodynamic-cycle efficiency of about 20 per cent would be considered good. In the freezing process the same thermodynamic considerations apply, except that here low temperatures must be preserved through efficient heat exchange rather than high ones. Since thermodynamic losses are inevitable, large amounts of energy are required to heat water in the distillation process and to cool it in the freezing process. Additional large amounts of energy are needed to pump water into the plant and through the process equipment. My engineering associates at the Fairbanks Whitney Corporation have estimated that in a large-scale plant using the freezing process about 10 per cent of the total electric power consumed will provide the minimum energy needed for separating salt from water, about 60 per cent will be used to make up thermodynamic losses and about 30 per cent will be needed for operating pumps and auxiliary equipment of all kinds.

One point should be cleared up regarding the relative efficiency of distillation and freezing for desalting water. It is sometimes stated erroneously that freezing is inherently more efficient than distillation because only 80 calories must be removed to freeze a gram of water, whereas 540 calories must be added to evaporate a gram. If none of the energy needed for freezing or evaporation were recovered, freezing would indeed be cheaper, but careful thermodynamic design can recover much of the energy input. Consequently in actual practice the

cycle efficiency is about the same whether desalination is performed by evaporation or by freezing.

A decade ago it was calculated that the minimum energy requirement for a practical freezing process would be about 38 kilowatt hours of electricity per 1,000 gallons of fresh water. Recently Fairbanks Whitney, which has put a lot of effort into desalination, has stated that its present process could produce fresh water by freezing at an energy cost of 40 kilowatt hours per 1,000 gallons. It further predicted that the power consumption might eventually be reduced to 30 kilowatt hours. These values compare favorably with the lowest values quoted by proponents of evaporation processes and are only 10 to 15 times greater than the energy requirements of a theoretically perfect process.

Let us now turn to some of the actual freezing systems for producing fresh water from salt water. All of them have the basic objective of making pure ice and separating it from residual brine. Although it is not the most promising method, the indirect-refrigeration process shown in the bottom illustration on page 42 illustrates the steps fundamental to all the processes. The incoming salt water is first chilled by being pumped through a heat exchanger containing coils



VAPOR ABSORPTION is a variant of direct refrigeration in which the water vapor, instead of having to be compressed mechanically, is taken up by an absorbent from which it can subsequently be separated. An absorbent medium such as concentrated lithium bromide solution is cooled and sprayed through the vapor in the melting and absorption unit. Now cold and dilute, the absorbent is led through a heat exchanger to the absorbent generator, where steam heating drives off the water vapor, which is then condensed.

that carry the cold waste brine and the cold desalinated water produced by the melting of ice. The sea water then enters a freezing chamber that contains the coils of a separate refrigerating system. Ice crystals are formed, and a slurry of ice and brine flows to a separation unit. The brine is discharged as waste and the ice is transferred to a melting unit, where the heat originally removed by the refrigerant is used to melt the ice as the refrigerant is condensed. The melted ice is then taken from the melting unit as product water, part of which is used to wash brine from the ice crystals in the separation unit.

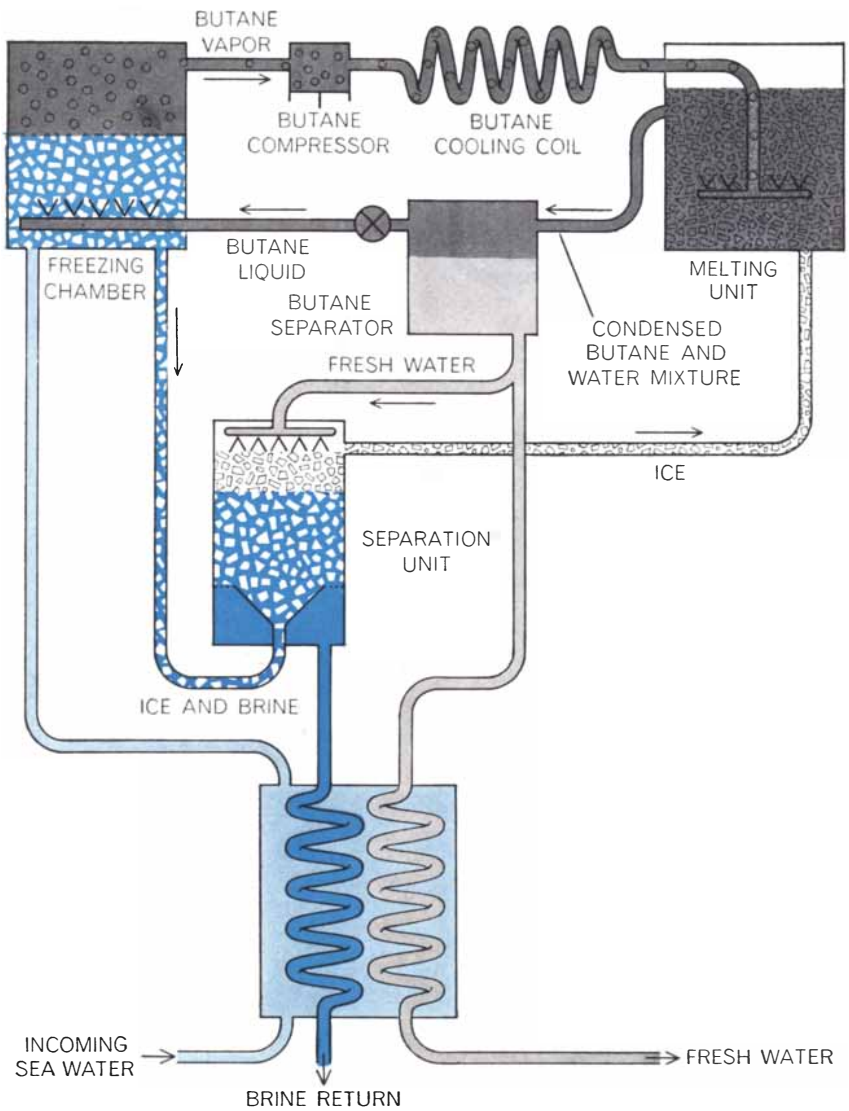
The indirect-refrigeration method is relatively inefficient because in the freezing chamber the heat in the salt water must pass through the metal walls of cooling coils before it can be removed by the refrigerant. Therefore a method that will allow a direct exchange of heat between the sea water and the refrigerant is highly desirable. One direct-refrigeration method, illustrated on page 44, uses the water itself as a refrigerant. The sea water is sprayed into a low-pressure chamber; as a result some of the water immediately flashes into vapor. If the pressure in the chamber is equal to the vapor pressure of sea water at or below the freezing point (as shown in the phase diagram on page 43), the flash evaporation will produce subfreezing temperatures. In principle each gallon of water that evaporates removes enough heat to freeze about seven gallons of the water remaining behind.

As before, the ice and brine slurry is piped to a separation unit, from which the ice passes to a melting chamber. The water vapor produced in the freezing chamber is, of course, salt-free also. It is compressed and pumped into the melting unit, where it condenses and in the process supplies all the heat needed to melt the ice crystals. In fact, an auxiliary refrigeration coil may be needed in the melting unit to condense all the water vapor entering the unit. The direct-refrigeration method is quite simple and requires a minimum of accessory equipment. The main problem that had to be overcome in this method was the development of efficient large compressors, which must handle in vapor form about a seventh of all the fresh water produced by the process.

One way to avoid the difficulties of compressor design is to use a direct-refrigeration method in which the water vapor is absorbed in a suitable medium, such as lithium bromide. This method, illustrated on the preceding page, is similar to the direct-refrigeration method except that the water vapor leaving the freezing chamber is taken up by the absorbent and is subsequently driven out by heat. The vapor-absorption method requires more complex equipment, however, than the vapor-compression technique.

An interesting variation of the direct-refrigeration method employs a refrigerant that can be sprayed directly into the sea water, as illustrated at the left. The refrigerant, of course, must be insoluble in water and ideally should have a boiling point just below the freezing point of water. One refrigerant that meets the requirements is isobutane, which boils at -10.2 degrees C. Liquid isobutane is pumped into the sea water, where it evaporates and produces ice. The isobutane vapor is then compressed, liquefied and recycled. Other freezing schemes have been examined, but the three methods of direct refrigeration outlined here appear to have the greatest potential.

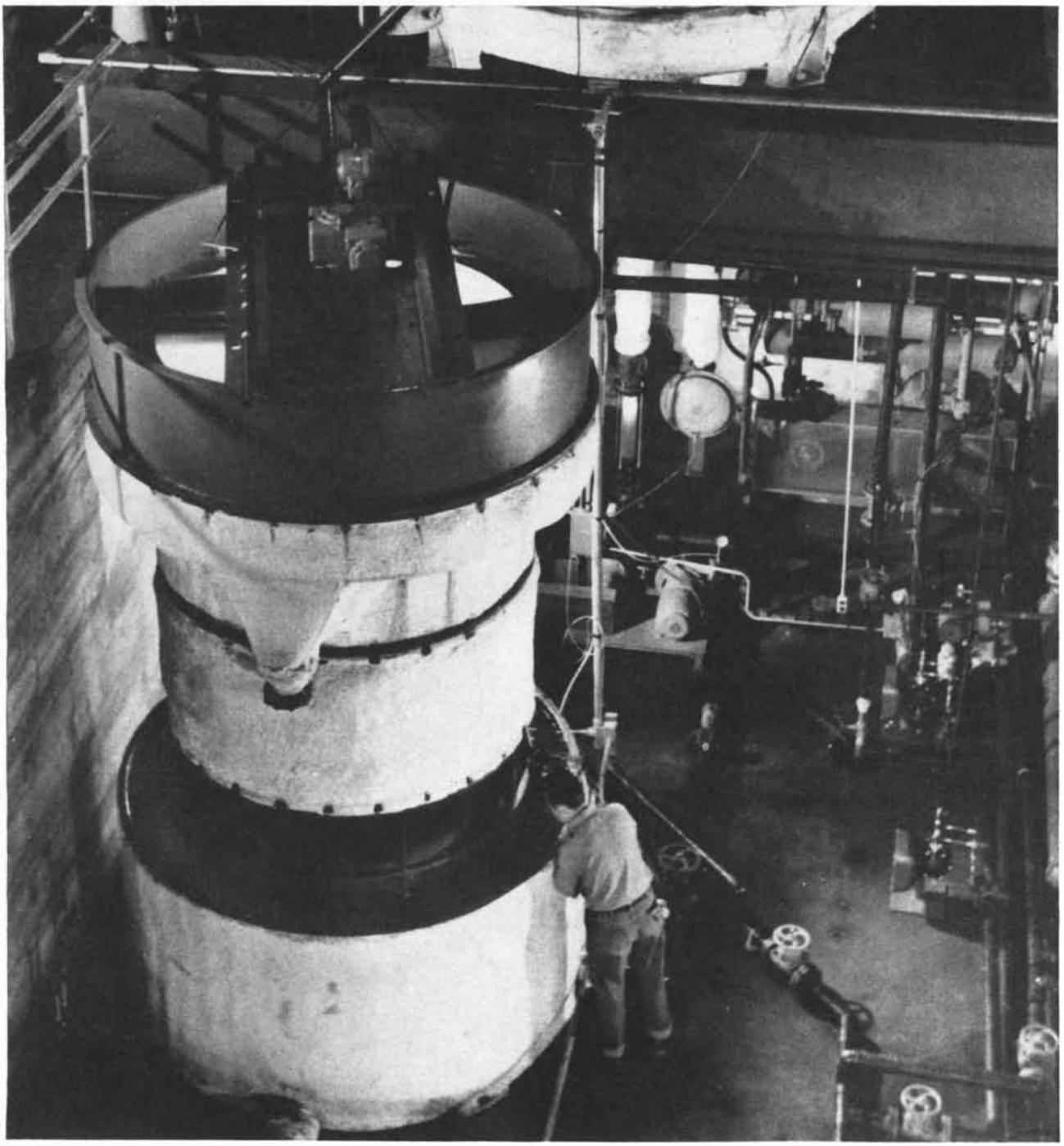
All the methods depend on an efficient mechanism for separating ice from brine. In principle it is no problem to separate ice from brine and to wash the ice, but it is difficult to hold losses to a minimum. Ice that melts before it is separated represents an efficiency loss, and the washing itself must be accomplished with as little melting as possible and with the use of a minimum of fresh



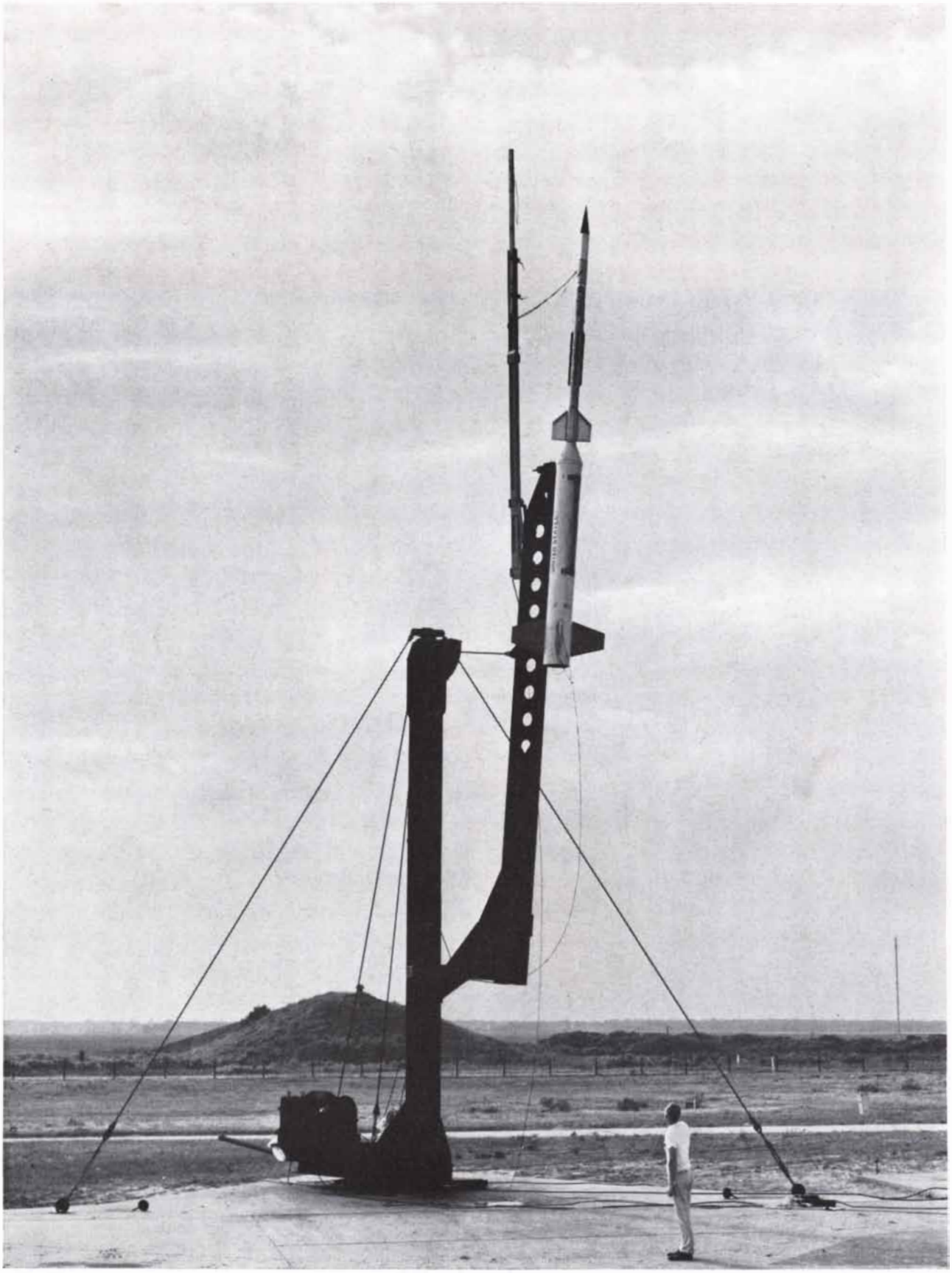
"BUTANE METHOD" is another variant of direct refrigeration. A refrigerant such as isobutane, which is insoluble in water, is dispersed as a liquid into the sea water in the freezing chamber. It vaporizes, freezing the water into a slurry that is separated as in the other methods. The butane gas, compressed, is led to the melting unit to melt the ice and be condensed in the process. The butane-water mixture is separated to provide pure water.

water. In almost all freezing processes ice-brine separation is accomplished by countercurrent washing with fresh water in a vertical moving bed called the wash-separation column. The ice-brine slurry enters at the bottom, where much of the brine is removed by filtration. As the bed of ice crystals floats slowly upward it is washed free of entrapped brine by a descending stream of fresh water. The ice is continuously harvested at the top of the column and from there passes to the melting unit.

Proponents of the freezing process are confident that it can compete favorably with any other process for desalting sea water and that large freeze-separation plants will be built in many parts of the world within the next decade. Plants with capacities ranging from two million to 10 million gallons per day have been designed, and their economics are being given close study. Depending on capacity, and with power figured at one cent per kilowatt hour, they will produce water at a cost ranging from 50 to 80 cents per 1,000 gallons. Water at this price cannot be widely used for irrigation, but for many coastal cities in arid and semiarid regions it will be cheaper "municipal" water than they can obtain by impounding rain water 100 miles or more from the site of consumption.



PROTOTYPE PLANT of the Fairbanks Whitney Corporation at Beloit, Wis., uses direct refrigeration with vapor compression [*see illustration on page 44*]. **This unit is the wash-separation column; the freezing, compressor and melting stages are in another unit.**



NIKE-CAJUN SOUNDING ROCKET at Wallops Island, Va., carries grenades that have been set to explode at predetermined intervals during an atmospheric probe that may take it to an altitude of 75 miles. The time required for sound waves from the explosions to reach the ground can be used as the basis for calculating wind direction and velocity as well as temperature at different altitudes.

ATMOSPHERIC TIDES

Tiny regular pulsations of the atmosphere have long been attributed to the pull of the sun and the moon. Rocket observations now suggest that the cause is the absorption of ultraviolet radiation by ozone

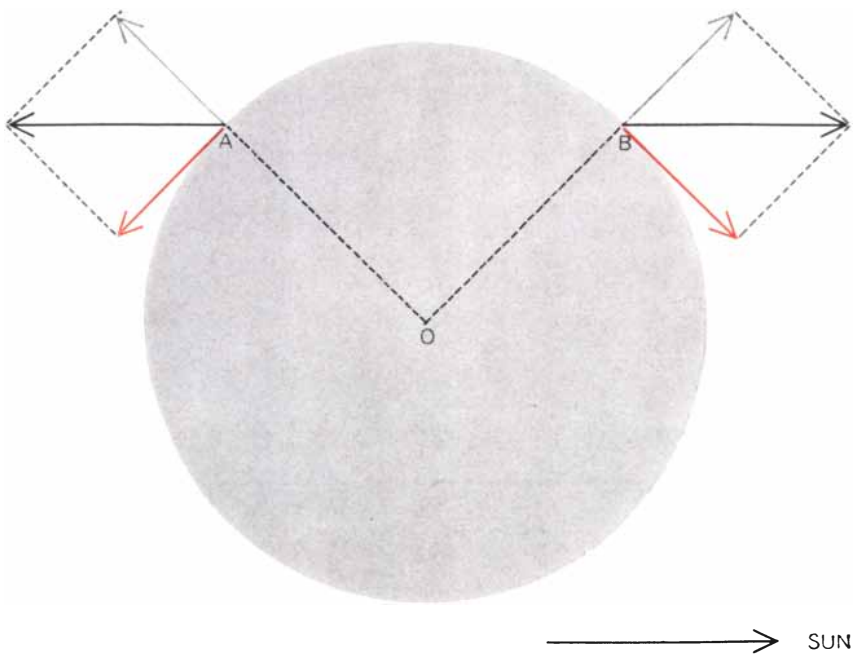
by S. T. Butler

Ever since men have lived near the sea they have been aware of the ebb and flow of ocean tides. The ocean of air in which all men live is also subject to tidal pulsations, but it was not until comparatively recent times that anyone was aware of them. Men are bottom dwellers in the ocean of air, and tidal changes in air pressure cannot be perceived without the aid of instruments. Today air tides are a subject of lively interest, and it seems likely that they have at long last been satisfactorily explained.

The behavior of ocean tides has been well understood since the days of the great 19th-century French mathematical physicists. The cause of these tides is gravity. A point on the surface of the earth that is nearer the sun than is the center of the earth is subject to a little more inward gravitational force and a little less outward centrifugal force (centrifugal force that arises from the earth's orbit around the sun and not from the earth's spin). Conversely, a point on the far side of the center of the earth is subject to a little less gravitational force and a little more centrifugal force. The result is a net force that tends to push the surface material toward points directly in line with the sun [*see illustration at right*]. If the earth did not spin, water would simply pile up at these two polar points in a permanent high tide. In a sense the tides are permanent: they are fixed on a line from the sun to the center of the earth. With respect to a point on the surface of the rotating earth, however, the water surges up and down with a 12-hour period.

The same considerations apply to the earth-moon system. In fact, due to the proximity of the moon, its effect is 2.2 stronger than that of the sun. Here it should be realized that the earth is traveling in a nearly circular orbit around the center of mass of the earth-moon system; tides are again produced by the imbalance of centrifugal and gravitational forces. Because the moon completes its trips around the earth in 24 hours and 51 minutes, the lunar tide has a period of 12 hours and 25.5 minutes. Being stronger, the moon's force is what determines the actual tidal rhythm. When the sun tide is most nearly in phase with the moon tide, the total tide is large; when the two are most nearly out of phase, the tide is small.

The same forces act on the atmosphere, and clearly they must also produce tides in it. Such tides are in fact observed. The first man to observe atmospheric tides was Pierre Simon de Laplace, who recorded the barometric pressure in Paris four times a day for eight years. He and those who came after him found a regular daily variation in surface pressure—the effect of the tide observable at the bottom of the atmospheric ocean. Better readings than those of Laplace's were later obtained in the tropics, where the barometric pressure tends to remain constant for long periods [*see illustration on page 52*]. Since the

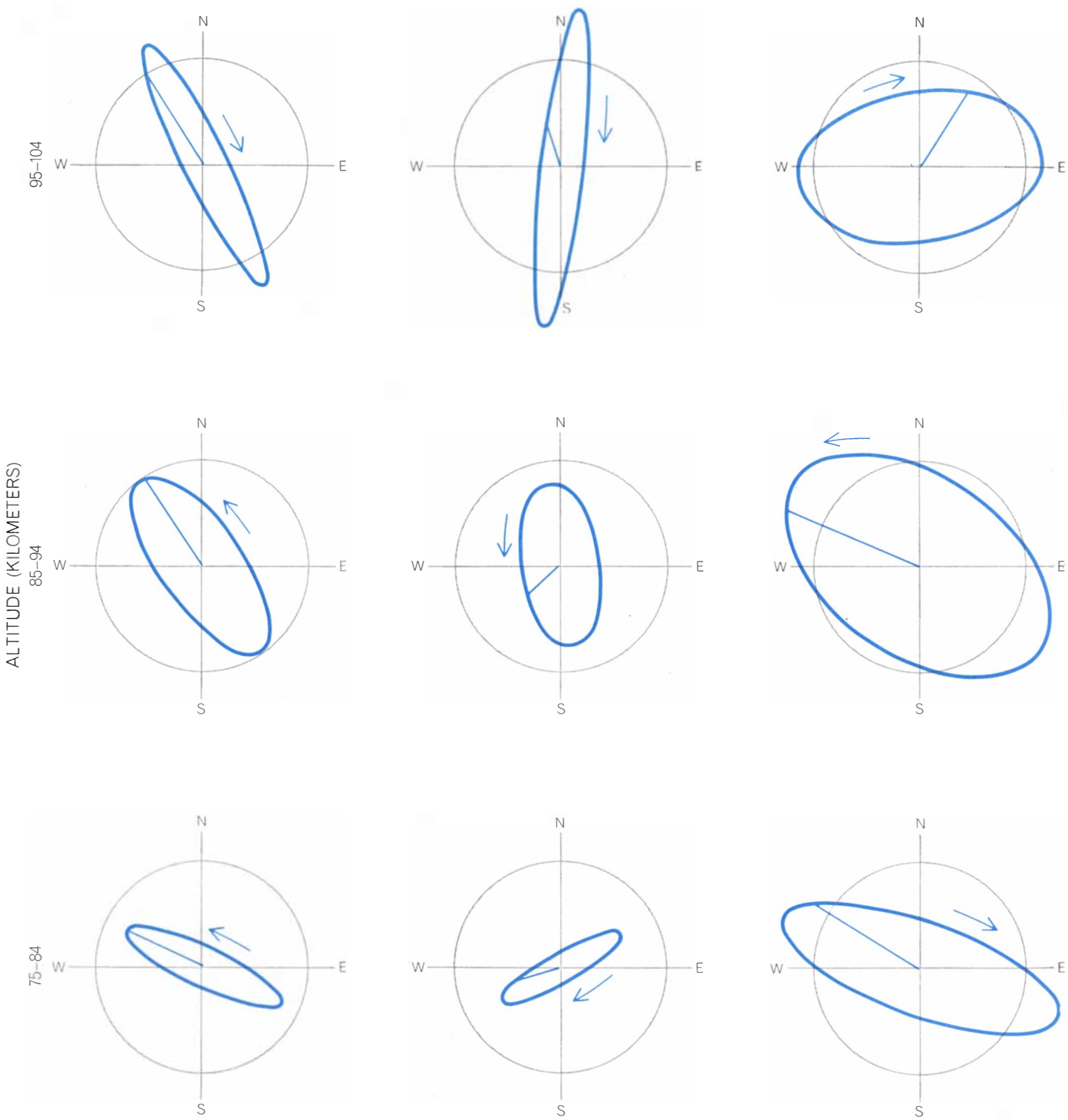


TIDAL FORCE produced by the sun is a component of the net force, or difference, at any given point on the earth's surface (*e.g., A or B*), between the sun's gravitational attraction and the centrifugal force of the earth's orbital motion. On the day side the net force (*black arrow*) is directed toward the sun; on the night side it is directed away from it. Of the two components of this force, one perpendicular to the surface of the earth (*gray arrow*) and the other tangent to it (*colored arrow*), it is the latter that contributes to the tides.

time of Laplace a tremendous amount of data has been accumulated on barometric variations at sea level from stations all over the world. These records show a maximum pressure at approximately 10 a.m. and another at 10 p.m.

In other words, the atmospheric tide follows the 12-hour solar cycle and not the 12-hour-25.5-minute lunar cycle. Although this major variation is apparent to anyone looking at an appropriate record, it is far from the only frequency represented. As Jean Fourier showed, any irregular curve can be analyzed into a series of sine waves of different frequencies and amplitudes. When such analysis is performed on the atmospheric-pressure graph at the Equator, some interesting relations emerge [*see top illustration on page 53*].

To begin with, the lunar effect is seen



PERIODIC WINDS at altitudes of 75 to 100 kilometers possess 12- and 24-hour components. From left to right the vertical rows of diagrams plot the behavior of the 12-hour component over Adelaide, Australia, in December, 1952, and March, 1953, and of the corresponding 24-hour component in the same two months. The straight colored line in a diagram indicates the wind direction and strength (the distance from the center to the gray circle represents a speed of 25 meters per second, or roughly 56 miles per

to be much less than the solar. Of the solar components, it is the 12-hour oscillation that is by far the strongest and that has attracted the most interest over the past 100 years. The magnitude of this semidiurnal pressure oscillation is remarkably constant in time and seems to be a function only of latitude and not of local geography. At a given latitude, for example, the magnitude of the 12-hour component is independent of whether the observing station is located on a small island, near the coast line of a large continent or at the foot of a high mountain range. Its amplitude decreases uniformly as one moves away from the Equator.

The 24-hour component is much more variable, both in having greater fluctuations at any one location and also in its dependence on geographic factors such as the height of the station above sea level. The smaller eight-hour and six-hour components are also somewhat variable, particularly in their seasonal changes.

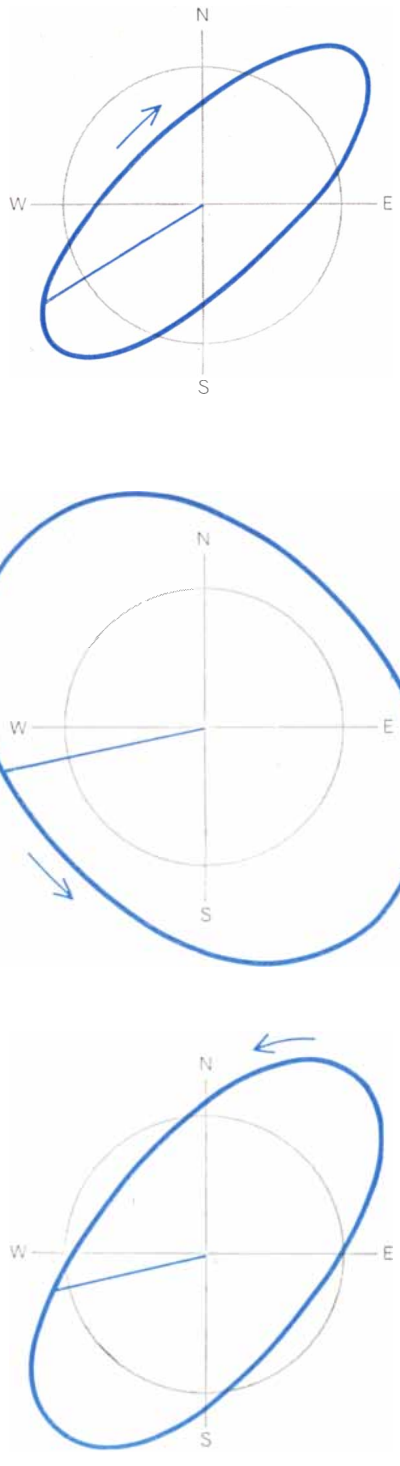
Atmospheric tides can be perceived not only in barometric records but also in records that are produced by newer methods. One such method is the study of meteor trails: the wake of ions left behind by a meteorite plunging into the earth's atmosphere. By means of radar techniques that take advantage of radio echoes from meteor trails it is possible to evaluate the velocity of atmospheric drift—the wind—in the environment of the meteor trail. The method provides information on winds at altitudes in the vicinity of 75 to 100 kilometers (50 to 60 miles). It has been employed particularly by Leonard G. H. Huxley and his co-workers at the University of Adelaide in Australia and by J. Stanley Greenhow at the Nuffield Radio Astronomy Laboratories at Jodrell Bank in England.

The radar measurements show that at such altitudes there are periodic winds with strong 12-hour and 24-hour components, corresponding to the semidiurnal and diurnal components of pressure fluctuations on the ground [*see illustration at left*]. This periodic wind system can be analyzed in terms of pressure changes and thereby correlated with the periodic fluctuations of pressure at ground level. The results indicate that the pressure fluctuations in the upper atmosphere are strongly correlated with those at ground level but that there is a change of phase between the two: a pressure minimum in the 12-hour component at ground level corresponds to a maximum in the 12-hour component at high altitude, and so on.

Experimental information on the tidal fluctuations at altitudes intermediate between ground level and the region of meteor trails is difficult to obtain. There is some information from balloon observations at the lower altitudes (less than 25 kilometers), and this shows oscillations in phase with the ground observations. At present, however, there is almost no detailed experimental information on the oscillations between 25 and 75 kilometers. Of course, in recent years there has accumulated a mass of rocket data on the atmosphere at all altitudes; this provides valuable information on the average temperature, density and constitution of the air as a function of altitude, but as yet it has yielded little or no information on variations over a period of time. There are not enough rocket observations for them to be analyzed with respect to time.

Although there are many more observations to be made at intermediate and high altitudes, there is an abundance of data actually available that must be explained by any theory of the atmospheric tides. High on the list is the question of the large solar semidiurnal component compared with the small lunar semidiurnal component. Laplace was the first to face this question, but he dismissed the solar component as being due to solar heating effects, which he was unable to calculate and which in any case he found uninteresting. It was in order to compare his gravitational theory of the tides with observations of the atmosphere that he undertook his eight-year series of barometric readings. The lunar tide, however, was too small for his instruments to detect and had to wait on more accurate measurements.

A new interpretation of the phenomena was proposed by Lord Kelvin in 1882—a proposal that was to become widely accepted. This is the well-known atmospheric-resonance theory that has been discussed in an earlier article in SCIENTIFIC AMERICAN [see "Tides in the Atmosphere," by Sydney Chapman; SCIENTIFIC AMERICAN, May, 1954]. Kelvin was of the opinion that any tidal motion in the atmosphere due to solar heating must have a predominantly 24-hour period. Thus he attributed the somewhat variable diurnal component of the atmospheric pressure fluctuations to heating effects. He maintained, however, that the constancy of the semidiurnal component was much more in line with a gravitational tide than with a thermal one. Kelvin therefore proposed that the atmosphere has a sharp natural resonance with a period of precisely 12 hours. In this way, he argued, the tides due to the sun's gravitational force would be amplified tremendously, whereas the lunar tides would be little affected. This theory has waxed and waned in



hour) at the beginning of the period. The elliptical figure swept out by this line as it rotates (*arrow*) once during a period plots the changes of wind direction and strength.

acceptance, and today it is considered by many to be a fact of nature. In this article, however, I shall discuss the results of recent calculations by K. A. Small and myself that weigh heavily against the resonance hypothesis.

First, the accumulation of rocket data for the average density and the temperature of the atmosphere as a function of altitude gives a new set of values for the "equilibrium" atmosphere. The temperature [*see bottom illustration on opposite page*] at first decreases with altitude and then increases to about 300 degrees Kelvin (27 degrees centigrade) at about 45 kilometers; thereafter it decreases again up to about 80 kilometers, at which point we are in the lower region of the ionosphere. The temperature of the ionosphere then steadily increases with altitude, but the latter increase is not a major factor in the over-all behavior of the atmosphere at lower altitudes.

With the temperature and density of the atmosphere much more accurately known, it is possible to analyze carefully the tidal effects of the solar and lunar gravitational forces. It turns out that the question of the atmospheric resonance is intimately concerned with the temperature peak at 45 kilometers. On the basis of the new temperature profile, Small and I have calculated that there is indeed some magnification of the semidiurnal solar gravitational tide but that the magnification is only by a factor of about two instead of the required 100.

It is now difficult to escape the conclusion that the gravitational contributions to the atmospheric tides are extremely—one might almost say negligibly—small and that one must turn to heating effects for an explanation not only of the diurnal component but also of the semidiurnal component and higher components.

What happens to the energy of the solar radiation that impinges on our atmosphere? Some of it is reflected back into space by clouds; some passes through the atmosphere and is absorbed by the earth; some is absorbed by the atmosphere before it reaches the ground. In the last process an important region is the ozone band at a height of about 45 kilometers, which absorbs all the solar radiation—chiefly ultraviolet—with a wavelength of less than 3,200 angstrom units. In fact, the ozone band absorbs about 8 per cent of the total solar energy falling on the earth and its atmosphere. At lower altitudes water vapor and carbon dioxide molecules absorb radiation—principally infrared—with a wavelength longer than that of light.

Small and I have recently completed detailed computations on the absorption of ultraviolet in the ozone band. As is well known, the oxygen of the atmosphere at the lower altitudes is in diatomic form; that is, the molecule consists of two oxygen atoms bound together (O_2). In the region from 20 kilometers up there is a considerable concentration of ozone, the molecules of which consist of three oxygen atoms (O_3). The density of ozone is greatest at the temperature peak in the vicinity of 45 kilometers; indeed, it is the ozone that causes this temperature peak.

How is the ozone formed? There are four steps in the maintenance of a fairly constant ozone band:

1. O_2 + ultraviolet $\rightarrow$ O + O.

2. $O_2 + O + M \rightarrow O_3 + M$, where M is any other molecule to carry off the necessary energy and momentum in the process.

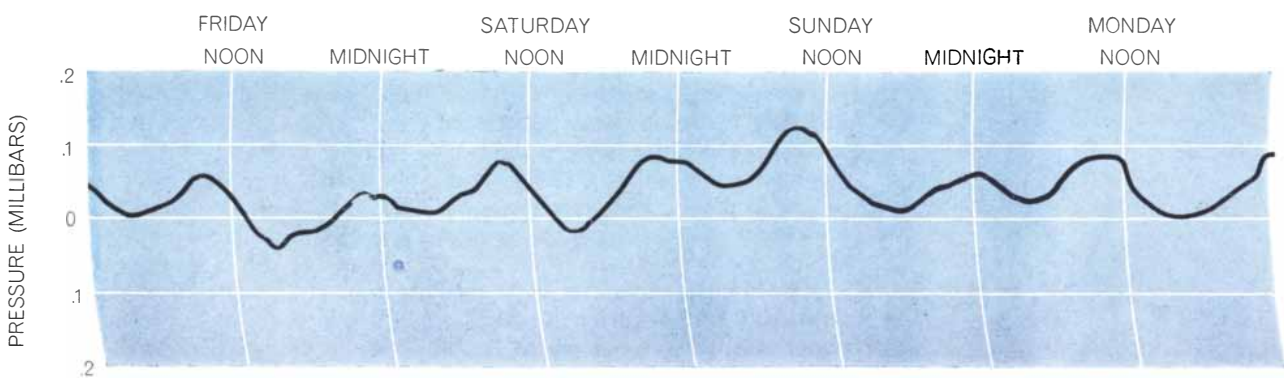
3. O_3 + ultraviolet $\rightarrow O_2 + O$. The wavelength bands most effective in promoting this reaction range from 2,400 angstroms down to 2,000.

4. $O_3 + O \rightarrow O_2 + O_2$.

Thus in four steps the cycle ends and the O_2 molecules are reconstituted. The four reactions occur continuously in the sunlit half of the atmosphere. The balance among them determines the average equilibrium concentration of ozone.

There is, however, a further extremely important effect. The ozone molecules have additional strong radiation-absorption bands up to a wavelength of 3,200 angstroms. Absorption of ultraviolet in the region from 2,000 to 2,400 angstroms breaks up or dissociates the ozone. The absorbed radiation with wavelengths in the region from 2,400 to 3,200 angstroms does not have enough energy to dissociate the molecule but puts it into an "excited" state; in such a state electrons in the molecule are raised to a higher energy level, and the molecule may be vibrating more violently than in its lowest normal energy state. When an excited ozone molecule collides with any other molecule, the additional internal energy of the O_3 can be converted into ordinary kinetic energy; after such a collision the two molecules are traveling at higher speeds than before. In this way the original energy of the ultraviolet radiation is converted into kinetic energy and so produces a higher temperature in the ozone band.

It is the absorption of the ultraviolet of wavelengths up to 3,200 angstroms by ozone that shields the earth from strong ultraviolet radiation at ground level, and in the process of absorption the ozone produces the atmospheric temperature maximum at around 45 kilometers. The picture, then, is that during the day, when the sun is shining on it, a given region of the atmosphere will be absorbing energy and its temperature will increase somewhat. Of course all regions of the atmosphere are radiating energy away continuously, mainly at infrared wavelengths. For any particular region in the ozone band the heat intake and output as a function of



BAROGRAPHIC RECORD in Jamaica in the West Indies of a typical four-day period reveals the periodic fluctuations in atmospheric pressure produced by atmospheric tidal oscillations. One millibar equals a pressure of 1,000 dynes per square centimeter.

time can be represented as it is in the upper illustration on page 55; the heat gained exactly balances the heat radiated away over a 24-hour period. During the daylight hours, however, there is a net inflow of heat.

To understand how this can produce a tidal effect one may consider a model atmosphere consisting of a cylindrical column of air [*see left side of top illustration on next page*]. The pressure at any point is determined by the weight of atmosphere above it. Suppose there is a region (the ozone band), lying between the heights h_1 and h_2, into which heat energy is to be pumped. One can even imagine that at the boundaries there are weightless, heat-insulating diaphragms that can slide freely up or down to eliminate the effects of convection or conduction. (In point of fact in the actual atmosphere conduction and convection rates are sufficiently slow to be largely omitted from considerations of the tides.)

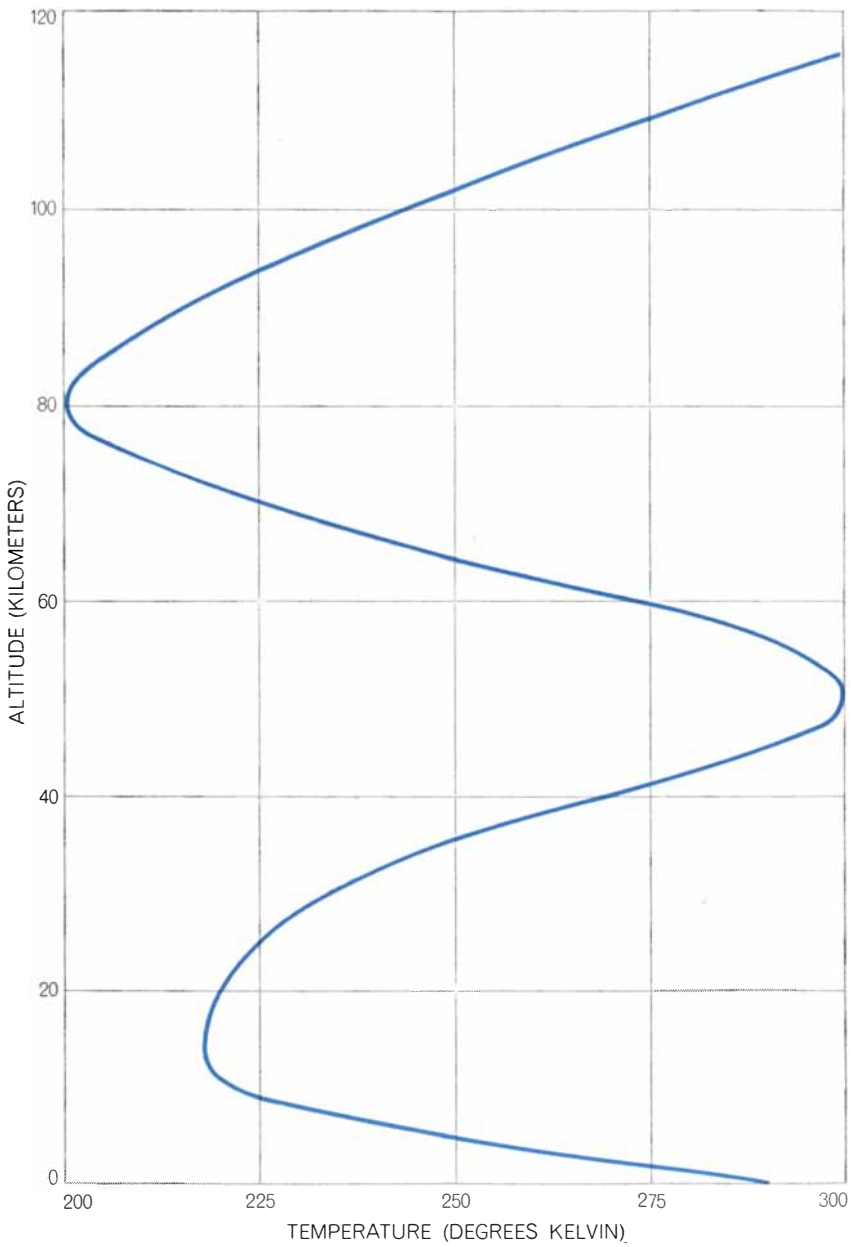
When heat is pumped in, the model ozone band expands, chiefly by means of a rise in the upper boundary, although the lower boundary will also be slightly depressed. Because of the lower pressure at the upper edge, this boundary will rise far more than the lower one will drop. As a first approximation it can be considered that the h_2 level moves up to some new level designated h_2'.

The pressure at the h_1 level must remain the same, since the amount of atmosphere above has not increased. Similarly, the pressure of the h_2 level must remain the same, and for the same reason. In between, however, the pressure must fall off more slowly with height [*see bottom illustration on next page*]. The main effect is that at any height above h_1 the pressure is increased by the process. The pressure increase will therefore automatically accompany the addition of heat energy to the ozone band and will only gradually subside as the energy is radiated away.

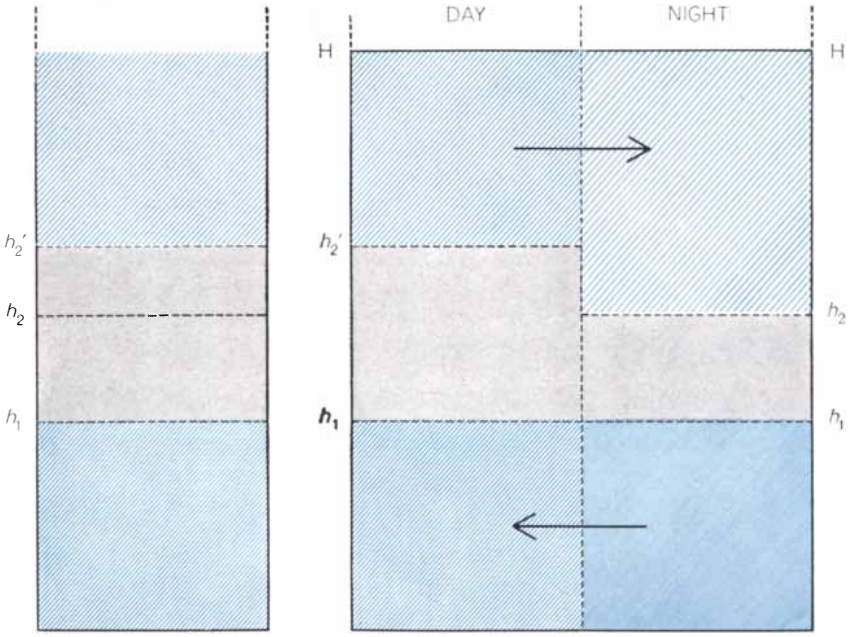
Now let us consider two model atmospheres side by side [*see right side of top illustration on next page*], one representing the "day" side of the earth's atmosphere and the other the "night" side. Let us also imagine that an amount of heat energy designated Q has just been pumped into the ozone band of the day atmosphere. At any altitude above the h_1, the bottom of the ozone band, the pressure will initially have increased on the day side and not on the night side. At each height above h_1 the pressure on the day side will be greater than it is on the night side. There is therefore a large-scale pressure gradient from day

PERIOD	PRESSURE OSCILLATION (MILLIBARS)
24 HOURS (1 SOLAR DAY)	∽.7
12 HOURS (1/2 SOLAR DAY)	1.3
8 HOURS (1/3 SOLAR DAY)	∽.2
6 HOURS (1/4 SOLAR DAY)	∽.02
12 HOURS 25.5 MINUTES (1/2 LUNAR DAY)	.08

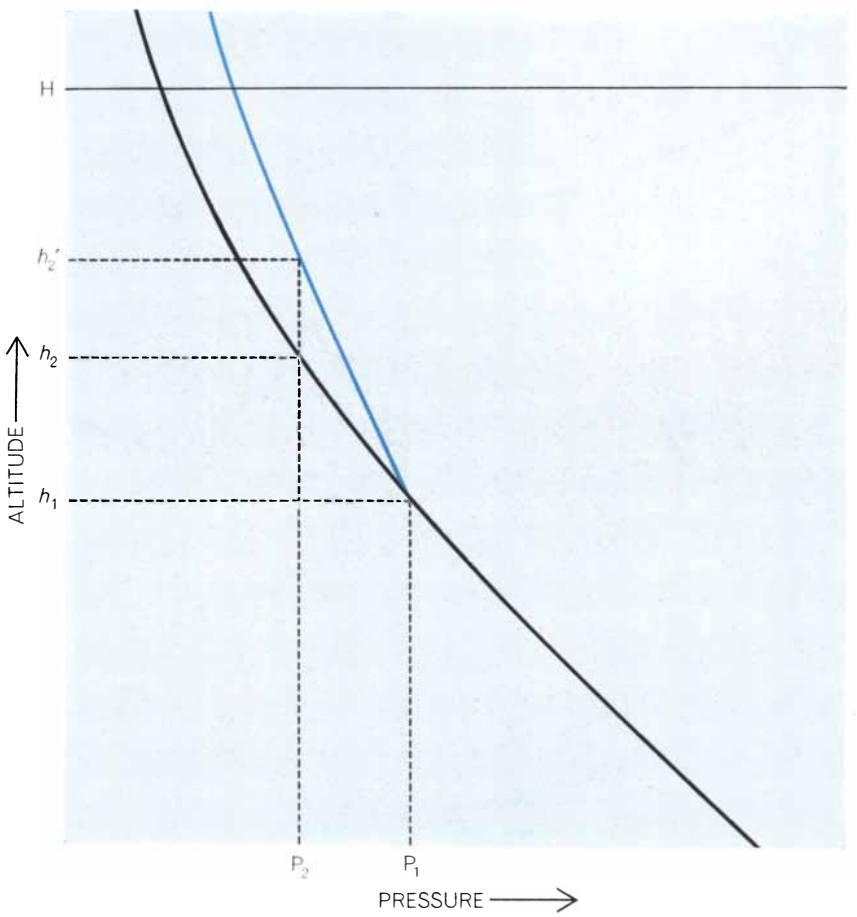
BAROMETRIC VARIATIONS over prolonged periods, when analyzed into various components (or oscillations), reveal four that are related to the solar day and one to the lunar.



TEMPERATURE VARIATION with altitude, as plotted here, is based largely on data obtained by sounding rockets like that on page 48. The temperature scale ranges from — 73 degrees to + 27 degrees centigrade. The altitude scale ranges from zero to 72 miles.



MODEL ATMOSPHERES illustrate calculations of the author and K. A. Small in determining tidal effects of the heating up of the ozone band (*see illustration below*). The single model (*left*) shows the daytime expansion of the band (*gray area*); that is, its upper boundary shifts from h_2 to h_2'. The day and night models (*right*) show the pressure gradients that result: from day to night in the upper atmosphere; from night to day in the lower.



MAIN EFFECT of the heating of the ozone band, as explained in the text, is such that at any altitude H above h_1 the normal falling off of pressure with altitude (*black curve*) changes (*colored curve*). For example, pressure P_2 expected at h_2 is now found at h_2'.

to night that sets up a flow from the day side to the night side in the upper atmosphere.

Such flow is reflected at the low altitudes below the ozone band. On the day side the pressure will drop because of the lessening in the weight of atmosphere above; on the night side the pressure will rise. Thus at low altitudes there is a reverse pressure gradient. It is clear that the fluctuations at high altitudes will be out of phase with those at low altitudes; the nodal point (where there is no oscillation) occurs in the lower region of the ozonosphere, which in our model is at the lower boundary of the ozone band. At first sight it may seem that such pressure variations would have primarily a 24-hour period, since the sun passes over a given region of the atmosphere only once in 24 hours.

This, however, is not completely true, and a detailed analysis of the effect yields a strong semidiurnal component. The result can be understood qualitatively if one realizes that the "driving force" in any one region of the atmosphere is something like a rectified sine wave [*see lower illustration on opposite page*]. Clearly the fundamental component of the pulsation has a period of 24 hours. The first harmonic has a 12-hour period; the second harmonic, an eight-hour period, and so on. In fact, if the driving force were a pure sine wave with the lower loops cut off, the amplitude of the first (12-hour) harmonic would be almost as large as that of the fundamental: the ratio is about 8 to 9.4. The semidiurnal driving force is almost equal to the diurnal component.

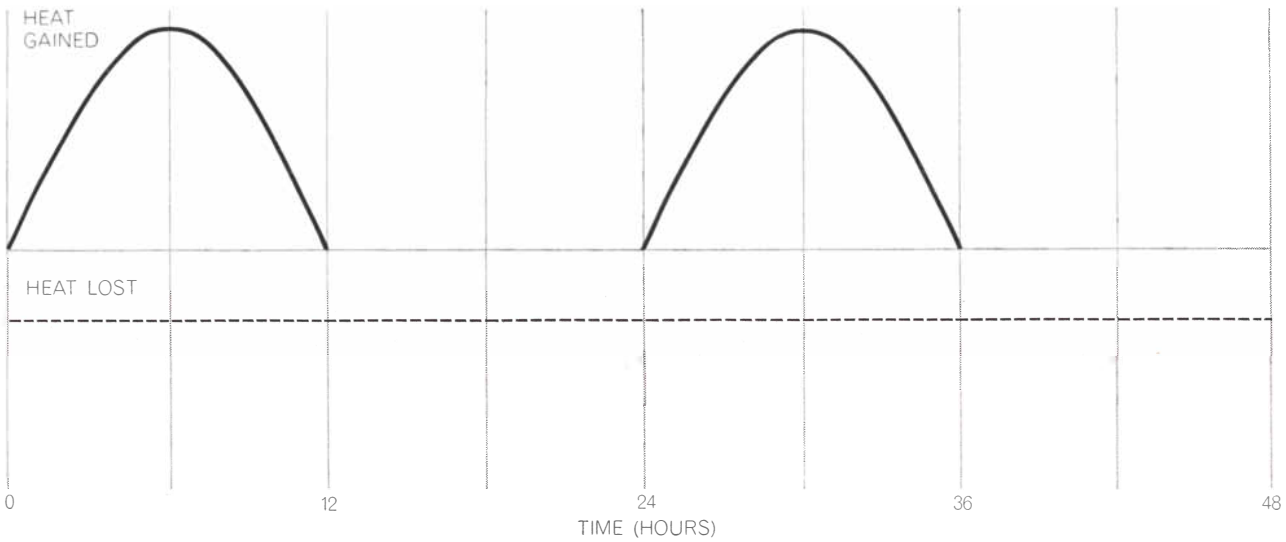
In the complete atmospheric analysis the fact that there is some small resonance magnification—about a factor of two—of the 12-hour component means that even for solar radiation the largest oscillation induced in the atmosphere is a semidiurnal one. The full analysis that we have performed yields the result that ozone absorption alone provides 60 per cent of the observed semidiurnal pressure fluctuations at ground level with maxima occurring within an hour of the observed times (and thereby having approximately correct phase). Similar agreement is obtained for all altitudes for which reliable experimental results are available.

Naturally we cannot expect all the observed oscillations to come from the one effect discussed here. Other absorption effects must contribute to the oscillations. The total amount of energy absorbed at low altitudes by water vapor

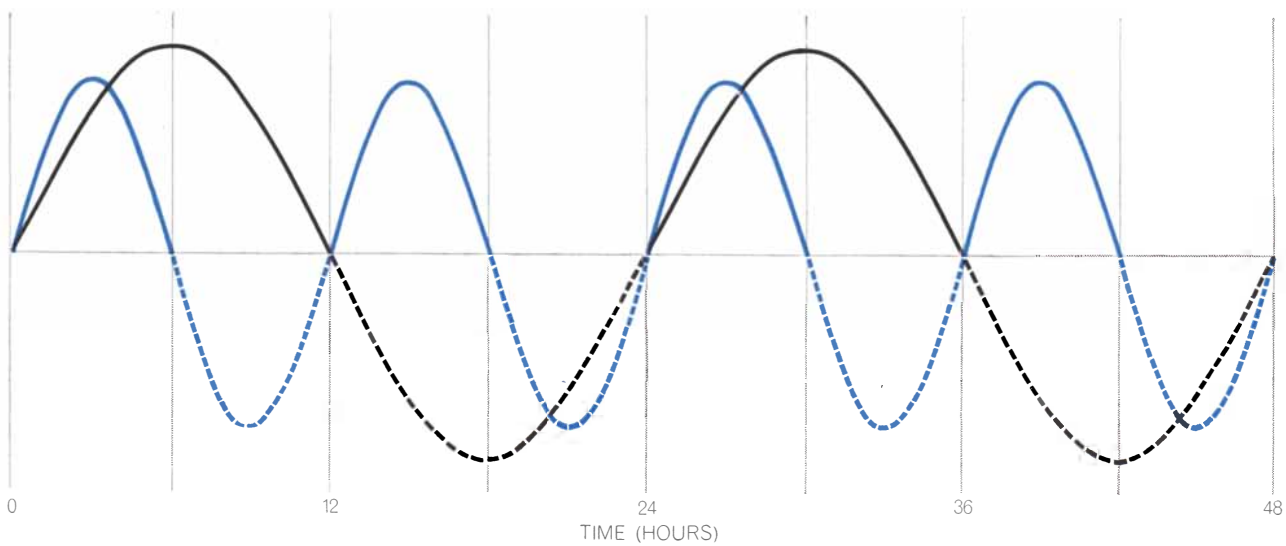
and carbon dioxide is in fact several times greater than that absorbed higher in the ozone. The over-all effect of the absorption, however, seems to be smaller than that of the ozone absorption. The reason, at least for the higher altitudes, is easy to understand. In our model atmosphere, for example, a given output of energy changes the height by an amount inversely proportional to the density. Therefore a given pressure level at higher altitudes will rise much farther when energy is supplied in the ozone region than when it is supplied near ground level, since the density in the ozone band is much smaller than it is at the lower altitudes.

The last word on this subject of atmospheric oscillations has certainly not been spoken, and there is room for considerably more experimental and theoretical effort. One aspect to be understood, for example, is why the diurnal component at ground level is variable, depending somewhat on local weather conditions and geography, whereas the semidiurnal component is remarkably steady. Perhaps the conduction and convection of heat into the atmosphere from the earth's surface—a relatively slow process, with more of a diurnal than a semidiurnal component, and one that would be somewhat dependent on local conditions—is responsible.

In the main, however, it does seem that the tidal oscillations of the atmosphere are due to radiation absorption and that they represent a phenomenon quite different from the ocean tides.



HEAT INTAKE AND OUTPUT of the ozone band as a function of time is depicted diagrammatically. The "Heat gained" curve represents the daytime absorption of ultraviolet light; the "Heat lost" curve, the continuous radiation of energy into space. In the 12 hours of daylight there is a net gain of heat by the atmosphere; but over a 24-hour period heat gained is balanced by heat lost.



"DRIVING FORCE" chiefly responsible for tidal oscillations in the atmosphere is the energy gained by the ozone band when it absorbs ultraviolet light during the day. If the pressure oscillations are analyzed into various components, the fundamental can be represented by a sine wave with a period of 24 hours (*black curve*). The driving force is the upper loop of each wave, or a rectified sine wave: a sine wave with the lower loops (*broken lines*) removed. The first harmonic (*colored curve*) has a period of 12 hours. The amplitude of this harmonic (the semidiurnal component) is almost as great as that of the fundamental (the diurnal component).

The Evolution of the Hand

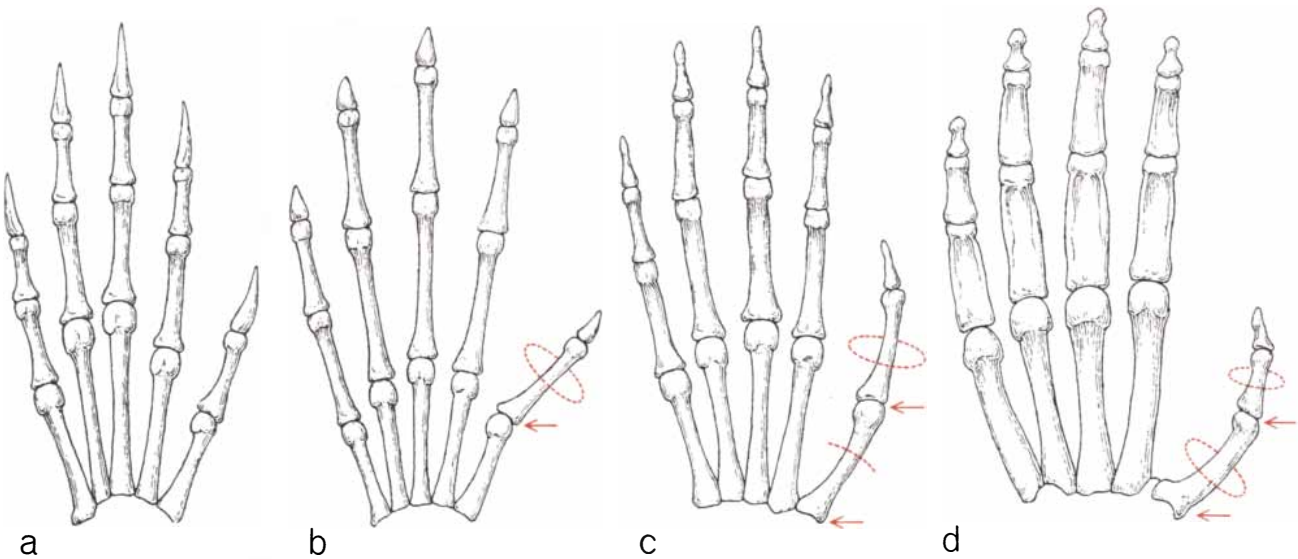
In 1960 tools were found together with the hand bones of a prehuman primate that lived more than a million years ago. This indicates that the hand of modern man has much earlier origins than had been thought

by John Napier

At Olduvai Gorge in Tanganyika two years ago L. S. B. Leakey and his wife Mary unearthed 15 bones from the hand of an early hominid. They found the bones on a well-defined living floor a few feet below the site at which in the summer of 1959 they had excavated the skull of a million-year-old man-ape to which they gave the name *Zinjanthropus*. The discovery of *Zinjanthropus* has necessitated a complete revision of previous views about the cultural and biological evolution of man. The skull was found in association with stone tools and waste flakes indicating that at this ancient horizon toolmakers were already in existence. The floor on which the hand bones were discovered has also yielded stone tools and a genuine bone "lissoir," or leather working tool. Hence this even older living site carries the origins of toolmaking still further back, both in time and evolution, and it is now possible for the first time to reconstruct the hand of the earliest toolmakers.

Research and speculation on the course of human evolution have hitherto paid scant attention to the part played by the hand. Only last year I wrote: "It is a matter of considerable surprise to many to learn that the human hand, which can achieve so much in the field of creative art, communicate such subtle shades of meaning, and upon which the pre-eminence of *Homo sapiens* in the world of animals so largely depends, should constitute, in a structural sense, one of the most primitive and generalized parts of the human body." The implication of this statement, which expresses an almost traditional view, is that the primate forebears of man were equipped with a hand of essentially human form long before the cerebral capacity necessary to exploit its potential had appeared. The corollary to this view is that the difference between the human hand and the monkey hand, as the late Frederic Wood Jones of the Royal College of Surgeons used to insist, is largely one of function rather than structure. Although broadly speaking it is true that the human hand has an extraordinarily generalized structure, the discovery of the Olduvai hand indicates that in a number of minor but nevertheless highly significant features the hand is more specialized than we had supposed.

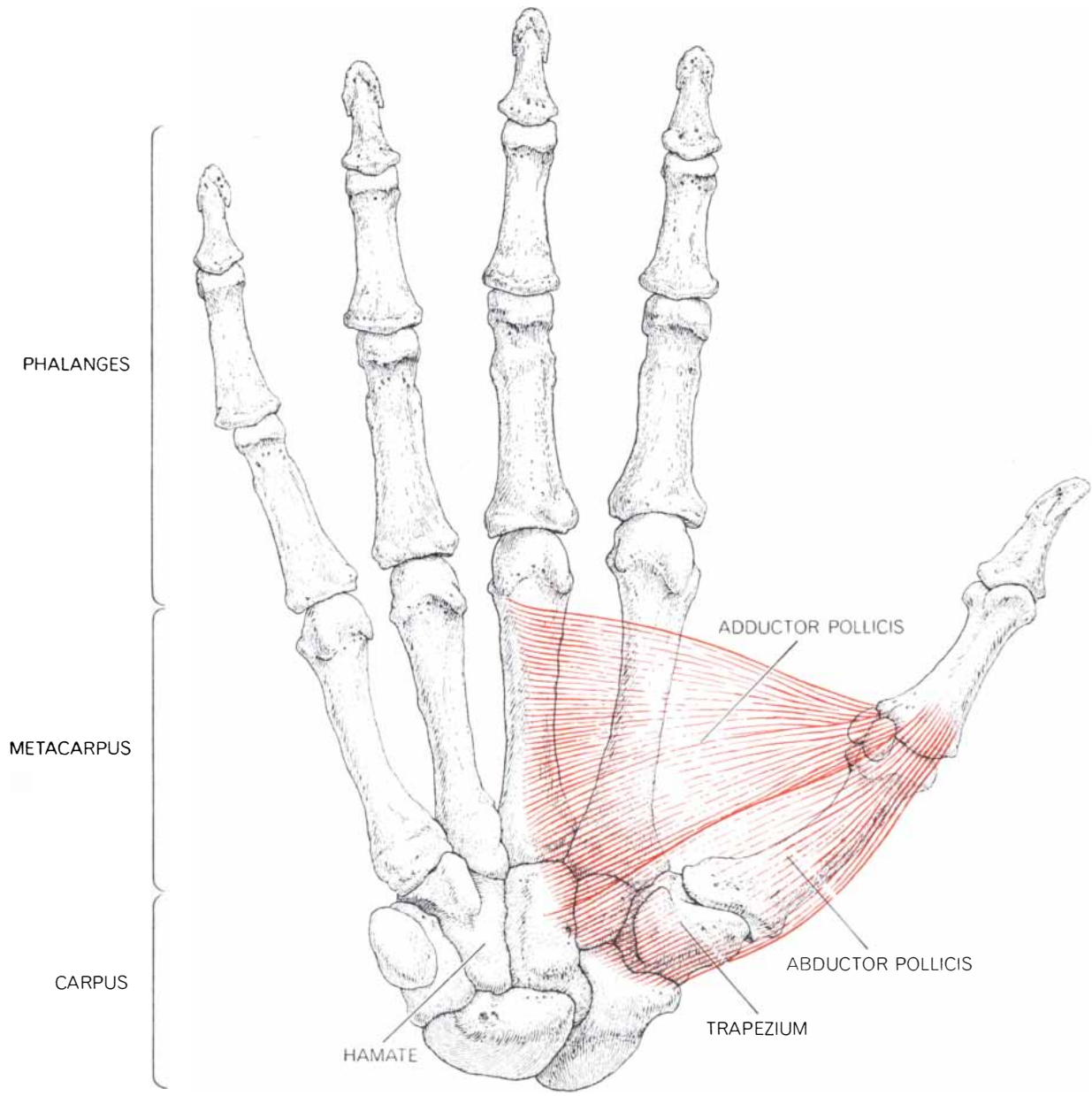
Tool-using—in the sense of improvisa-



HANDS OF LIVING PRIMATES, all drawn same size, show evolutionary changes in structure related to increasing manual dexterity. Tree shrew (*a*) shows beginnings of unique primate possession, specialized thumb (*digit at right*). In tarsier (*b*) thumb is distinct and can rotate around joint between digit and palm. In capuchin monkey (*c*), a typical New World species, angle between thumb and finger is wider and movement can be initiated at joint at base of palm. Gorilla (*d*), like other Old World species, has saddle joint at base of palm. This allows full rotation of thumb, which is set at a wide angle. Only palm and hand bones are shown here.

tion with naturally occurring objects such as sticks and stones—by the higher apes has often been observed both in the laboratory and in the wild and has even been reported in monkeys. The making of tools, on the other hand, has been regarded as the major breakthrough in human evolution, a sort of status symbol that could be employed to distinguish the genus *Homo* from the rest of the primates. Prior to the discovery of *Zinjanthropus*, the South African man-apes (Australopithecines) had been associated at least indirectly with fabricated tools. Observers were reluctant to credit the man-apes with being toolmakers, however, on the ground that they lacked an adequate cranial capacity. Now that hands as well as skulls have been found at the same site with undoubted tools, one can begin to correlate the evolution of the hand with the stage of culture and the size of the brain. By the same token one must also consider whether the transition from tool-using to toolmaking and the subsequent improvement in toolmaking techniques can be explained purely in terms of cerebral expansion and the refinement of peripheral neuromuscular mechanisms, or whether a peripheral factor—the changing form of the hand—has played an equally important part in the evolution of the human species. And to understand the significance of the specializations of the human hand, it must be compared in action—as well as in dissection—with the hands of lower primates.

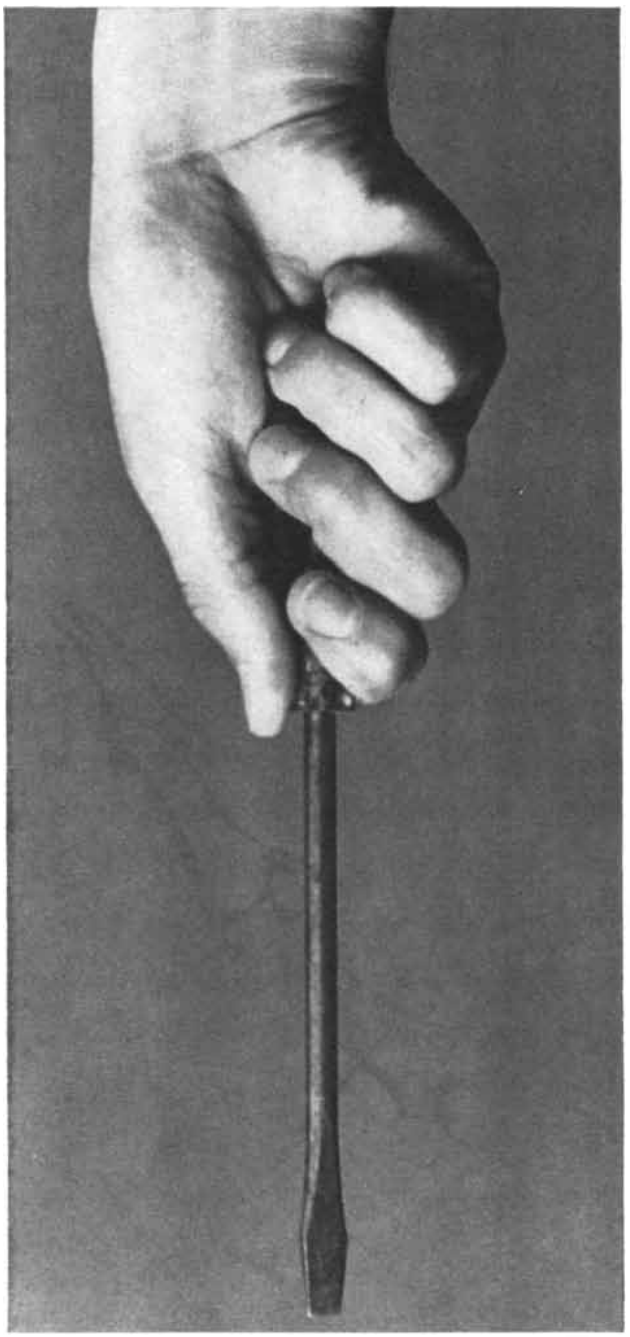
In the hand at rest—with the fingers slightly curled, the thumb lying in the plane of the index finger, the poise of the



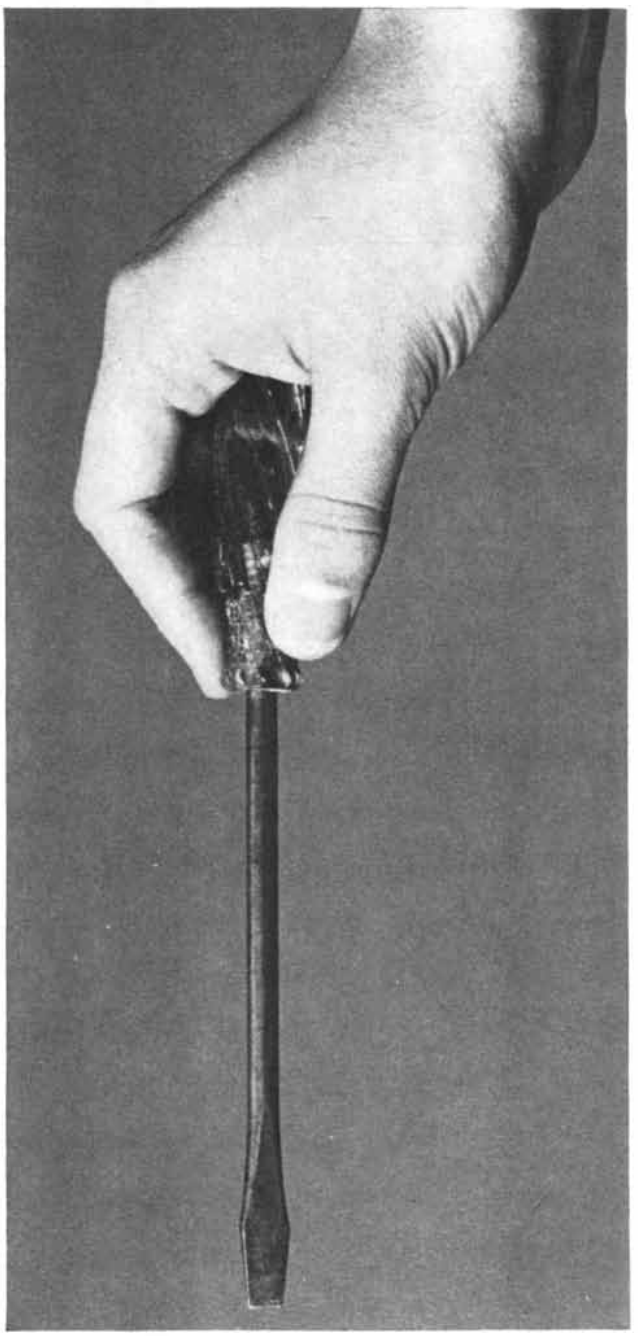
HAND OF MODERN MAN, drawn here actual size, is capable of precise movements available to no other species. Breadth of terminal phalanges (end bones of digits) guarantees secure thumb-to-finger grip. Thumb is long in proportion to index finger and is set at very wide angle. Strong muscles (*adductor pollicis* and *abductor pollicis*) implement movement of thumb toward and away from palm. Saddle joint at articulation of thumb metacarpal (a bone of the palm) and trapezium (a bone of the carpus, or wrist) enables thumb to rotate through 45 degrees around its own longitudinal axis and so be placed in opposition to all the other digits.

whole reflecting the balanced tension of opposing groups of muscles—one can see something of its potential capacity. From the position of rest, with a minimum of physical effort, the hand can assume either of its two prehensile working postures. The two postures are demonstrated in sequence by the employment of a screw driver to remove a screw solidly embedded in a block of wood [*see illustration below*]. The hand first grips the tool between the flexed fingers and the palm with the thumb reinforcing the pressure of the fingers; this is the "power grip." As the screw comes loose, the hand grasps the tool between one or more fingers and the thumb, with the pulps, or inner surfaces, of the finger and thumb tips fully opposed to one another; this is the "precision grip." Invariably it is the nature of the task to be performed, and not the shape of the tool or object grasped, that dictates which posture is employed. The power grip is the grip of choice when the full strength of the hand must be applied and the need for precision is subordinate; the precision grip comes into play when the need for power is secondary to the demand for fine control.

The significance of this analysis becomes apparent when the two activities are correlated with anatomical structure. The presence or absence of these structural features in the hands of a lower primate or early hominid can then be



POWER GRIP is one of two basic working postures of human hand. Used when strength is needed, it involves holding object between flexed fingers and palm while the thumb applies counterpressure.

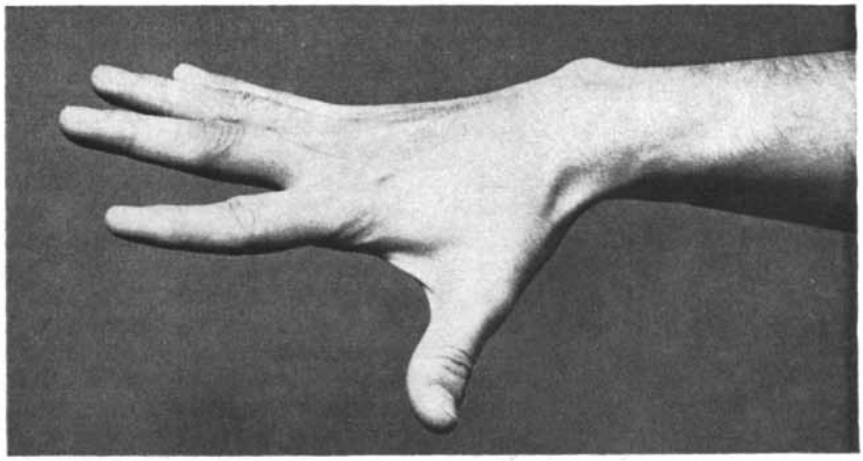


PRECISION GRIP is second basic working posture and is used when accuracy and delicacy of touch are required. Object is held between tips of one or more fingers and the fully opposed thumb.

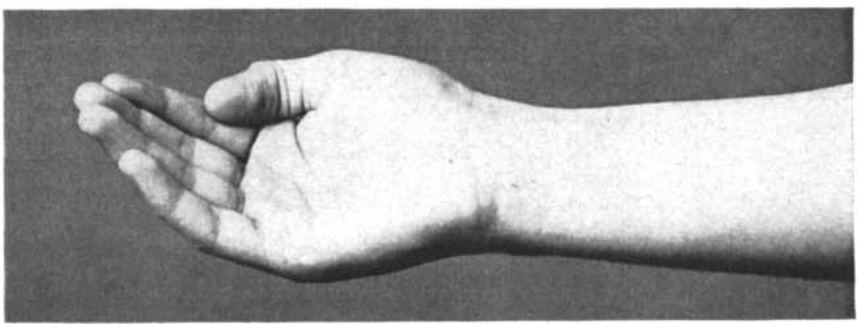
taken to indicate, within limits, the capabilities of those hands in the cultural realm of tool-using and toolmaking. In the case of the hand, at least, evolution has been incremental. Although the precision grip represents the ultimate refinement in prehensility, this does not mean that more primitive capacities have been lost. The human hand remains capable of the postures and movements of the primate foot-hand and even of the paw of the fully quadrupedal mammal, and it retains many of the anatomical structures that go with them. From one stage in evolution to the next the later capability is added to the earlier.

The study of primate evolution is facilitated by the fact that the primates now living constitute a graded series representative of some of its principal chapters. It is possible, at least, to accept a study series composed of tree shrews, tarsiers, New World monkeys, Old World monkeys and man as conforming to the evolutionary sequence. In comparing the hands of these animals with one another and with man's, considerable care must be taken to recognize specializations of structure that do not form part of the sequence. Thus the extremely specialized form of the hand in the anthropoid apes can in no way be regarded as a stage in the sequence from tree shrew to man. The same objection does not apply, however, to certain fossil apes. The hand of the Miocene ancestral ape *Proconsul africanus* does not, for example, show the hand specializations of living apes and can legitimately be brought into the morphological sequence that branches off on the man-ape line toward man.

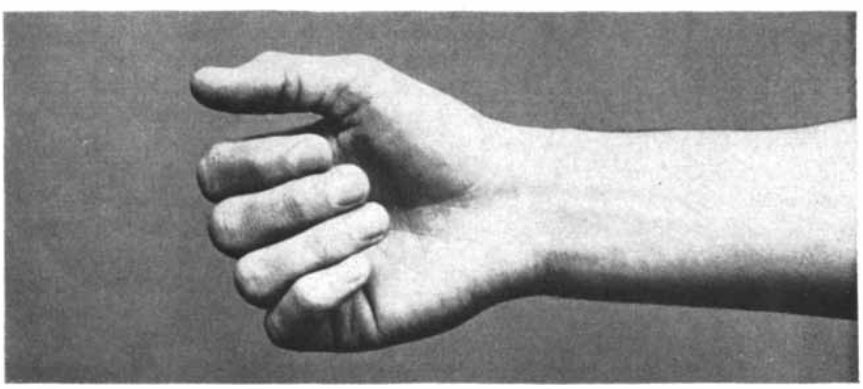
In the lowliest of the living primates —the tree shrew that inhabits the rain forests of the East Indies and the Malay Archipelago—the hand is little more than a paw. It exhibits in a primate sense only the most rudimentary manual capability. This is the movement of convergence that brings the tips of the digits together by a flexion of the paw at the metacarpophalangeal joints, which correspond in man to the knuckles at the juncture of the fingers and the rest of the hand. The opposite movement—divergence—fans the digits outward and is related to the pedal, or weight-bearing, function of the paw. With its paws thus limited the tree shrew is compelled to grasp objects, for example its insect prey, in two-handed fashion, two convergent paws being the functional equivalent of a prehensile hand. For purposes of locomotion in its arboreal



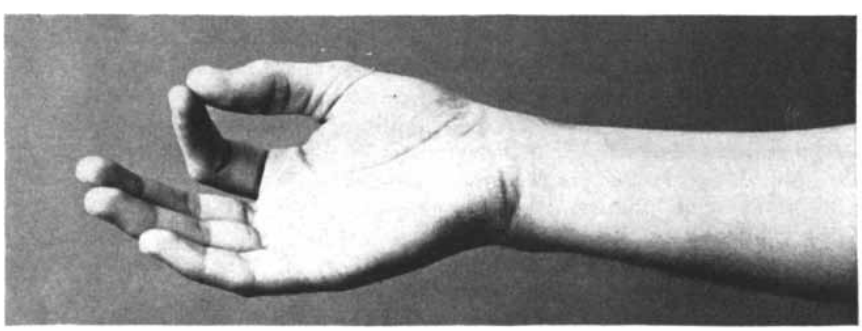
DIVERGENCE, generally associated with weight-bearing function of hand, is achieved by extension at the metacarpophalangeal joints. All mammalian paws are capable of this action.



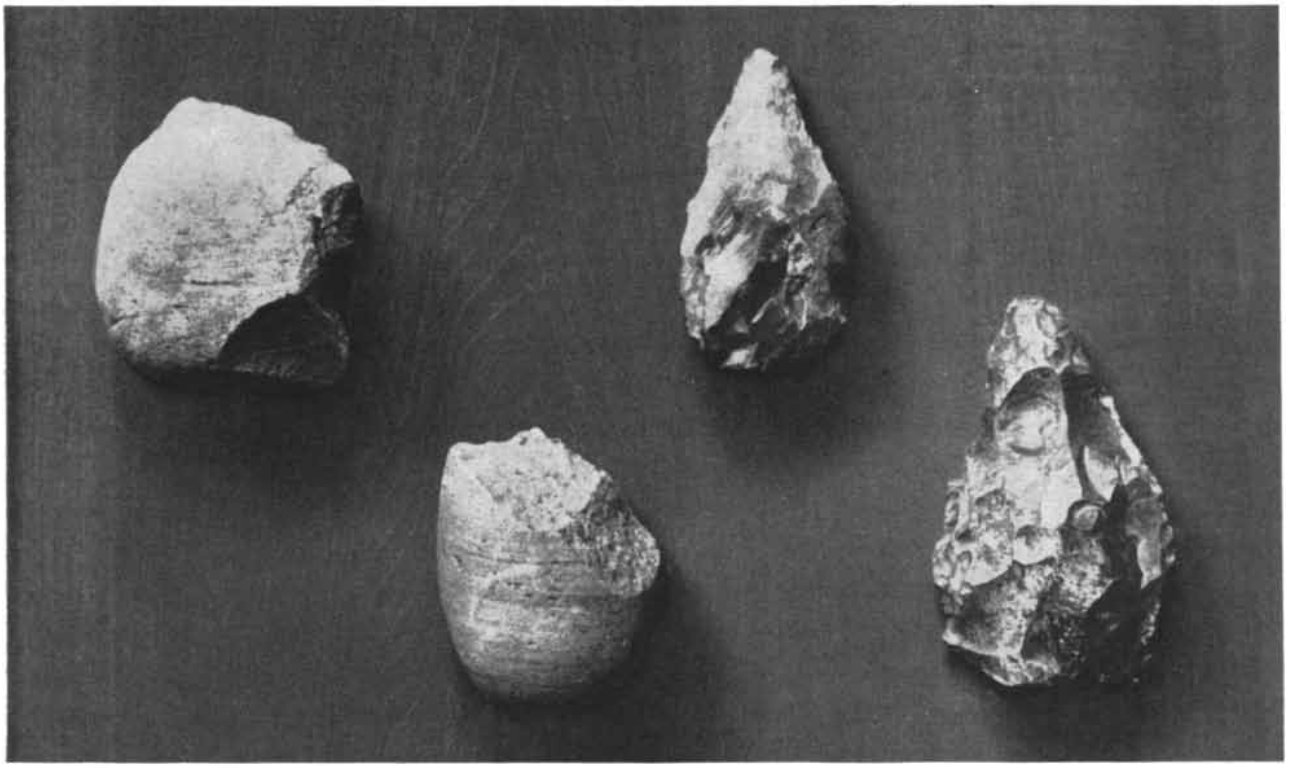
CONVERGENCE is achieved by flexion at metacarpophalangeal joints. Two convergent paws equal one prehensile hand; many mammals hold food in two convergent paws to eat.



PREHENSILITY, the ability to wrap the fingers around an object, is a special primate characteristic, related to the emergence of the specialized thumb during evolutionary process.



OPPOSABILITY is ability to sweep thumb across palm while rotating it around its longitudinal axis. Many primates can do this, but underlying structures are best developed in man.



STONE TOOLS to left of center are similar to those found at Olduvai Gorge, Tanganyika, in conjunction with the hand bones of an early hominid. Such crude tools can be made by using the power grip, of which the Olduvai hand was capable. Finely flaked Old Stone Age tools at right can be made only by using the precision grip, which may not have been well developed in Olduvai hand.

habitat, this animal does not require prehensility because, like the squirrel, it is small, it has claws on the tips of its digits and is a tree runner rather than a climber. Even in the tree shrew, however, the specialized thumb of the primate family has begun to take form in the specialized anatomy of this digit and its musculature. Occasionally tree shrews have been observed feeding with one hand.

The hand of the tarsier, another denizen of the rain forests of the East Indies, exhibits a more advanced degree of prehensility in being able to grasp objects by bending the digits toward the palm. The thumb digit also exhibits a degree of opposability to the other digits. This is a pseudo opposability in that the movement is restricted entirely to the metacarpophalangeal joint and is therefore distinct from the true opposability of man's thumb. The movement is facilitated by the well-developed abductor and adductor muscles that persist in the hands of the higher primates. With this equipment the tarsier is able to support its body weight on vertical stems and to grasp small objects with one hand.

The tropical rain forests in which these animals live today are probably not very different from the closed-canopy forests of the Paleocene epoch of some 70 million years ago, during which the first primates appeared. In the wide variety of habitats that these forests provide, ecologists distinguish five major strata, superimposed like a block of apartments. From the top down these are the upper, middle and lower stories (the last being the main closed canopy), the shrub layer and the herb layer on the ground. To these can be added a sixth deck: the subterrain. In the emergence of prehensility in the primate line the three-dimensional arrangement of this system of habitats played a profound role. Prehensility is an adaptation to arboreal life and is related to climbing. In animals that are of small size with respect to the branches on which they live and travel, such as the tree shrew, mobility is not hampered by lack of prehensility. They can live at any level in the forest, from the forest floor to the tops of the tallest trees, their stability assured by the grip of sharp claws and the elaboration of visual and cerebellar mechanisms.

The tree-climbing as opposed to the tree-running phase of primate evolution may not have begun until the middle of the Eocene, perhaps 55 million years ago. What environmental pressure brought about this adaptation can only be guessed at. Thomas F. Barth of the University of Chicago has suggested that the advent of the widely successful order of rodents in the early Eocene may have led to the displacement of the primates from the shrub strata to the upper three strata of the forest canopy. In any case little is known about the form of the primates that made this transition.

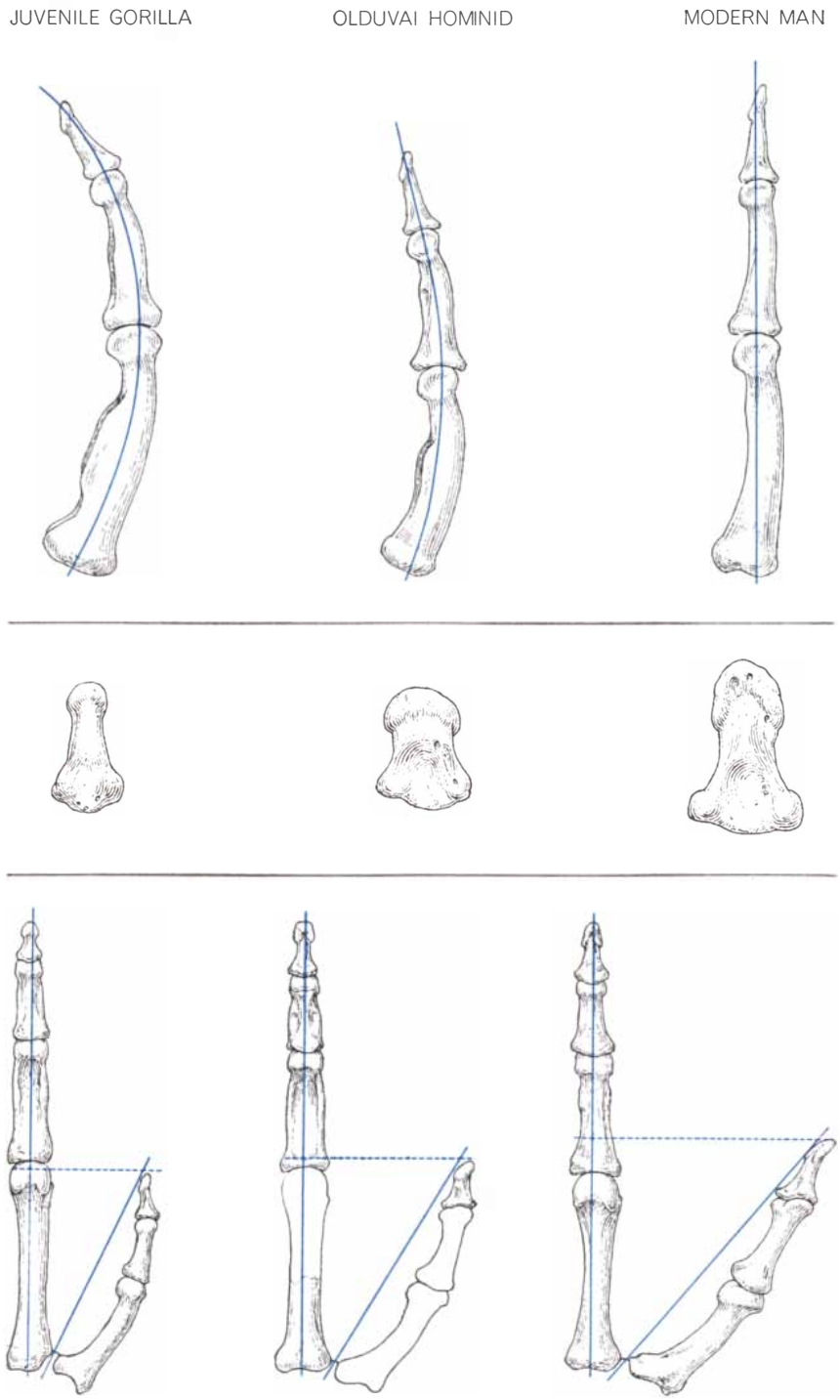
In *Proconsul*, of the early to middle Miocene of 20 million years ago, the fossil record discloses a fully developed tree-climbing primate. His hand was clearly prehensile. His thumb, however, was imperfectly opposable. Functionally this hand is comparable to that of some of the living New World monkeys.

True opposability appears for the first time among the living primates in the Old World monkeys. In these animals the carpometacarpal joint shows a well-developed saddle configuration comparable to that in the corresponding joint of the human hand. This allows rotation of the thumb from its wrist articulation. Turning about its longitudinal axis through an angle of about 45 degrees, the thumb can be swept across the palm, and the pulp of the thumb can be directly opposed to the pulp surfaces of one of or all the other

digits. This movement is not so expertly performed by the monkeys as by man. At the same time, again as in man, a fair range of movement is retained at the metacarpophalangeal joint, the site of pseudo opposability in the tarsier.

The hands of anthropoid apes display many of these anatomical structures but do not have the same degree of functional capability. This is because of certain specializations that arise from the fact that these apes swing from trees by their hands. Such specializations would seem to exclude the apes from the evolutionary sequence that leads to man. In comparing the hand of monkeys with the hand of man one must bear in mind an obvious fact that is all too often overlooked: monkeys are largely quadrupedal, whereas man is fully bipedal. Variations in the form of the hand from one species of monkey to the next are related to differences in their mode of locomotion. The typical monkey hand is rather long and narrow; the metacarpal, or "palm," bones are short compared with the digits (except in baboons); the terminal phalanges, or finger-tip bones, are slender and the tips of the fingers are consequently narrow from side to side. These are only the most obvious differences between the foot-hand of the Old World monkey and that of man. They serve nonetheless to show how too rigid an application of Frederic Wood Jones's criterion of morphological similarity can mislead one into assuming that the only important difference between the hands of men and monkeys lies in the elaboration of the central nervous system.

It seems likely that the terrestrial phase of human evolution followed on the heels of *Proconsul*. At that time, it is well known, the world's grasslands expanded enormously at the expense of the forests. By the end of the Miocene, 15 million years ago, most of the prototypes of the modern plains-living forms had appeared. During this period, apparently, the hominids also deserted their original forest habitats to take up life on the savanna, where the horizons were figuratively limitless. Bipedal locomotion, a process initiated by life in the trees and the ultimate mechanism for emancipation of the hands, rapidly followed the adoption of terrestrial life. The use of the hands for carrying infants, food and even weapons and tools could not have lagged far behind. As Sherwood L. Washburn of the University of California has suggested on the basis of observations of living higher primates, tool-using must have appeared at an early stage in hominid evolution. It is a very short step from tool-using to tool-modifying, in the sense of stripping twigs and leaves from a branch in order to improve its effectiveness as a tool or weapon. It is an equally short further step to toolmaking, which at its most primitive is simply the application of the principle of modification to a stick, a stone or a bone. Animal bones are a convenient source of tools; Raymond A. Dart of the University of Witwatersrand in South Africa has advanced the hypothesis that such tools



HAND BONES of juvenile gorilla, Olduvai hominid and modern man are compared. Phalanges (*top row*) decrease in curvature from juvenile gorilla to modern man. Terminal thumb phalanx (*middle row*) increases in breadth and proportional length. Third row shows increase in length of thumb and angle between thumb and index finger. Olduvai bones in outline in third row are reconstructed from other evidence; they were not found.

CHIMPANZEE, attempting to grasp experimenter's finger, uses an inefficient precision grip. Because animal's thumb is so short in proportion to the digits, it is compelled to bend the digits forward and grasp the object between the sides of index finger and thumb.

were used by early man-apes as part of an "osteodontokeratic" (bone-tooth-hair) culture.

The tools from the pre-*Zinjanthropus* stratum at Olduvai Gorge are little more than pebbles modified in the simplest way by striking off one or more flakes to produce a chopping edge. This technology could not have required either a particularly large brain or a hand of modern human proportions. The hand bones of the pre-*Zinjanthropus* individuals uncovered by the Leakeys in their more recent excavation of Olduvai Gorge are quite unlike those of modern *Homo sapiens*. But there seems to be no reason, on either geological or anthropological grounds, for doubting that the tools found with them are coeval. Modern man must recover from his surprise at the discovery that hands other than his own were capable of shaping tools.

At this point it may be useful to return to the analysis of the manual capability of modern man that distinguishes the power and the precision grip. When compared with the hand of modern man, the Olduvai hand appears to have been capable of a tremendously strong power grip. Although it was a smaller hand, the relative lengths of the metacarpals and phalanges indicate that the proportion of digits and palm was much the same as it is in man. In addition, the tips of the terminal bones of all the Olduvai fingers are quite wide and the finger tips themselves must therefore have been broad—an essential feature of the human grip for both mechanical and neurological reasons. The curvature of the metacarpals and phalanges indicates that the fingers were somewhat curved throughout their length and were normally held in semiflexion. Unfortunately no hamate bone was found among the Olduvai remains. This wristbone, which articulates with the fifth metacarpal, meets at a saddle joint in modern man and lends great stability to his power grip.

It seems unlikely that the Olduvai hand was capable of the precision grip in its fullest expression. No thumb metacarpal was found in the Olduvai deposit; hence any inference as to the length of the thumb in relation to the other fingers must be derived from the evidence of the position of the wristbone with which the thumb articulates. This evidence suggests that the Olduvai thumb, like the thumb of the gorilla, was set at a narrower angle and was somewhat shorter than the thumb of modern man, reaching only a little beyond the metacarpophalangeal joint of the index finger. Thus, although the thumb was opposable, it can be deduced that the Olduvai hand could not perform actions as precise as those that can be undertaken by the hand of modern man.

Nonetheless, the Olduvai hand activated by a brain and a neuromuscular mechanism of commensurate development would have had little difficulty in making the tools that were found with it. I myself have made such pebble tools employing only the power grip to hold and strike two stones together.

The inception of toolmaking has hitherto been regarded as the milestone that marked the emergence of the genus *Homo*. It has been assumed that this development was a sudden event, happening as it were almost overnight, and that its appearance was coincidental with the structural evolution of a hominid of essentially modern human form and proportions. It is now becoming clear that this important cultural phase in evolution had its inception at a much earlier stage in the biological evolution of man, that it existed for a much longer period of time and that it was set in motion by a much less advanced hominid and a much less specialized hand than has previously been believed.

For full understanding of the subsequent improvement in toolmaking over the next few hundred thousand years of the Paleolithic, it is necessary to document the transformation of the hand as well as of the brain. Attention can now also be directed toward evidence of the functional capabilities of the hands of early man that is provided by the tools they made. These studies may help to account for the radical changes in technique and direction that characterize the evolution of stone implements during the middle and late Pleistocene epoch. The present evidence suggests that the stone implements of early man were as good (or as bad) as the hands that made them.

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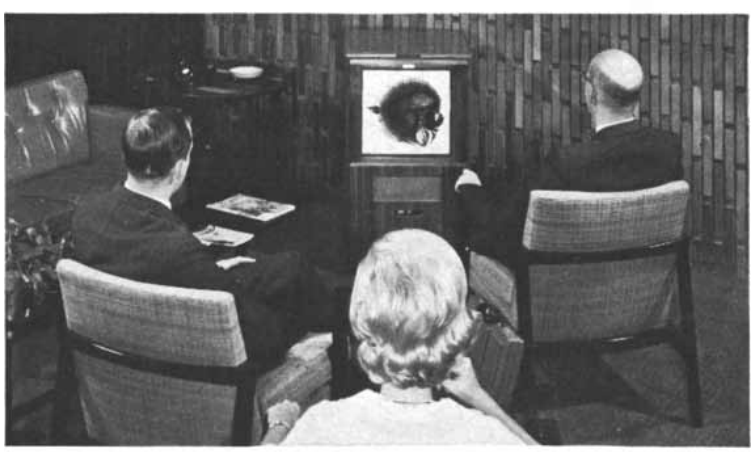
Let the snickers cease. With a modulated electron beam playing directly on this humble outcome of the efforts of cowboys and silver miners, stronger reasons begin to unfold for speaking of modulation transfer characteristics. The modulation, indeed, seems to get itself transferred a great deal better this way than the old way. In fact, the monkey now rides on the electronics to generate as much as the photography can take.

We peddle no hardware for this and can therefore talk freely with would-be hardware peddlers and their prospective customers. We wish to tell them we have looked into it deeply enough to know

- that conventional medium-speed film such as you used to take along on camping trips before you switched to color can, when recording with electrons, resolve detail considerably smaller than 5μ;
- that we can make a film for which the modulation transfer level remains above 50% out to 355 cycles/mm, which corresponds to nearly 65 megacycles in TV 16mm format;
- that a high-resolution film (far too slow to consider for the light available from a phosphor screen), when exposed to an electron beam of low current at little more than half the accelerating potential customary in c-r tubes, gives far more resolution and far less graininess than can be expected of the medium or fast films that the phosphor screens need;
- that freedom from the graininess and other imperfections of the phosphor screens themselves is beautiful;
- that no harsh remarks should be uttered about the lenses that image phosphor screens on film because, until some practical equipment appears on the market for the new direct-electron technique, a lot of people will want to write to Eastman Kodak Company, Apparatus and Optical Division, Rochester 4, N. Y. for details and prices on what we believe to be the sharpest lenses for the purpose in the world.

For further information on the new technique, write Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y.



Two problems are being solved here in one swell foop. Problem No. 1: What further benefits can be realized from the reception room besides serving as a setting for display of the most charming girl that Personnel has been able to find? Problem No. 2: What further benefits can be realized from all those KODACHROME slides that chronicle the organization's activities?

That's not a TV. It's an instance of somebody (Lester A. Dine Co., 102 Jericho Turnpike, Floral Park, N.Y., to be precise) buying one of our products (the KODAK CAROUSEL Projector, to be precise) and doing something smart with it. Inside this fine walnut cabinet the projector shows 80 slides automatically and a tape machine plays a commentary along with them. $550 complete, they tell us.

Electric sugar, $5 per lb.

A mighty industry breaks down the sugar molecule in the interests of conviviality. Use of the sugar molecule as a base for further building is little practiced, except by us. (We do it in the northeast corner of a state which respects the venerable craft that works the other way.)

And what is achieved thereby?

A high dielectric constant, a large increase in the capacitance of an electrical condenser compared with when there is nothing between the plates.

Obviously, the manufacturers of capacitors and of electroluminescent panels have had to be notified. We find them interested and alert.

We divert a little sucrose from coffee breaks and react it with acrylonitrile, forming a clear, viscous liquid designated *Cyanoethyl Sucrose* in which a statistical 7.3 of the 8 available hydroxyls are replaced by OC_2H_4CN groups. At 60 cycles this substance has a dielectric constant of 38 and competes with other cyanoethylated dielectrics at 11-19 and with chlorinated aromatic hydrocarbons at 4-6. (The dielectric constant of water runs around 80, but water is such watery stuff!)

Other invidious comparisons:

	Cyanoethyl Sucrose	other cyanoethylated dielectrics	chlorinated aromatics
cost per lb.	$5 (development)	$12-$27	15c-25c
dissipation factor (25°C, 60 cycles)	0.010	0.17-2.7	< 0.1
volume resistivity (25°C, ohm-cm)	5×10^{11}	$3\text{-}6 \times 10^{9}$	$> 5 \times 10^{12}$

Request an 8-ounce sample of Cyanoethyl Sucrose and a data sheet from Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company).

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

EACH OF THESE JOBS
IS DONE BETTER WITH NATURAL DIAMONDS

The grinding and polishing jobs on these pages are being performed on carbide steel, case-hardened steel and alumina ceramic. Yet they share one important detail: in every instance, natural diamonds are doing the job quickly—and economically.

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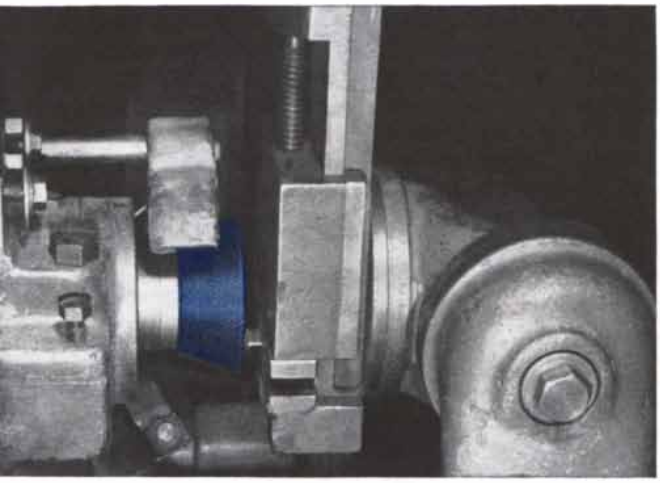
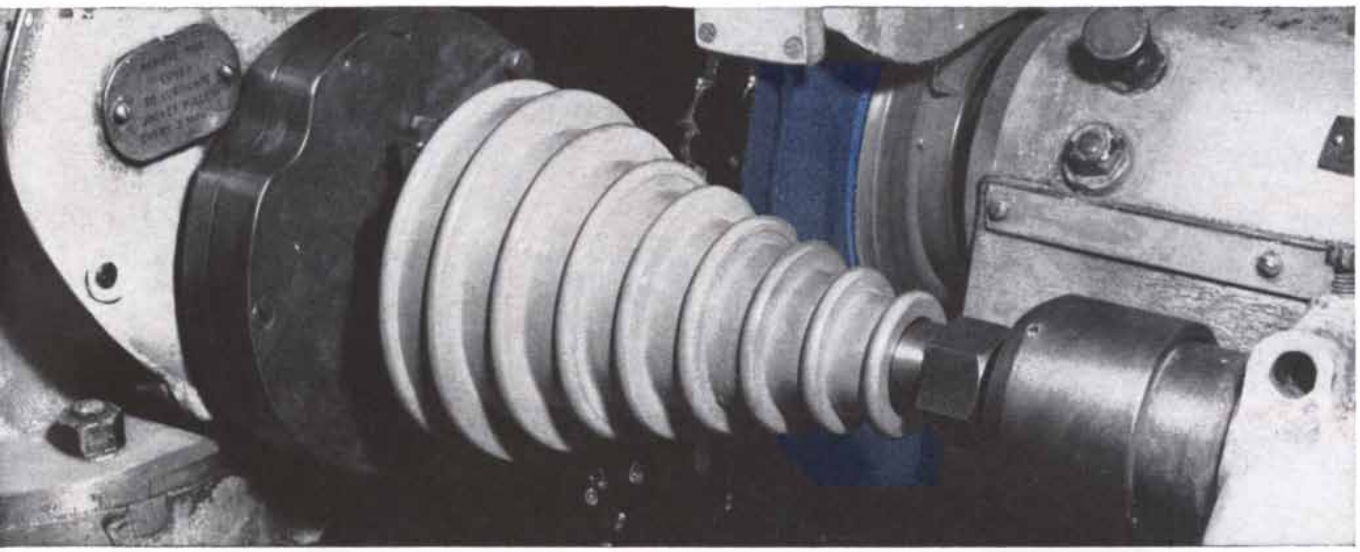
World's leading supplier of diamonds for industry

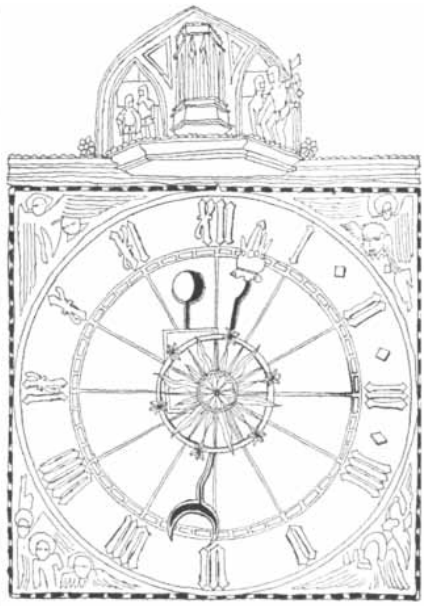
Carbide tool tips are ground and finished with two diamond wheels at Borg-Warner, Ltd., Hartfordshire, England. Right: rough grinding is done with coarse-grit (150-mesh) natural-diamond wheel. As much as .010 inch is removed in a pass without coolant. Far right: after tip is cleaned of scarred surface, new chipbreaker is ground into its face with periphery-type natural-diamond wheel. For fine finishes, a conventional diamond-impregnated resin-bond wheel is used.

Sintered alumina ceramic step cones, used in wire drawing, are precision finished with natural-diamond wheels at Royal Worcester Industrial Ceramics, Ltd., Glamorgan, South Wales, England. Each step is ground to within .003-inch specified diameter, and to within .001-inch concentricity with the steel bore of the cone. Each step has a 1-degree taper toward the large end of the cone. A 12-inch metal-bond diamond wheel with 1-inch face is used. Wheel speed: 4000 surface feet per minute. Cone revolves at 55 rpm.

Case-hardened steel ways (Rockwell C60) are diamond-lapped to achieve accuracy of .000030 inch at Moore Special Tool Co., Bridgeport, Conn. Ways for tables of jig borers, jig grinders and measuring machines are ground to conventional tolerances, then lapped both mechanically and by hand with 13-M natural-diamond paste until extremely close tolerances are achieved.







The Nobel Prizes

The 1962 Nobel prize in physiology and medicine was shared by James Dewey Watson, 34, of Harvard University, Francis H. C. Crick, 46, of the University of Cambridge and Maurice H. F. Wilkins, 46, of King's College of the University of London. They were honored for experimental and theoretical studies elucidating the structure of deoxyribonucleic acid (DNA), the genetic material of the living cell.

In the early 1950's Wilkins succeeded in pulling a fiber from a viscous gel of DNA. Suspecting that the fiber might have an ordered, or crystalline, structure, he examined it by X-ray diffraction. The result was a series of complex patterns on photographic plates that indicated the angles between the principal constituent atoms and provided clues to their spatial arrangement.

In 1953, largely on the basis of Wilkins' data, Watson and Crick published in *Nature* a paper that opened with disarming simplicity: "We wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest." The paper went on to describe the now famous molecular model in which DNA is depicted as a two-strand helix, much like a spiral staircase, with cross links, or "treads," consisting of pairs of four different bases [see "The Structure of the Hereditary Material," by F. H. C. Crick; SCIENTIFIC AMERICAN, October, 1954]. The most striking feature of the model was the postulate that the bases always enter the molecule in complementary pairs: adenine linked to thymine and guanine to cytosine. This implied that one half of the helix contained all the information needed for the construction of the other half. If it could be shown that the sequence of bases attached to one strand of DNA constituted a genetic code, one could see for the first time how the code might be replicated and passed on from generation to generation. The correctness of the Watson-Crick model was subsequently confirmed in all essential details and, within the past year, remarkable progress has been made in deciphering the genetic code itself [see "The Genetic Code," by F. H. C. Crick; SCIENTIFIC AMERICAN, October].

The prize in chemistry was given to Max Ferdinand Perutz, 48, and John Cowdery Kendrew, 45, both of the Cavendish Laboratory at the University of Cambridge, who worked together and then independently to map the structure of complex globular proteins. Born in Vienna, Perutz left Austria at the accession of the Nazis in 1936 and went to Cambridge. There he received his doctorate in 1940. He was just beginning to study the structure of hemoglobin when he was diverted into war work. After the war Perutz returned to the hemoglobin problem and was soon made chairman of the Medical Research Council Laboratory of Molecular Biology at Cambridge.

The problem tackled by Perutz was formidable. Hemoglobin, the oxygen-bearing protein in blood, is made up of some 600 amino acid units, which form an intricate three-dimensional pattern encapsulating four heme groups, each containing an atom of iron. In all the molecule contains more than 10,000 atoms. To obtain clues to their position Perutz beamed X rays at hemoglobin crystals and recorded the patterns of the reflected rays, much as Wilkins had done for DNA. The immediate objectives of the two studies, however, were quite different. The smallest DNA molecules, such as those found in viruses, contain at least 1,000 times more atoms than the hemoglobin molecule does, and the base sequence in DNA is different for every organism. In other words, DNA is not a single substance but virtually an infinity of substances, slightly different for every living organism.

THE CITIZEN

Hemoglobin, however, is a specific chemical substance in which the arrangement of atoms varies only slightly from species to species (and only negligibly from individual to individual). Perutz, therefore, could hope to fix the precise location of each of its 600-odd amino acid subunits. Unfortunately there seemed to be no way to decipher the X-ray diffraction patterns produced by some 10,000 atoms arranged asymmetrically. Finally, in 1953, Perutz conceived the idea of attaching heavy atoms, such as mercury and gold, to certain positions in the hemoglobin molecule. The presence of the heavy elements changed the diffraction pictures greatly and provided the means for cracking the problem.

Meanwhile, at Perutz' suggestion, Kendrew began studying the structure of myoglobin, a junior relative of hemoglobin found in muscle, where it acts as a temporary storehouse for oxygen that has been delivered by hemoglobin. Myoglobin is only about a quarter the size of hemoglobin and is composed of about 150 amino acid units tied to a single heme group. Using a modification of Perutz' labeling method, Kendrew made "a formidable number" of diffraction pictures of myoglobin, and a team of six associates worked many months measuring tens of thousands of reflection angles, which were fed into a high-speed electronic computer. Out of all this came the data for constructing an elaborate model of myoglobin [see "The Three-dimensional Structure of a Protein Molecule," by John C. Kendrew; SCIENTIFIC AMERICAN, December, 1961]. Myoglobin turns out to have a structure closely resembling that of each of the four chains that together constitute hemoglobin.

The prize in physics went to Lev Davidovich Landau, 54, long regarded as the leading theoretical physicist in the U.S.S.R. Since 1937 Landau has been head of the theoretical section of the Institute for Physical Problems in Moscow. The fourth Soviet citizen to win a Nobel prize in physics, he was cited for "pioneering theories for condensed matter, especially liquid helium."

The award came at a time of personal tragedy for Landau. Last January he was gravely injured when his automobile skidded on an icy road, and he re-

mained unconscious for many months. According to Soviet sources he was "clinically dead" several times, but each time he responded to special treatment. Although he is improving slowly, it is reported that he has not fully recovered his memory and that it is doubtful he can travel to Stockholm to receive his award.

Landau has written more than 100 scientific papers and 10 textbooks, including four written in collaboration with Eugene M. Lifshitz that have been translated into English and are widely used in U.S. universities. In 1940 and 1941 Landau advanced an elaborate theoretical explanation for the strange behavior of helium II [see "Superfluidity," by Eugene M. Lifshitz; SCIENTIFIC AMERICAN, June, 1958]. Helium II is the name given to liquid helium that has been cooled to within 2.2 degrees centigrade of absolute zero, when the liquid undergoes a dramatic change in behavior and becomes a "superfluid." Helium II flows through tiny capillaries without apparent resistance and climbs over the walls of open containers. It also conducts heat about 200 times more readily than copper does at room temperature.

Landau was able to show that helium II demonstrates on the macroscopic scale some of the improbable behavior normally found only in events taking place on the atomic and subatomic scale. Such events find their explanation in quantum theory. He made certain predictions about the behavior of helium II that were subsequently confirmed by experiment. One of these predictions was that two different kinds of waves could travel simultaneously through the liquid at two different speeds. It was evident that ordinary sound waves represented one form of wave transmission, but the predicted second kind of wave proved elusive. Finally, in 1944, one of Landau's associates discovered that heat pulses, created by a heater with an oscillating temperature, were transmitted by helium II, thus satisfying the prediction of a second kind of wave propagation. The phenomenon is now called second sound.

Tektite Crater

A pronounced dip in gravity points to what may be a huge meteorite crater, some 150 miles in diameter, beneath the ice of Wilkes Land in the Antarctic. The putative crater lies close to the predicted point of impact for the giant meteorite that has been suggested as the source of the tektites (glassy stones) found in Tasmania and southern Australia.

The gravity measurements were made by the American Victoria Land Traverse, which crossed the southern (poleward) portion of the crater area, and a French expedition from Adélie Land, which covered an area nearer the coast, in 1958 to 1960. When the two sets of records were put together by Richard A. Schmidt of the University of Wisconsin Geophysical and Polar Research Center, they showed a dip, or negative anomaly, of 150 milligals (equivalent to a little more than a ten-thousandth of the average pull of gravity at the earth's surface) at a point near 71 degrees south latitude and 140 degrees east longitude.

Writing in *Science,* Schmidt noted that similar dips in gravity are a feature of known meteorite craters; they are due to depression of the rock surface and the presence of large volumes of pulverized rock, which is less dense and exerts less gravitational pull than solid rock, around the crater. In the area of the Wilkes Land anomaly the American traverse party found, by means of "seismic shooting," a depression in the rock surface beneath the ice large enough to account for a third of the dip. A crater large enough to cover the area of the anomaly could well contain enough fragmented rock to account for the other two-thirds.

If the Wilkes Land anomaly can be proved to be due to a meteorite crater, it will provide support for a thesis advanced by Virgil E. Barnes of the University of Texas [see "Tektites," by Virgil E. Barnes; SCIENTIFIC AMERICAN, November, 1961]. Barnes, among others, has pointed out that most tektites are found not far from large meteorite craters and are probably best explained as having been formed from rock melted and splashed upward by meteorite impact. In the case of the Australian tektites, however, he could find no sign of the crater from which they might have been splashed. Instead, when he plotted their distribution on a map, he found that they formed an arc with a radius of 3,000 to 3,500 miles centering in Wilkes Land. The Wilkes Land anomaly is almost exactly 3,000 miles from southern Australia.

Oldest Fossils

The oldest known unequivocal traces of living matter, the fossil remains of a group of fungi and algae, have now been dated by radioactive techniques as being 1.7 to 2.1 billion years old. The fossils were originally discovered in a Pre-Cambrian formation near Lake Superior in 1954. Patrick M. Hurley and his associates at the Massachusetts In-

stitute of Technology have just completed their study of the radioactivity of the samples and have reported their results in *The Journal of Geology*.

The fossils were found near Schreiber, a town in central Ontario, by Elso S. Barghoorn of Harvard University and Stanley A. Tyler of the University of Wisconsin. They include two primitive species of fungus, a single-celled organism probably belonging to the calcareous flagellates and two types of blue-green alga, the last resembling species still living. Barghoorn and Tyler concluded that they were about two billion years old on geological grounds; there were then no radioactive dating methods for the sedimentary rocks in which the fossils were deposited. Hurley's group was finally able to date the fossils by the potassium-argon and strontium-rubidium procedures.

Confirmation of the age of the Schreiber fossils has pushed back by several hundred million years the known age of life on earth. Still older rocks containing organic carbon have been found. Paleontologists are generally willing to accept only one—a 2.5-billion-year-old sedimentary rock from Southern Rhodesia—as containing what are probably traces of once living cells, but the case is not considered proved.

Buzzing the Queen

The first direct evidence that bees perceive sound and use it as well as "dancing" to communicate was announced recently by Adrian M. Wenner of the University of California at Santa Barbara. Writing in *Science,* Wenner described a conversation he has had with a trapped queen bee in an experimental hive. For his end of the exchange Wenner used a sound generator operating between 600 and 2,000 cycles per second and pulsed to imitate the "piping" of a virgin queen bee: a one-second tone followed by five or more short pulses each lasting less than half a second. The caged queen, which was obtained by mail from another part of the state and put into the hive in its mailing carton, replied with a "quacking" call, a series of short bursts of sound.

To demonstrate that the bee's sound was actually produced in response to his artificial call Wenner had an assistant listen to the queen for 10 seconds a minute for an hour. Thirty times at random during the hour, just before the 10-second listening period, he sent out his piping notes. The queen quacked 24 times out of the 30 instances in which

a message was sent and not at all when there was no transmission.

In the successful experiments the sound generator was placed in contact with one of the supports of the hive and communicated its vibrations directly to the hive material. Although the nature of the bee's sound receptor is not known, it apparently operates only with this type of vibration; when the generator's sound was sent through air, the bee did not respond.

The sound transmitted to the trapped bee was a replica of that recorded from a five-day-old virgin queen that had recently emerged from her cell. The response of the trapped bee, Wenner notes, was the same as that made by a queen that is being forcibly contained in her cell by workers. This situation arises naturally when a colony is raising a new queen. The bees make several queen cells and raise several queens. The first one to mature is let out of her cell, whereas the others are kept in theirs.

Photosynthetic Particle

The structural unit in green plants that converts light into chemical energy has been identified by the Bio-Organic group at the University of California, according to its leader, Melvin Calvin. In a recent talk Calvin described the "quantasome," as the unit has been named, and proposed a theory of its operation.

Quantasomes are visible as tiny particles in electron micrographs of grana: the flat disks of which chloroplasts are composed. (The chloroplast, itself microscopic, is the largest chlorophyll-containing unit in plants.) The quantasomes are about 200 angstrom units in diameter (an angstrom unit is one hundred-millionth of a centimeter) and contain some 200 to 300 molecules of chlorophyll together with protein. By proper mechanical treatment the grana can be broken so as to release whole quantasomes. These are able to absorb light and to carry out some of the steps of photosynthesis. If the quantasomes are broken into smaller pieces, they can no longer do either.

Experiments on free quantasomes have also provided evidence as to the mechanism for converting light energy into chemical energy. When in the light, a preparation of quantasomes absorbs radio waves; in the dark it does not. This demonstrates the existence of unpaired electrons in the material when it is absorbing light energy, and it shows that the light energy is taken up by excited

electrons, an idea that has been gaining acceptance but that had not been directly proved.

Calvin and his associates propose that chlorophyll molecules having light-excited electrons can behave in two ways. Sometimes the chlorophyll donates its excited electron to another substance, where the energy is subsequently transferred to chemical reactions. Sometimes the chlorophyll picks up an electron, filling the level vacated by the light-excited one. Then the positive "hole" in the donor atom carries out the energy transfer. Eventually, according to the theory, the two types of chlorophyll molecule, one of which has gained and one of which has lost an electron, neutralize each other, completing the cycle and making the quantasome again sensitive to light.

Modulated Optical Masers

Three laboratories have independently succeeded in obtaining sharply defined beams of coherent infrared radiation by direct electric excitation of a semiconducting crystal of gallium arsenide. Devices that produce coherent visible and near-visible radiation, in which the emitted waves are all in step, are called optical masers. The devices have great potential value for communications because the higher the frequency of a transmission signal is, the more information it can carry.

The virtue of the new devices is that the input, since it is an electric current, is directly susceptible to modulation. In previous solid-state optical masers the input energy was provided by intense light sources and there seemed to be no simple way to modulate the output radiation at full channel capacity. Although gas optical masers have been built in which the input is an electric current, their efficiency is quite low. The new semiconductor optical masers convert electrons to photons with an efficiency of 100 per cent, and their net operating efficiency should be 50 per cent or more.

One of the new optical masers was announced in the November 1 issue of *Physical Review Letters* by five members of the General Electric Research Laboratory. A similar device was described in the November 1 issue of *Applied Physics Letters* by five members of the International Business Machines Corporation. A third device of the same sort has been developed by members of the Lincoln Laboratory of the Massachusetts Institute of Technology and will be announced shortly.

MATERIAL WITNESSES FOR THE PROSECUTION

A piece of cloth becomes an informer, a blot of ink a formidable witness for the state. Paper, paint, plastics, materials of all kinds become hard-to-discredit evidence when analyzed by spectrometry. Through infrared analysis, for example, the geographic origin of narcotics can be pinpointed by analyzing trace impurities in the parts per million range. Perkin-Elmer has developed highly precise electronic-optical systems that measure and record radiations as they interact with different levels of electron energy. The data recorded leads to extremely accurate qualitative, elemental, functional and structural analyses. Infrared and ultraviolet spectrophotometers are examples of Perkin-Elmer's dedication to the development of techniques and instruments for precise measurement for industry, science and defense. The Perkin-Elmer Corporation, Norwalk, Connecticut.

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Improved safety and new mission capabilities can be added to virtually any aircraft with the new, flight-tested* terrain-following radar developed by General Dynamics|Electronics. Regardless of visibility, aircraft and drones using the compact system can fly ground-hugging penetration missions below enemy radar. Flying manually or automatically at altitudes under 400 feet, equipped aircraft escape detection while the terrain-following radar detects unseen obstacles ahead. The low-cost system also enables pilots to letdown safely through cloud-cover to non-instrumented airports and protects aircraft that drift off course when over unknown terrain at night or during inclement weather. The General

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Dynamics|Electronics equipment requires a minimum of maintenance since the non-scanning antenna approach uses no moving parts. No radar-scope is required either. Instead, a simple indicator provides continuous flight instructions. For information about Terrain Avoidance Radar write Department C-89, General Dynamics|Electronics-San Diego, P.O. Box 127, San Diego 12, California.

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BIOLOGICAL LUMINESCENCE

A remarkable variety of organisms from bacteria to fishes shine by their own light. The light is produced by diverse chemical systems, the best understood of which is the system isolated from fireflies

by William D. McElroy and Howard H. Seliger

The light of fireflies and other luminescent organisms has always charmed human observers. What benefit does the ability to produce light confer on an organism? Is the light completely "cold," that is, is its production 100 per cent efficient? Exactly how is the light produced? In spite of much study, dating back more than a century, these questions cannot be answered completely. But the main steps in the process have been established, its efficiency has been measured and the principal substances involved in it have been identified. With this knowledge in hand it is possible to make a reasonable guess as to how biological luminescence, or bioluminescence, arose in the course of evolution.

Bioluminescence is not only of interest in itself but also provides a sharp tool for studying other biological processes. This has resulted in part from the development of highly sensitive and rapid recording devices for the measurement of light. Because the emission of light by an organism is a chemical reaction catalyzed by an enzyme, the intensity of the light provides direct evidence of the rate of a kind of reaction that is common to all life processes. Consequently light emission by cells or cell extracts can be studied under various conditions and can serve as a valuable quantitative tool for biochemical and biophysical investigations.

One of the most striking features of bioluminescence is the sheer diversity of organisms that have developed the ability to emit light. They include certain bacteria, fungi, radiolarians, sponges, corals, flagellates, hydroids, nemerteans (vividly colored marine worms), ctenophores (small jellyfish-like animals), crustaceans, clams, snails, squids, centipedes, millepedes and insects. Among the last are of course the insects familiarly known as fireflies and glowworms. Many fishes are also luminous, but there are no self-luminous forms among amphibians, reptiles, birds or mammals. None of the higher plants is luminous. With the possible exception of a few strains of luminous bacteria, no freshwater organism is luminous, even though many of them are closely related to light-emitters that live in the sea.

Light emission can occur whenever a physical system undergoes a discrete change in free energy. The source of the original excitation of the system can be thermal, as in an incandescent lamp; electrical, as in a flash of lightning; mechanical, as in the scintillation that attends the breaking of a sugar crystal; or chemical, as in the glow of phosphorus. Bioluminescence is chemical luminescence, or chemiluminescence.

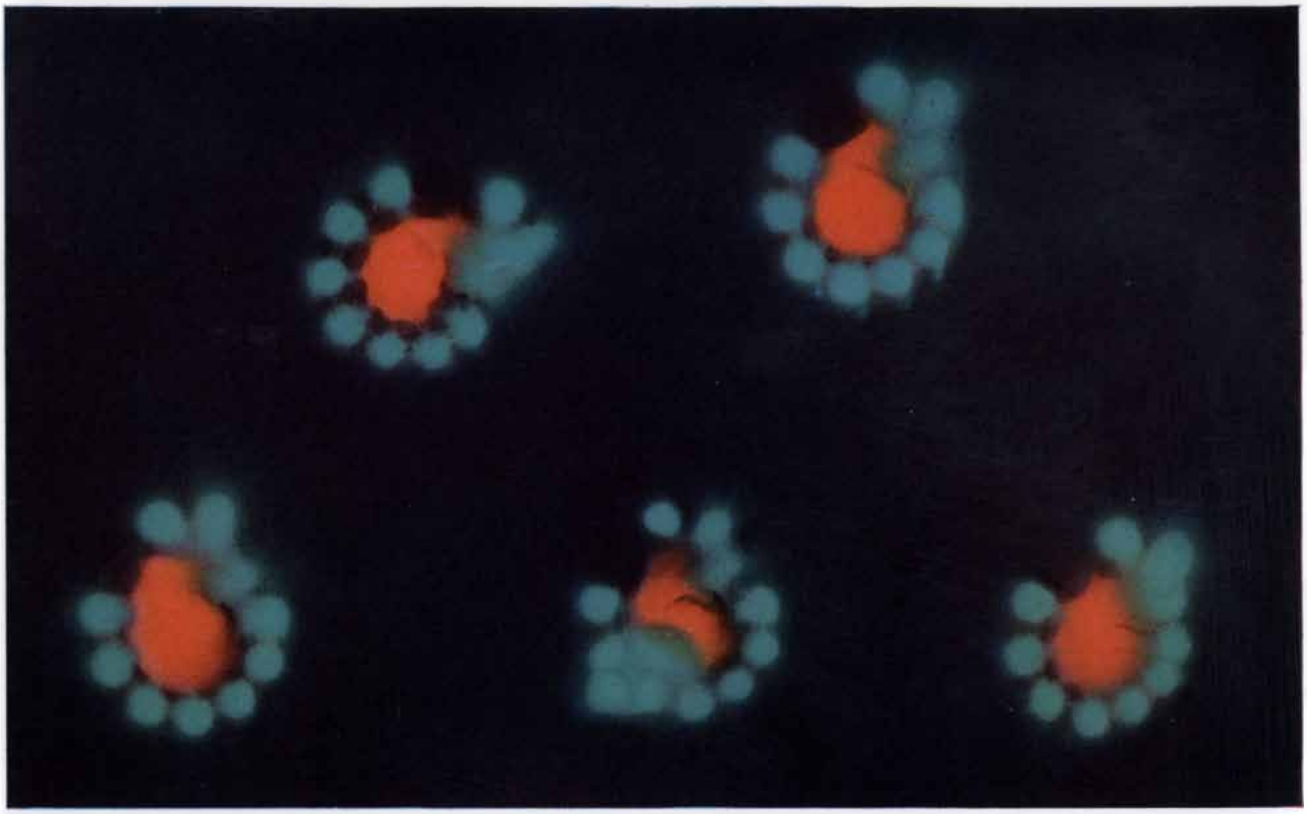
In a secluded bay in Jamaica certain protozoa that glow when they are disturbed are so abundant that they brightly illuminate the fish swimming in their midst. In Thailand one species of firefly congregates on certain trees, and all the fireflies flash on and off in unison like Christmas-tree lights. In Brazil the "railroad worm," the larva of a large beetle, bears green lights along its sides and a red light on its head. In the waters off Bermuda the female of a species of marine worm comes to the surface three days following a full moon and secretes a glowing circle of luminous material. The male, emitting puffs of light, heads straight for the circle of light, and both eggs and sperm are discharged into the water. A deep-sea angler fish carries a luminous organ at the tip of a retractable rodlike appendage with which it lures victims into its jaws. One deep-sea member of the squid family, quite unlike its ink-emitting cousins, spurts a luminous cloud when it wants to hide. In this symphony of living light most chords are blue. The greens and yellows of the fireflies and the green and red of the railroad worm are grace notes ornamenting the azure theme of the luminous bacteria and larger marine organisms.

The Luminous Clams

Probably the best known of the luminous mollusks is the boring clam *Pholas dactylus*, which men have regarded as a delicacy since antiquity. In Greek *pholas* means lurking in a hole, which describes the mollusk's habit of boring into soft rock and hiding there with only its siphon exposed. In 1887 the French physiologist Raphaël Dubois used *Pholas* in his pioneering studies of the substances involved in bioluminescence. Dubois demonstrated that a cold-water extract of *Pholas* would continue to emit light for several minutes. He found that after the light emission had ceased it could be restored by adding a second extract obtained by washing a fresh clam in hot water and cooling the juice. Dubois concluded that there was some substance in the hot-water extract that was essential for light emission and that it was not affected by heating. He called this material luciferin, a name he coined from Lucifer, meaning light-bearer. The substance in the cold-water extract he called luciferase, indicating by the suffix "-ase" that it had the properties of an enzyme. Enzymes are biological catalysts, and like most enzymes luciferase is heat-sensitive. Dubois reasoned that both luciferin and luciferase were extracted by water—hot or cold—but that hot water inactivated the luciferase, leaving only the luciferin active.

The other pioneer in the field of bioluminescence was the late E. Newton

GLOWING TOADSTOOLS of the genus *Mycena* were photographed by self-emitted light. The light is given off principally from the gills beneath the caps of the fungus. Luminous mold is often seen in the vegetative state on rotting logs, but it is rare for luminescence to continue into the fruiting state shown here. The photograph was made by Yata Haneda of the Yokosuka City Museum.



RAILROAD WORM is the larval form of a South American beetle. F. W. Goro made this unusual photograph by pressing a sheet of Kodachrome directly against a single larva several times to obtain multiple images. The picture is consequently a true autograph, made without the intervention of lens or camera. It is reproduced through the courtesy of *Life*. Copyright 1945 by Time Inc.

HATCHET FISH, *Argyropelecus hemigymnus*, is one of the more than 100 species of light-emitting fish. The photograph is by Haneda. In classifying many thousands of fish netted below 400 meters, the deep-sea investigator William Beebe found that more than 95 per cent were luminous. It seems likely that the light patterns found in various species play a role in hunting and recognition.

Harvey of Princeton University. Following Dubois's observations Harvey did much to show clearly that light emission in organisms is an enzymatic process. He described luciferin-luciferase reactions in a variety of organisms and demonstrated that they were of several different types. On a field trip to Japan he found a crustacean (*Cypridina hilgendorfii*) that, when dried, provided a convenient source of both luciferin and luciferase. Harvey and his students used many pounds of the material in their studies. *Cypridina* is a small crustacean with two hinged valves covering its body. It is found in both fresh and salt water, but only the marine forms are luminous. During World War II, Japanese soldiers used dried *Cypridina* as a source of low-intensity light when they did not want to run the risk of using a flashlight. A small quantity of *Cypridina* powder placed in the palm of the hand and moistened provided enough light for reading a map or a message.

Cypridina live in the sea bottom near the shore and come out to feed at night. The organism is not itself luminous; it excretes luciferin and luciferase into the surrounding water, and the interaction of the two substances produces a blue light. The luciferin is apparently synthesized in one gland and the luciferase in another. Japanese biochemists have recently purified the luciferin from *Cypridina* and have published a tentative description of its molecular structure. This appears to resemble the structure of firefly luciferin, about which we will have more to say.

Fireworms of the Sea

There are a large number of luminous forms among the annelid worms, which range in length from a fraction of an inch to several inches. The luminescence is particularly striking during the mating period of the "fireworms," annelids of the order Polychaeta. It seems likely that Columbus saw fireworms on his first voyage to the New World. He wrote of seeing lights in the water resembling moving candles as he approached the Bahamas. The relation between luminescence, the phase of the moon and periodicity in the breeding of these marine organisms is beautifully illustrated by the Bermuda annelid *Odontosyllis enopla*. The worms begin to swarm two or three days after the full moon, the females appearing first. Each swims in a small circle at the surface, emitting a greenish light. Invariably the performance reaches a peak between 55 and 56 minutes after sunset. The circles of light evidently attract the male worms, which normally stay well below the surface. As the males swim toward the females, traveling 15 to 20 feet with remarkable accuracy, they emit short flashes of light. Commonly several males will converge on a single female; the whole group then rotates in a tight, glowing circle as its members discharge eggs and sperm into the water. The eggs are accompanied by a secretion that leaves a luminous cloud in the wake of the female. The females, which range up to 35 millimeters in length, are often twice as long as the males. The body of the female glows strongly and almost continuously. The male continues to glow with sharp intermittent flashes.

After the mating process has begun the males exhibit an additional positive response to light. For example, if a flashlight is aimed into the water, males will start swimming toward its beam. There is no evidence to indicate that the females will respond positively to the light, although they are obviously stimulated to release their eggs by the presence of the males. Recently we have been able to obtain from *Odontosyllis* extracts of luciferin and luciferase that give off light when the two are mixed together. We do not yet have enough of the two materials, however, to study the chemistry of the bioluminescent reaction in detail.

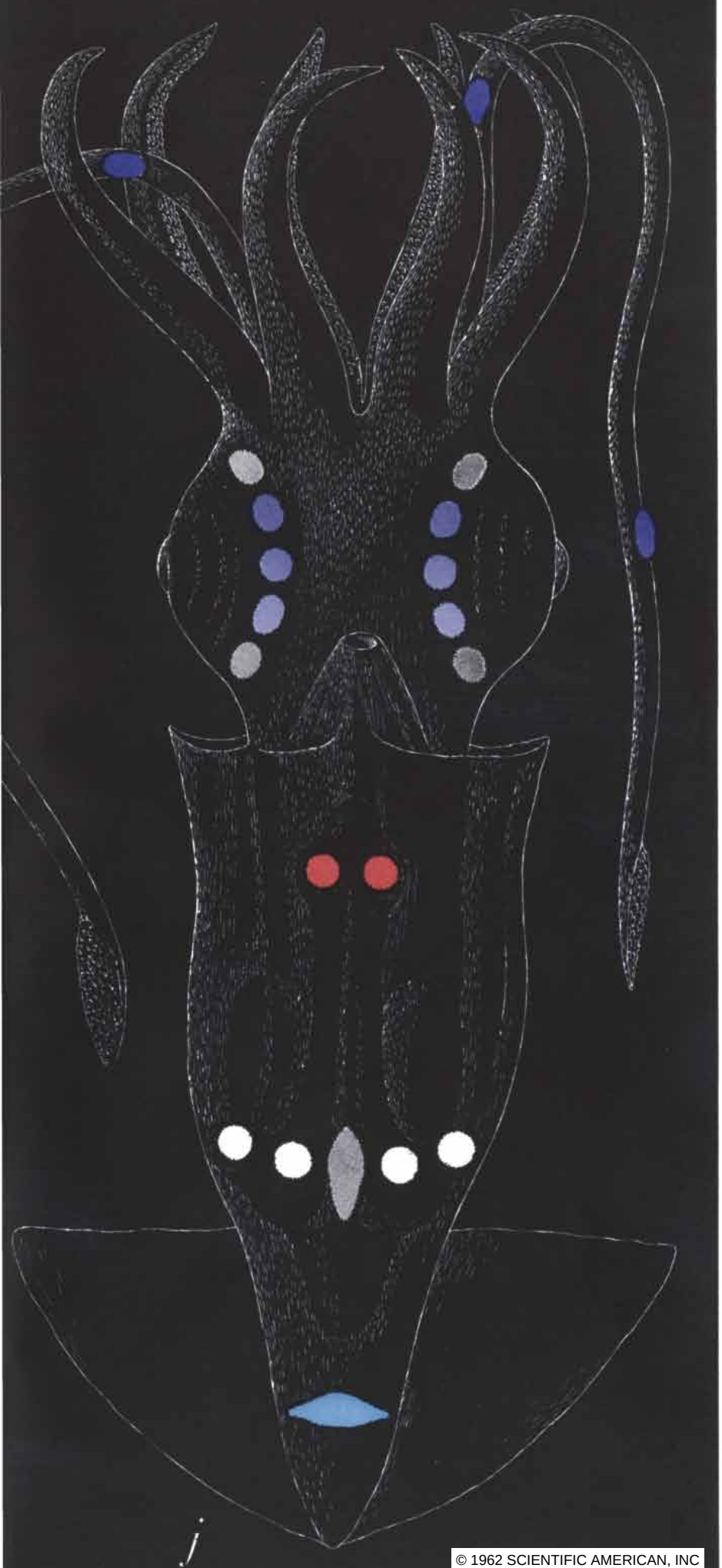
Marine Dinoflagellates

The "burning of the sea" presented a mystery to fishermen and other observers for centuries. The "burning" refers to the glow sometimes seen in the wake of a ship as it moves through tropical waters. The glow is due to the presence of large numbers of dinoflagellates that luminesce when they are disturbed. These one-celled organisms often develop in large quantities at favorable seasons of the year. In secluded bays a permanent heavy culture can develop; the waters of the bay can become so thick with dinoflagellates that the water itself is colored. Such luminescent bays have become famous tourist attractions. One of the most spectacular is Oyster Bay, near Falmouth on the northern coast of Jamaica; another is on the southern coast of Puerto Rico near Parguera. The two bays are inhabited chiefly by the luminous dinoflagellate *Pyrodinium bahamense*. If one travels across one of the bays at night, looking down from the bow of a moving boat, one can see fish sharply silhouetted against the glowing water as they dart out of the way. The movement of the fish triggers the luminescence, and every wave looks as if it were aflame.

The discovery that this luminescence comes always from living things was only slowly appreciated because most of the dinoflagellates are invisible to the naked eye. The mystery of the burning sea was not definitely settled until about 1830. In recent years dinoflagellates have been grown in the laboratory and their bioluminescence has been studied in great detail.

The "red tides" of the sea are due in most cases to dinoflagellates, which are also capable of forming patches of brown and yellow. The color of their nighttime luminescence, however, is always blue. On occasion the daytime red patches are due to the flagellate *Noctiluca,* which is large enough to be seen without a microscope. Along the Pacific coast of the U.S. it is not unusual to find patches of *Gonyaulax polyhedra,* a quite luminous dinoflagellate. The red tides reported along the Gulf Coast of Florida in recent years are produced by an organism (*Gymnodinium brevis*) that is unrelated to the flagellates and is nonluminous.

By growing cultures of *Gonyaulax* in the laboratory it has been found that they stop producing light at dawn and luminesce again in the evening. In addition to being luminescent *Gonyaulax* is a photosynthetic organism requiring light for growth. Under laboratory conditions one can readily obtain cultures of 10,000 to 20,000 cells per liter. When the culture vessel is shaken, the cells emit bright flashes of light lasting less than a tenth of a second. If the organisms are illuminated continuously with a dim light, so that they are no longer exposed to a normal day-night cycle, an interesting phenomenon takes place. When one shakes the culture to measure the maximum light output, one finds that the maximum output continues to occur each night at about 1 a.m. and decreases to a minimum some 12 hours later. In other words, the organism's normal day-night rhythm will continue unbroken for weeks under a steady weak light sufficient to supply energy. This remarkable biological clock can be altered, however, by subjecting the cells to an artificial light-dark cycle. For example, if *Gonyaulax* cells are exposed to eight hours of darkness followed by eight hours of light, they adopt a new rhythm in which they can emit light during the eight hours of darkness and are nonluminous for the eight hours of light. When the cells are removed from this artificial 16-hour cycle and are again placed under a continuous light of low intensity, the original



24-hour rhythm resumes. The mechanism underlying this behavior has not been discovered.

Recently we have looked for rhythmic behavior in dinoflagellates under natural conditions and have found that some species show a night-day rhythm and that others do not. In *Gonyaulax* both luciferin and luciferase, the necessary components for light production, are found in greater amounts in cell-free extracts prepared during the night hours than during the day, showing that the rhythm of luminescence reflects rhythmic biochemical processes. It would appear that the luminescent system is not the clock but rather that it is controlled by a master clock that regulates other physiological processes.

Luminous Fungi and Bacteria

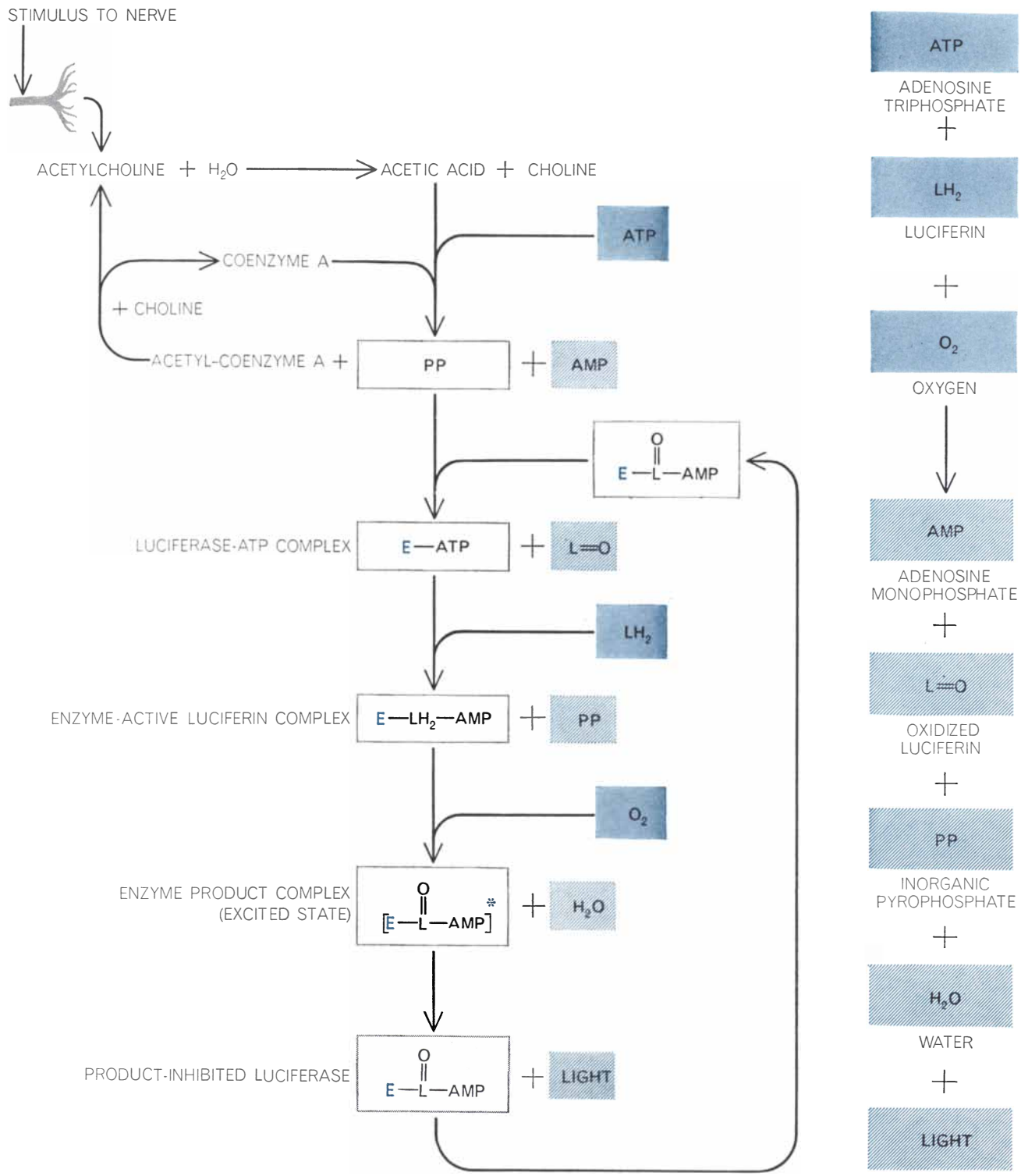
If you should chance to stumble over a rotten log in the woods at night, you might be surprised to find that freshly exposed parts of the log were glowing brilliantly. Luminescence of this sort is caused by fungi. The phenomenon was known to Aristotle, and it was studied by such illustrious figures as Francis Bacon and Robert Boyle. Not until early in the 19th century, however, was the role of the fungus properly appreciated.

One of the best known luminous fungi is *Panus stipticus,* which exists in two varieties: a North American form that is luminous and a European form that is not. The threadlike mycelia of the two varieties are able to fuse, and it can be shown by this mating technique that luminescence is under genetic control. Evidently the European variety lacks one or more genes needed to produce enzymes required for bioluminescence.

GALLERY OF ANIMALS at left suggests the diversity of bioluminescent organisms. Roughly speaking, bioluminescent organisms exist in about a third of the 33 phyla and a third of the 80 classes given in the official American classification of the animal kingdom. The 10 luminous animals at left are: *a,* a click beetle (*Pyrophorus noctilucus*); *b,* a common North American firefly (*Photuris pennsylvanica*); *c,* the Bermuda fireworm (*Odontosyllis enopla*); *d,* a Japanese crustacean (*Cypridina hilgendorfii*); *e,* a jellyfish (*Aequorea aequorea*); *f,* a protozoan (*Noctiluca miliaris*); *g,* a fish (*Photoblepharon*) in which the light is supplied by symbiotic bacteria; *h,* an edible clam (*Pholas dactylus*); *i,* one of the luminous hydroids (*Campanularia flexuosa*); *j,* deep-sea squid (*Thaumatolampas diadema*).

At least one of these enzymes is luciferase, which is found in the North American *Panus* but not in the European.

Before electric refrigerators came into general use there were often reports in the newspapers about "mystery meat" that gave off light. There should have been no mystery about the light; it has been known for a long time that luminous bacteria—all quite harmless—readily grow on meat and dead fish. Boyle experimented with such bacteria and in 1668 demonstrated that they need air if they are to emit light. Subsequently luminescent bacteria found in salt water became a favorite subject for studying bioluminescence. Most of these forms will grow easily on ordinary nutrient agar containing 3 per cent sodium chloride (the salinity of sea water) and



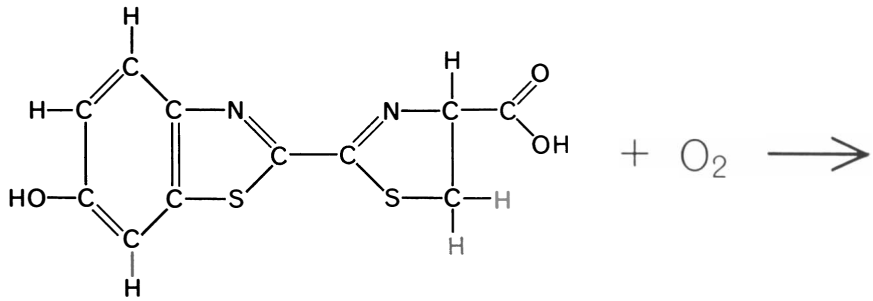
FIREFLY FLASH is probably triggered by a nerve impulse delivered to the luminous gland. A sequence of chemical reactions then produces light. The substances consumed in the reaction, as shown in the summary at right, are adenosine triphosphate (*ATP*), luciferin (LH_2) and oxygen (O_2). The products are oxidized luciferin ($L{=}O$), two phosphate compounds, water and light. The reaction is catalyzed by the enzyme luciferase, represented by *E*. One quantum of light is produced for each molecule of luciferin oxidized.

glucose or glycerol. Among the best sources of salt-water luminous bacteria are dead fish or squids that have not been washed in fresh water. If such material is incubated overnight at 15 or 20 degrees centigrade, it is usually covered with colonies of luminous bacteria by morning. The bacteria can then be transferred to agar plates and readily developed into pure cultures that emit a strong blue or blue-green light. This culture technique was exploited by Dubois, who wrote: "In 1900, at the Palace of Optics, at the International Exposition in Paris, I have been able to illuminate, as from the clearest light of the moon, a vast chamber using large glass flasks of 25-liter capacity... containing very brilliant photobacteria... In the evening as soon as one entered the chamber one could read and see all the people in the room." The light emitted by luminous bacteria is usually a broad band in the blue or blue-green region of the spectrum (wavelengths between 480 and 500 millimicrons).

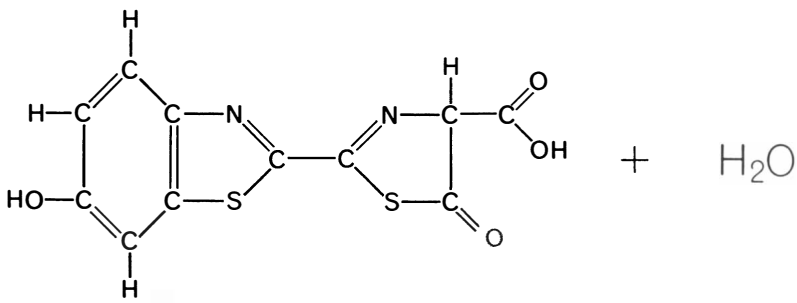
Some of the most interesting luminous bacteria live in symbiosis with other organisms, frequently squids and fishes. The host often has a complicated luminous organ in which the light is supplied by bacteria. Although the bacteria emit light continuously, the fish or squid may develop a special device, such as a movable screen, that serves to turn the light on and off. One of the most striking instances of bacterial symbiosis occurs in the Indonesian fish *Photoblepharon*. This fish has under each eye an oval white spot, richly supplied with blood vessels, in which the luminous bacteria grow. To turn off the light there is a black fold of skin that can be drawn over the luminous spot like an eyelid [*see illustration on pages 80 and 81*].

The physiology and biochemistry of bacterial luminescence have been studied in great detail. Although we do not know the exact mechanism for creating the luminescent state, we are reasonably certain of the compounds involved. It is now clear that the light-emitting reaction is intimately related to the oxidative, or electron-transport, processes of the bacterial cell. The top illustration on the next page outlines the current hypothesis, in which the light-emitting reaction is a side branch of the general electron-transport process by which the cell extracts energy from food. The requirements for luminescence are a reduced form of riboflavin, an aldehyde, oxygen and an enzyme.

Luminous bacteria have been favored organisms for studying the action of



LUCIFERIN (LH_2)



OXIDIZED LUCIFERIN (L=O)

STRUCTURE OF LUCIFERIN in the firefly has been established by the authors and their associates at Johns Hopkins University. In the light-producing reaction it combines with one molecule of oxygen to form oxidized luciferin and water. Other luciferins are known.

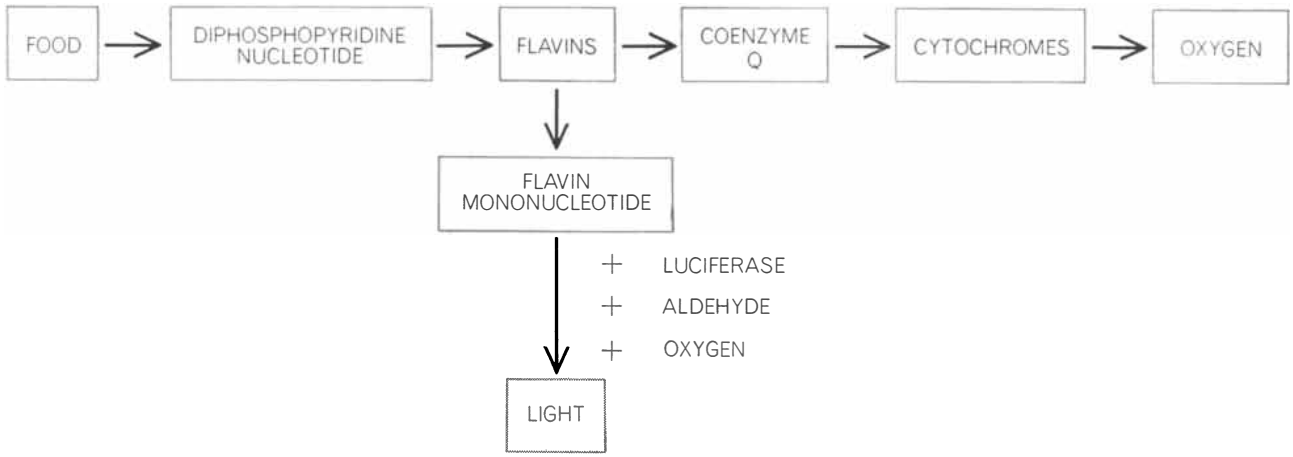
drugs and other inhibitors of cell respiration because the effects are observable externally by means of a photoelectric cell. It is also possible to obtain mutant strains of luminescent bacteria that are nonluminous or only weakly luminous. One can then examine the ability of various chemicals to restore luminescence. The illustration on page 85 shows how the dim light emitted by a suspension of certain mutant bacteria can be increased by the addition of a long-chain aldehyde such as dodecanal. To determine the rate at which the aldehyde penetrates the cell membrane one simply uses a photocell to measure the rate at which the light intensity increases.

Fireflies and Glowworms

Among the insects true instances of self-luminescence are to be found in the springtails, lantern flies, click beetles, the larvae of certain flies and, of course, in the fireflies and their larvae, called glowworms. It is a spectacular sight to see the glowworms that live in caves in New Zealand, the most famous being at Waitomo, about 200 miles north of Wellington. The ceilings of these caves are covered with thousands of glowing larvae, and from each is suspended a long luminescent thread that apparently serves to catch food particles or small insects. If one talks loudly, or if the wall of the cave is tapped sharply, the larvae turn off their lights virtually as one. After a brief period the lights come on again, tentatively at first and then more boldly, until the whole ceiling is once again ablaze.

The true fireflies, or lightning bugs, are found in many parts of the world and provide perhaps the most familiar example of bioluminescence. (Curiously, fireflies are almost unknown in England.) The scientific literature on this group of insects far exceeds that of any other luminous organism. The old hypothesis that the light of the firefly is a mating device to attract the sexes is now universally accepted. Nothing could be simpler than a flashing light to advertise the whereabouts of a flying male to a responsively flashing female waiting in the grass.

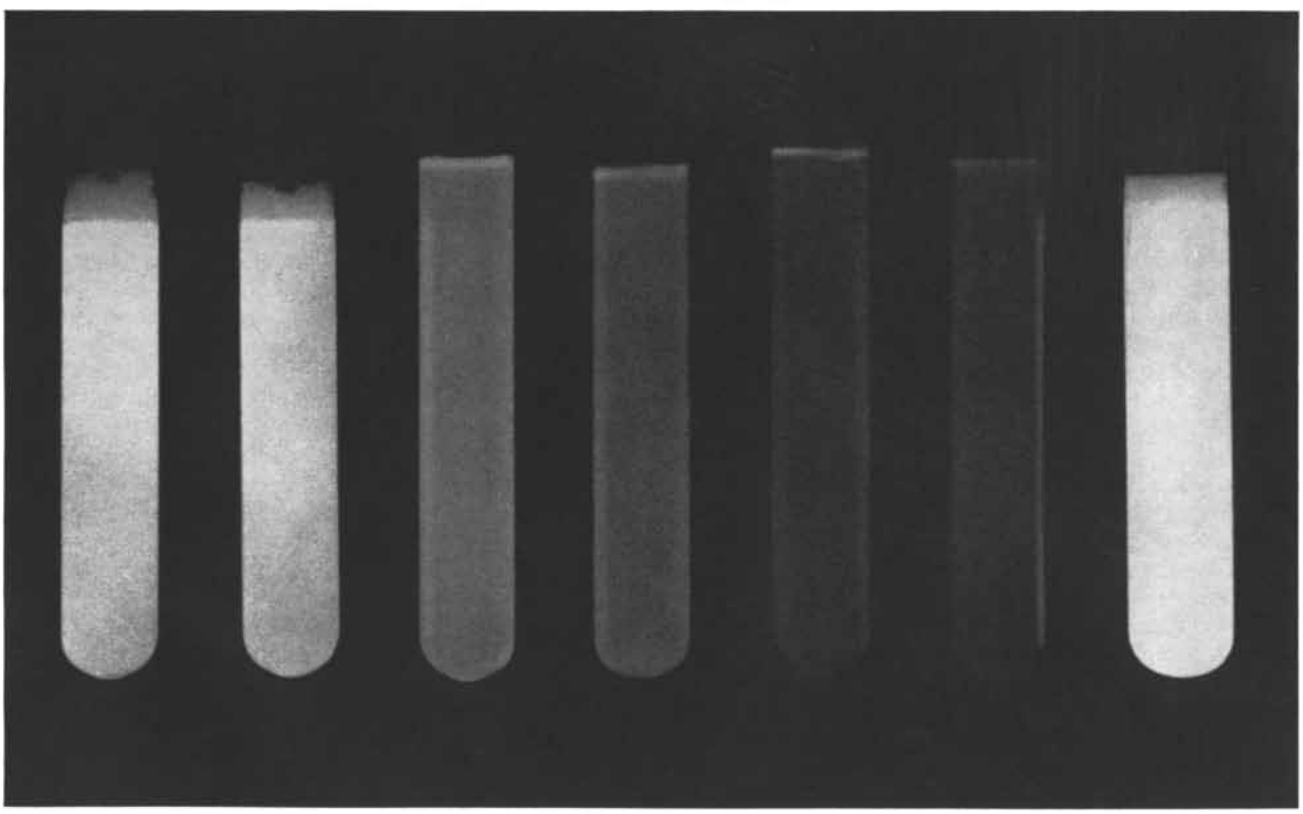
Each species of firefly has a characteristic flash that the female of the species can recognize. The signaling system of one common American species of firefly, *Photinus pyralis*, is fairly typical of the mating behavior of a number of species. At dusk the male and female emerge separately from the grass. The male flies about two feet above the ground and emits a single short flash at



SOURCE OF BACTERIAL LIGHT is a side branch of the oxidation-reduction reactions that extract energy from nutrients. In this sequence hydrogen atoms (or their equivalent electrons) are removed from nutrient and passed along (*colored arrows*) to a series of compounds. The final hydrogen-acceptor is oxygen and the final product is water. At certain steps in the sequence energy is removed from the reactants and stored in the form of ATP (*not shown*). Light is emitted when one of the reduced flavins (flavin mononucleotide) reacts with luciferase and oxygen in the presence of an aldehyde. In this reaction flavin takes the role of luciferin.

regular intervals. The female climbs some slight eminence, such as a blade of grass, and waits. Ordinarily she does not fly at all, and she never flashes spontaneously. If a male flashes within three or four yards of her, she will usually wait a decorous interval, then flash a short response. At this the male turns in her direction and glows again. The female responds once more with a flash, and the exchange of signals is repeated—usually not more than five or 10 times—until the male reaches the female, waiting in the grass, and the two mate.

Recognition apparently depends on the time interval between the male flash and that of the female. This interval in certain species is approximately two seconds at 25 degrees centigrade (77 degrees Fahrenheit) and varies with temperature. A flash of artificial light of about a second's duration, simulating the delayed response of a female firefly, will usually induce a male to fly toward it.



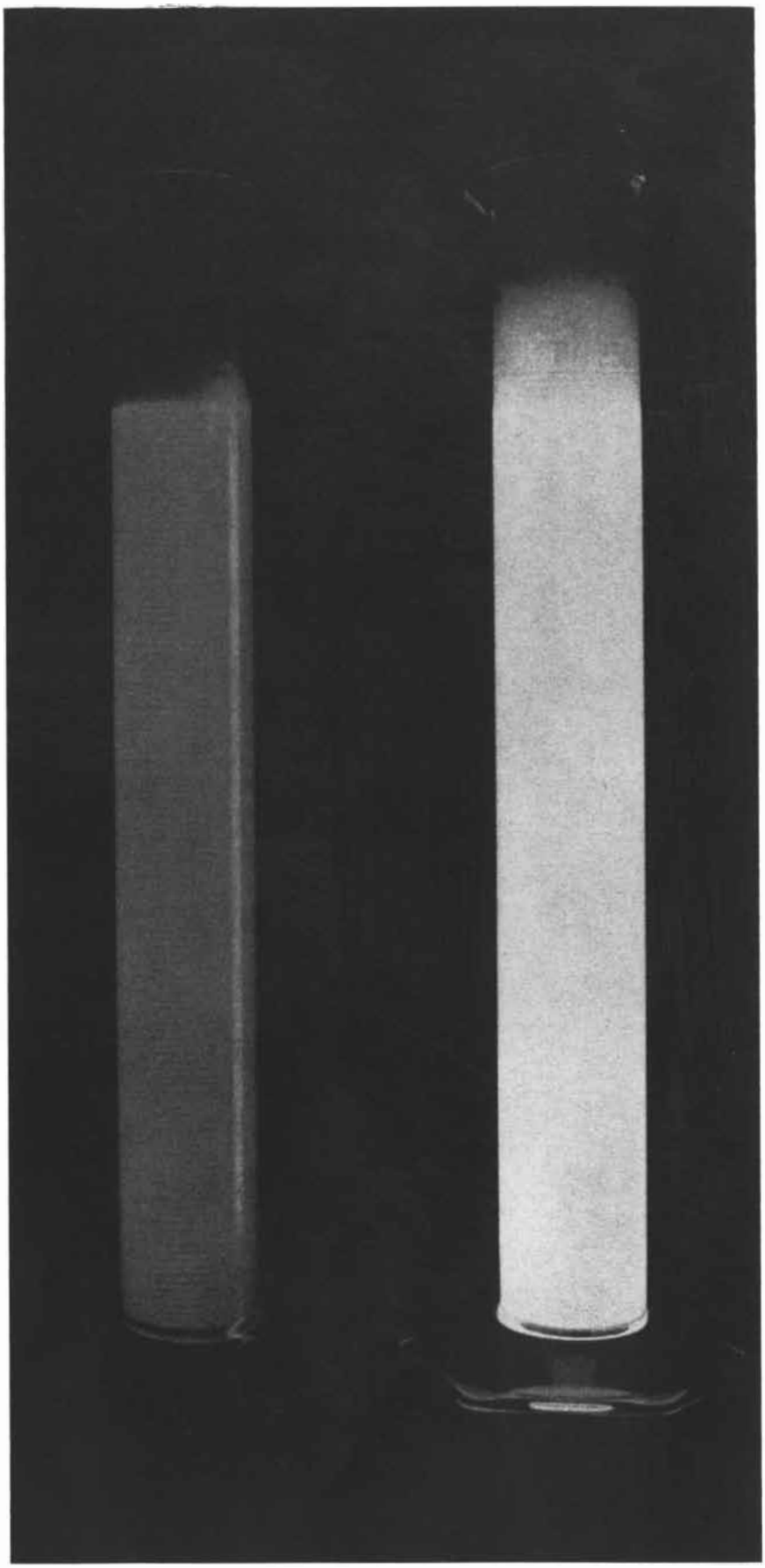
ROLE OF OXYGEN in bioluminescence can be nicely demonstrated with suspensions of luminous bacteria. The first two tubes at left had been aerated continuously prior to the making of the photograph. The next four tubes had been standing unaerated for two, three, four and five minutes respectively. With the passage of time their light emission declined. The last tube at the right, which had been standing undisturbed for 10 minutes, was shaken vigorously to introduce fresh oxygen just before the photograph was made. For a brief period it glows even more brightly than the two tubes that had been supplied with oxygen continuously.

Other species of fireflies have other systems and types of flashes. Synchronous flashing of a number of males to one female has been observed, but it is rare in North American species. Among tropical fireflies, however, it is fairly common. In Burma and Thailand, for example, all the fireflies on one tree may flash simultaneously, whereas those on another tree some distance away may also flash in unison but out of step with those on the first tree. It is conceivable that all the fireflies on one tree are males and those flashing out of phase nearby are all females, but this has not been established.

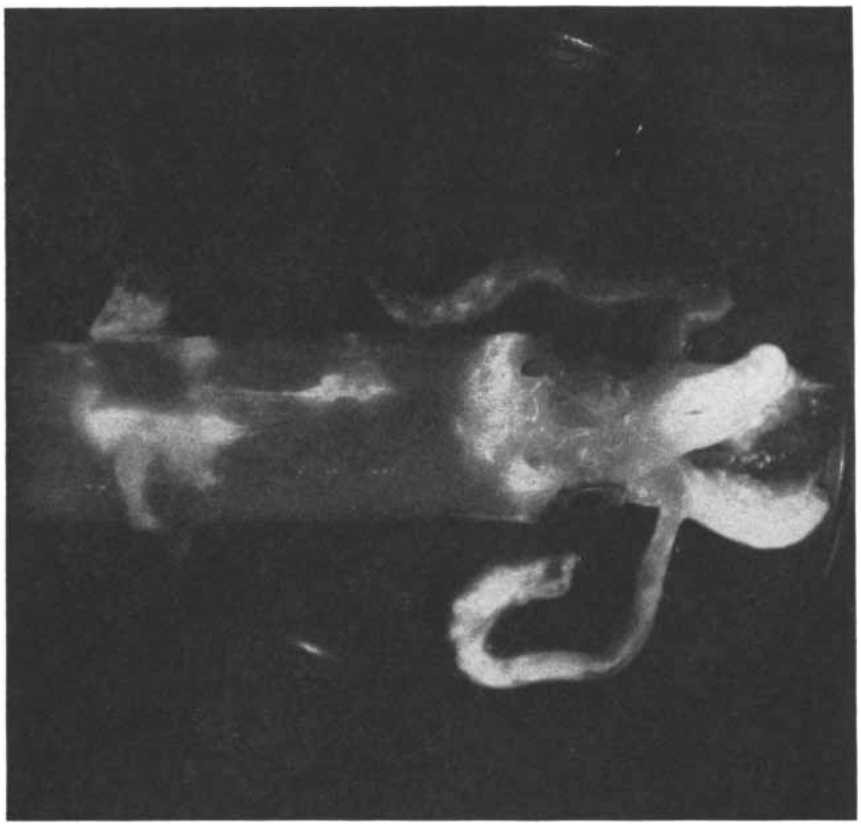
The eggs of American fireflies are laid on or near the ground and hatch in about three weeks. The larvae differ considerably in habit. They live mostly in damp places among fallen leaves, becoming active at night and feeding on slugs, snails and the larvae of smaller insects. The firefly larvae usually winter under stones or a short distance underground, often in specially constructed chambers. The larvae metamorphose into pupae near the surface.

The first indication of the formation of the light organ takes place about 15 days after egg development begins. After about 22 days of development the light organ has become functional and appears as two bright spots of light. The larvae emerge on about the 26th day of incubation and become glowworms, with the two small lights at one end. In about two years they reach maturity as pupae. During pupation additional light organs develop, which are to become the light organs of the adult firefly. The light organs of both the larva and the adult develop out of fatty bodies that differentiate into specialized luminescent and reflector layers.

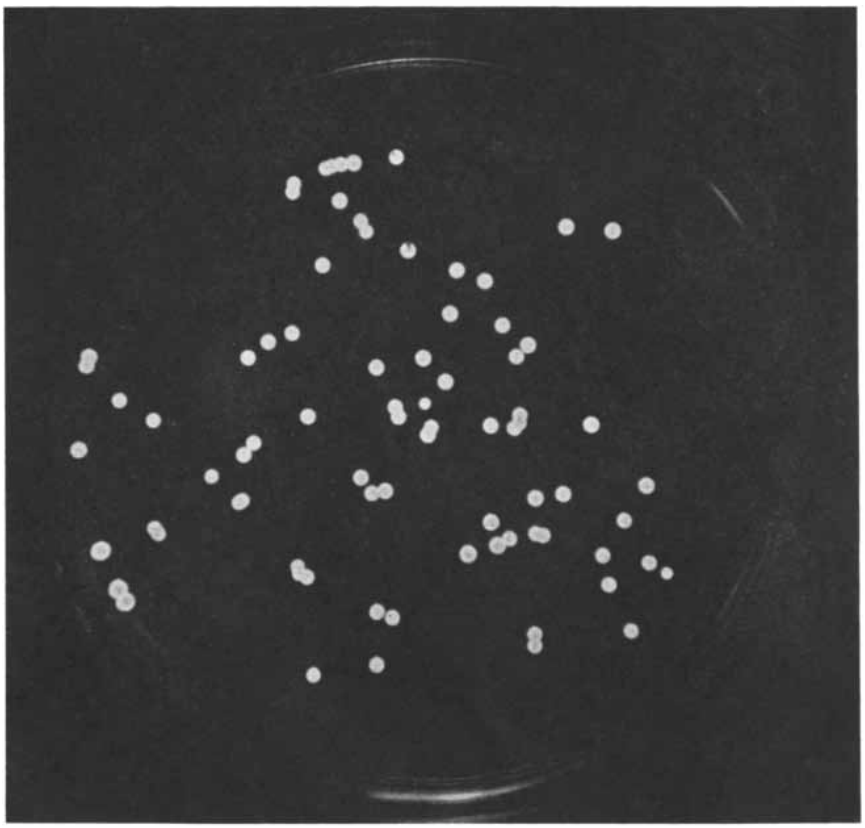
The light emission of fireflies depends on a rich supply of oxygen. The light organs are supplied with blood through an extensive capillary system and with oxygen through an extensive system of tracheal tubes. Unfortunately it is difficult to trace the air-supplying tracheae into the photogenic tissue; it is equally difficult to trace the nerve fibers that must control the flashing of the firefly. Investigators have been able to isolate an individual nerve fiber going to the luminous gland and have been able to stimulate light emission by applying an electric current to the nerve. Probably the best indication of nervous control of the flash is to be observed, however, when the animal is decapitated. Flashing ceases immediately. Subsequently the light organ may glow dimly, with random scintillations, for a long time. The



DARK MUTANT BACTERIA, in the cylinder at left, are barely luminous because they cannot make a long-chain aldehyde (dodecanal) essential for high luminosity. When this aldehyde is added to a suspension of the mutant organisms, they glow brightly (*right*).



LUMINOUS BACTERIA will usually develop on the surface of a salt-water squid kept overnight in a warm place. Only salt-water varieties of bacteria are luminous. The photograph, made by the authors, required a 15-second exposure at *f*/4.7 with Polaroid 3,000-speed film.



COLONIES OF LUMINOUS BACTERIA can readily be produced by removing bacteria from a decaying sea animal, such as the squid shown at the top of the page, and transferring them to a saline nutrient agar. Robert Boyle experimented with such bacteria in 1668.

exact mechanism of nervous control remains unknown. According to one hypothesis the nerve impulse simply liberates oxygen into the luminous gland, thereby stimulating luminescence. A second hypothesis, which we favor, proposes a series of steps triggered by the release of acetylcholine at a nerve ending in the luminous organ [*see illustration on page 82*].

The chemistry of the firefly light has been worked out in considerable detail since Harvey first established in 1916 that the glow of the firefly results from the same luciferin-luciferase reaction that Dubois had found in the luminous clam. We now know that firefly luminescence requires, in addition to oxygen, the ubiquitous energy-supplying substance adenosine triphosphate (ATP). If a cold-water extract obtained from firefly lanterns is allowed to stand until the light disappears, the light can be restored to more than its original intensity with the addition of ATP.

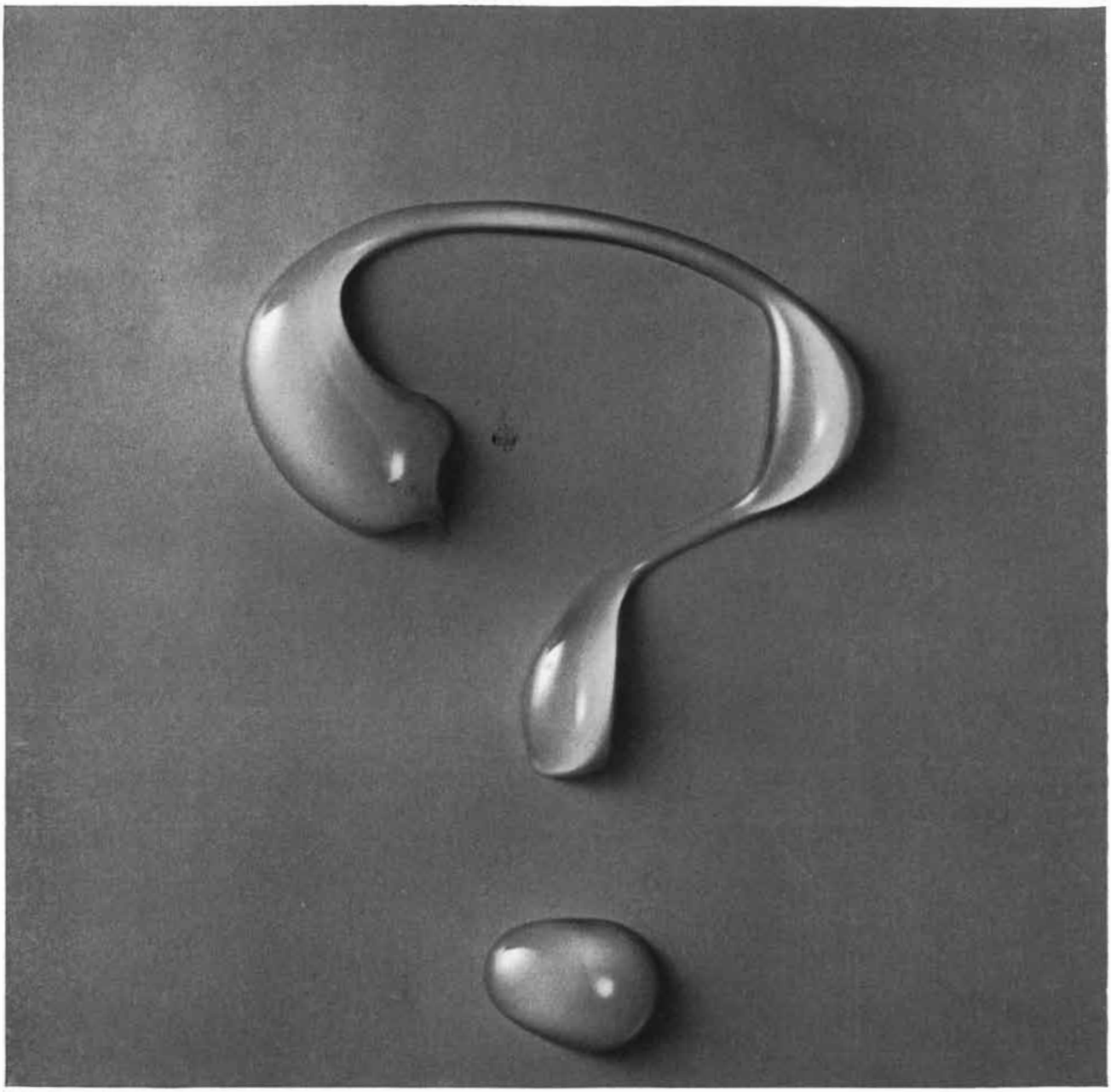
Within the past few years we have isolated firefly luciferin in our laboratory at Johns Hopkins University. We have established its chemical structure and have confirmed its validity by synthesizing the compound and showing that under the appropriate conditions it luminesces. We have also isolated and obtained in pure form the light-stimulating enzyme of the firefly, luciferase. It appears to contain about 1,000 amino acid subunits and is therefore larger than any of the proteins whose structure has so far been established.

The peak wavelength of the light emitted by the firefly *Photinus pyralis* is 562 millimicrons, in the yellow-green part of the spectrum. We have found that extracts of firefly lanterns emit light at the same wavelength when the acid-alkaline balance of the solution is neutral. If the solution is made acid, or if high concentrations of inorganic phosphate are added, the light shifts to red, with a peak emission at 614 millimicrons. Presumably shifts of this sort can explain the slight differences in the color of the light emitted by various fireflies.

The availability of luciferin in pure form has also enabled us to determine the efficiency of the light-emitting process. To do this we compare the number of luciferin molecules oxidized with the number of light quanta produced. It turns out that for each molecule of luciferin consumed exactly one light quantum is emitted. It has been fashionable for many years to describe bioluminescence as "cold light" to distinguish it from thermal luminescence. The finding that the quantum efficiency

"INSTANT" BIOCHEMICAL LIGHT is produced simply by adding water to the powder obtained by drying and pulverizing a small marine crustacean called *Cypridina*. Rich in luciferin and luciferase, dried *Cypridina* was sometimes used as a light source by Japanese soldiers during World War II when the use of a flashlight under battle conditions might have revealed their position.

SENSITIVE ASSAY FOR ATP uses the lanterns from four or five fireflies as the indicating agent. A small sample containing an unknown amount of ATP is added to a suspension of the pulverized lanterns. The more ATP present, the more intense the light emitted. The photograph shows the light produced by .1-milliliter samples containing various microgram amounts of ATP.



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of firefly light production is indeed 100 per cent makes the term "cold light" strictly accurate.

One of the few creatures to luminesce in two colors is the Central and South American beetle *Phrixothrix*. The larva of these insects is decorated with 11 pairs of luminous green spots that form two parallel rows running along the sides of the body; on the head of the larva are two luminous spots that glow a bright red. At night, when only the red spots are shining, the animal looks like a glowing cigarette. When the animal is disturbed and crawling, however, the green lights flash on, so that it rather resembles a railroad train with red head lamps. Not surprisingly, *Phrixothrix* is commonly called the railroad worm.

Other luminescent insects are found among the click beetles, the Elateridae. In some ways they look much like ordinary fireflies. Most of them, however, are decorated with two oval greenish spots, one on each side of the front part of the body. Because these luminous spots have the appearance of automobile headlights the insects are sometimes called "automobile bugs." In addition the click beetle usually has on its first abdominal segment a heart-shaped spot that glows orange and that is visible only when the beetle is in flight.

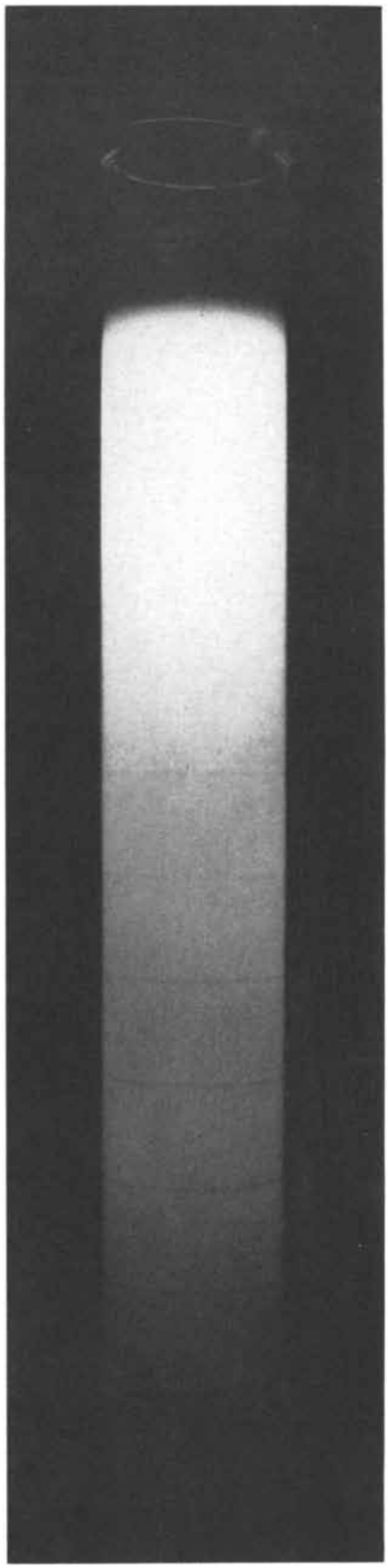
Luminescence in Evolution

Among the more advanced multicellular organisms, light emission has been adapted to fulfill very definite functions: as a mating signal for the fireworms and the fireflies, as a lure for the deep-sea angler fish and as a protective screen for certain squids and other marine animals. What function, if any, light emission has in the lower organisms such as the bacteria, the fungi and the dinoflagellates is not immediately obvious. The wide distribution of this large variety of different luminous organisms with entirely different chemical reactions for light emission would indicate that at some time this mechanism must have had some selective advantage.

Even though the luciferins from various luminous organisms are different, we are reasonably certain that all are associated either directly or indirectly with the energy-liberating reactions of the cell. In all cases where the detailed chemistry of the reactions leading to light emission has been examined, oxygen is an essential ingredient. For example, in the luminous bacteria the light-emitting reaction is a branch of the electron-transport system that is essential for growth and reproduction. It seems reasonable to expect that the origin of the light-emitting processes was in some way closely associated with the early evolution of life on earth. Furthermore, it is our belief that various "practical" adaptations of bioluminescence in the more advanced organisms came late in evolution.

We propose that bioluminescence was originally an incidental concomitant of the chemical reactions that were most efficient in removing oxygen from living systems. It is generally believed that the earliest forms of life on earth developed in the absence of oxygen. The first organisms, therefore, were anaerobes. When in the course of the millenniums free oxygen slowly appeared—as a result of solar decomposition of water vapor, augmented, perhaps, by primitive photosynthesis—it would have been highly toxic to anaerobic organisms that could not quickly get rid of it. Chemically the most efficient way to remove oxygen is to reduce it to form water. In the forms of life then present, the most likely reducing agents would have been those organic compounds that were already part of the hydrogen-transport system of the primitive anaerobes. When oxygen is converted to water by such compounds, enough energy is liberated in single packets, or quanta, to excite organic molecules to emit light. Low-energy packets will not do. Thus all the successful oxygen-removing organisms would have been potentially luminescent.

During subsequent evolution anaerobic organisms evolved that could use oxygen directly in their metabolic machinery. Then the oxygen-removing light reaction was no longer a selective advantage. But since it had evolved with the primitive electron-transport process, it was not easily lost. In most cases where it has been studied carefully bioluminescence is produced by a nonessential enzyme system. It is possible, for example, to grow luminous bacteria and luminous fungi under conditions that inhibit light emission without affecting growth. And it is possible to obtain mutant strains of luminous fungi and bacteria that are fully vigorous although nonluminous. We find additional support for our hypothesis in the observation that all luminescent reactions can detect and use oxygen at extremely low concentrations. Bacteria can easily produce measurable light when the oxygen concentration is as low as one part in 100 million. Thus we argue that bioluminescence is a vestigial system in organic evolution and that through the secondary processes of adaptation the system has been preserved in various and unrelated species.



DIMMING OF BACTERIA is observed when a well-aerated suspension is allowed to stand undisturbed. The dimming begins at the bottom, as oxygen is depleted, and works upward. Rising air bubbles postpone the dimming in the upper part of the cylinder.

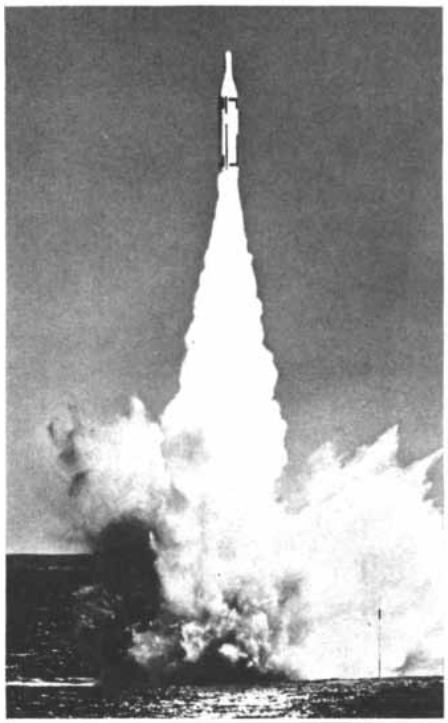
Help turn theory into hardware

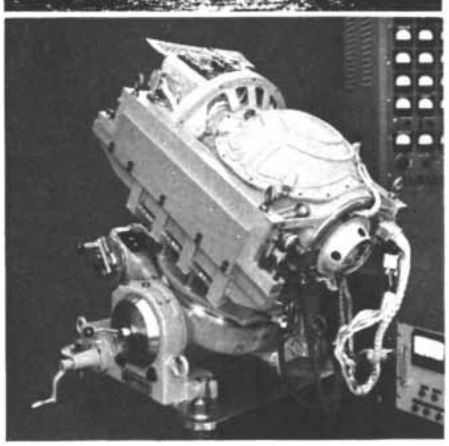
Some space-age companies are oriented to R&D work. Others specialize in application and hardware production.

Hughes is a company whose obligation is not limited to forming theories—but also to visualizing applications. And, then, to build hardware—both for man's defense and the betterment of his life.

This philosophy will interest the forward-looking engineer or scientist. For at Hughes this concern for the total has created an environment unique in its promise for professional development.

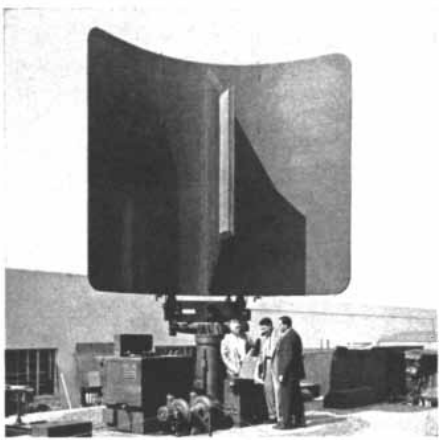
This advantage is complemented by the wide scope of Hughes activities—covering in breadth and depth virtually the complete spectrum of advanced electronics. As a qualified engineer or scientist you can choose from literally hundreds of programs, projects, studies and product





Polaris missile brain

Through the application of its advanced manufacturing technology, Hughes is now a a prime contractor in inertial guidance systems (illustrated above) for the U.S. Navy's Polaris missile. It is one of the world's mightiest, most reliable forces for freedom.

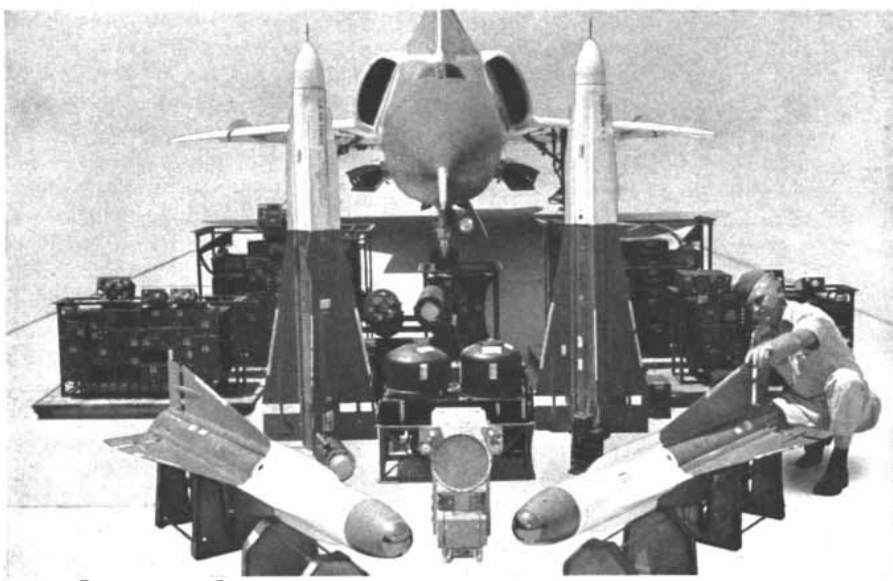


"No-rock" radar

Aware of the limitations of conventional radar which must "rock" to position its beams, Hughes pioneered a technology where the beams are positioned electronically. Based on land or aboard ships, this antenna gives 3-dimensional information—range, bearing and altitude—on hundreds of targets. Even more advanced Hughes antennas, which search hundreds of miles of sky, are now on operational duty.

Satellite "switchboard"

Soon, NASA is scheduled to launch the first communications satellite capable of being remotely spin stabilized and positioned in a 22,300 mile-high synchronous orbit. Just four similar Syncom satellites could relay the telephone, TV, telegraph and radio-photo messages of 130 nations. Hughes—developed and built for NASA, this Syncom system could add a new dimension to man's communication with his neighbors.



Modern Falconry

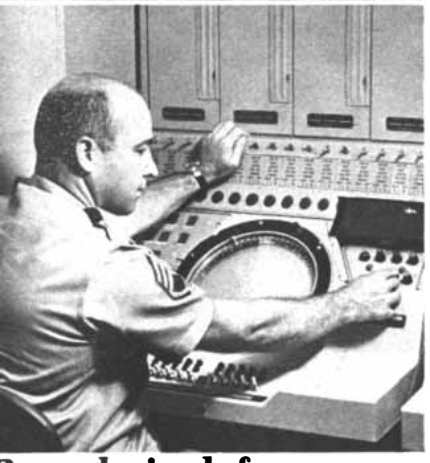
In the late 1940s, airborne electronics was in its infancy. Yet, in a few years, U.S. Air Force jets were equipped with Hughes advanced weapons control systems armed to fire Falcon missiles. Together (and vastly improved) they have become our most potent air defense weapon. Hughes—the leading builder—has delivered thousands of control systems and well over 30,000 infrared and radar-guided Falcons.

at Hughes

developments. This is particularly important to the specialist who may feel he is "bumping his head" in a more restricted environment.

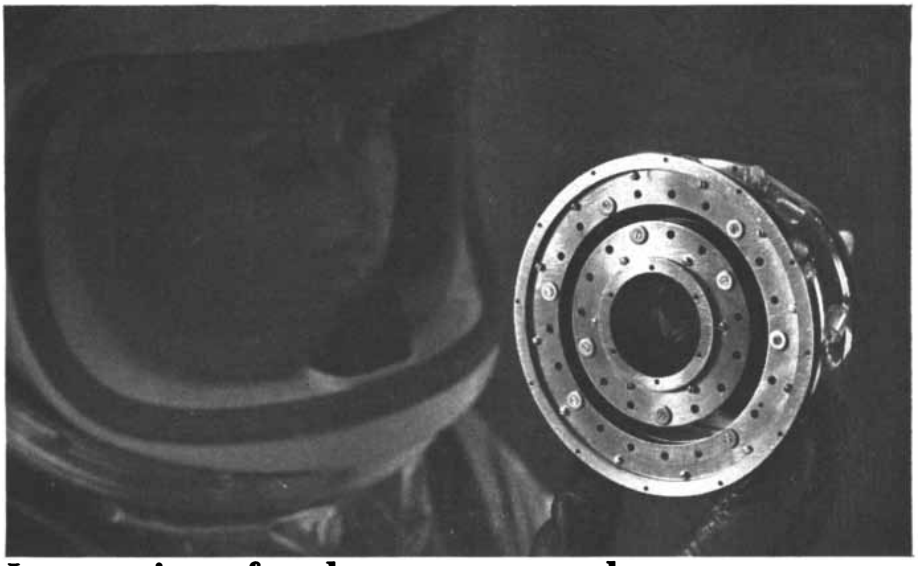
Your inquiry concerning opportunities at Hughes will receive prompt attention. Numerous positions are now open at all experience levels. Still others are opening daily as new expansions take place. Qualifications include US citizenship and a B.S., M.S. or Ph.D. degree from an accredited university. Hughes is an equal opportunity employer.

PLEASE ADDRESS YOUR INQUIRY TO Mr. S. L. Gillespie, Manager, Employment & Manpower, Hughes Aircraft Company, Culver City 8, California.



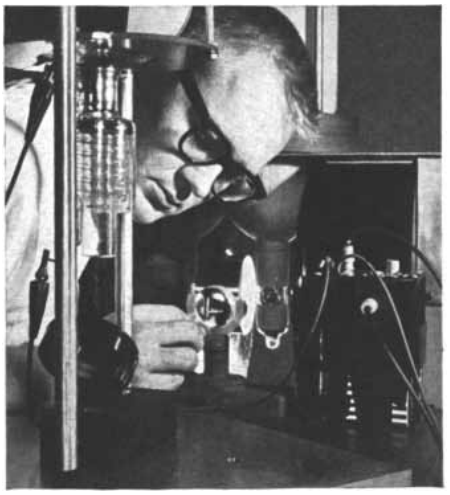
Boxed air defense systems go anywhere

Air-lifted by helicopter to inaccessible areas, Hughes new "packaged" air defense control systems can be ready for operation in minutes. The "helihuts" contain a highly miniaturized "operations central" plus communications networks for battlefield control of U.S. Army and Marine Nike and Hawk missile batteries.



Ion engines for deep-space probes

Hughes research into the theory of electrical propulsion has led to development of ion engines which are called the "ultimate" source of power for deep space trips. Built for NASA, Hughes cesium-powered ion engines have been "test-flown" in space-simulating vacuum chambers—and are scheduled for actual test in space within the year.



Laser-Maser

Combining the laser with a maser, Hughes scientists have opened the door to unprobed areas in the electromagnetic spectrum. The laser-pumped maser technique lays open the broad area between radio and light frequencies to provide a new tool for space communications and basic research applications.

Missile checker

Today's checkout systems must provide the "preventive medicine" that keeps our missiles in constant readiness. Result of Hughes advanced computer technology, D-PAT (Drum—Programmed Automatic Tester) has a built-in "intelligence" of 1 million bits of information. This capability is now in the U.S. Air Force's VATE program to check and evaluate ICBM missiles — in less time, with greater accuracy, at less cost.

Creating a new world with electronics

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The Conduction of Heat in Solids

It is a familiar observation that some materials are better conductors of heat than others. The process is governed by the properties of a unit of sound energy known as the phonon

by Robert L. Sproull

A sterling silver spoon and a silver-plated spoon immersed in a cup of hot coffee serve to demonstrate that solid materials conduct heat and that some conduct heat better than others. Early in the history of technology it became necessary to measure this property in materials of construction. Such measurements were made with great precision in the absence of any theory to explain the conduction of heat. They showed, for example, that metals are better heat conductors than nonmetals long before it was suspected that metals are also good conductors of something called electricity. And measurements of both properties in various materials were made before it occurred to anyone to connect these properties with the fact that solids also conduct sound. Today the demands of technology and fundamental questions put by science have carried the measurement of heat conduction by both metals and nonmetals into the extreme ranges of the temperature scale. From such work has come an understanding of this property of matter that relates it to the conduction of both sound and electricity. The conduction of heat can now be described in terms that take account not only of the particulate structure of matter but also of the particulate nature of energy, as expressed in the powerful generalizations of quantum theory.

Although many elaborate and ingenious methods for measuring the thermal conductivity of solids have been invented, the simplest method is still commonly used. One end of a bar of the solid is heated, perhaps by an attached electrical heater; the power input is measured, and the temperature difference between two points on the bar a measured distance apart is also measured. The thermal conductivity—the heat flow per unit of temperature difference in a standard length and cross section of a specimen—can then be calculated from these data by correcting for the size and shape of the sample. In a given material the heat flow is obviously larger through a short, thick specimen for the same temperature difference than it is through a long, thin one.

The finding that metals exhibit high electrical conductivity as well as high heat conductivity yielded the first insight into the primary mechanism of heat conduction in those materials. Metals owe their high heat conductivity to their abundance of free electrons, the familiar carriers of electricity. If one end of a bar of a metal is heated to a higher temperature than the other, the electrons in the hotter end acquire faster speeds than those in the cooler end do. Since the electrons in a metal belong to the solid as a whole and not to individual atoms, the energetic electrons can flow to the cold end and the less energetic electrons can flow to the hot end. Thus kinetic energy is transferred to the cold end, warming it.

What characteristics of a particular metal determine whether the conduction of heat will be greater or less than in another metal? Theory and a great deal of experimental evidence show that the heat flow is greater the farther each electron can move before it is diverted. If an energetic electron could move throughout a metal specimen without being scattered or losing its energy, the metal would have an infinite thermal conductivity. It might at first be thought that an electron would be constantly colliding with the closely packed atoms making up a solid. In a perfectly organized crystal, however, in which the atoms are all placed in an exactly regular array in the crystal lattice, an electron would travel a path of infinite length before being scattered. An electron cannot give up any of its kinetic energy to such a crystal. The perfect solid is transparent to electrons in the same way that glass is transparent to light: there are no processes by which the light can dribble away its energy in little pieces.

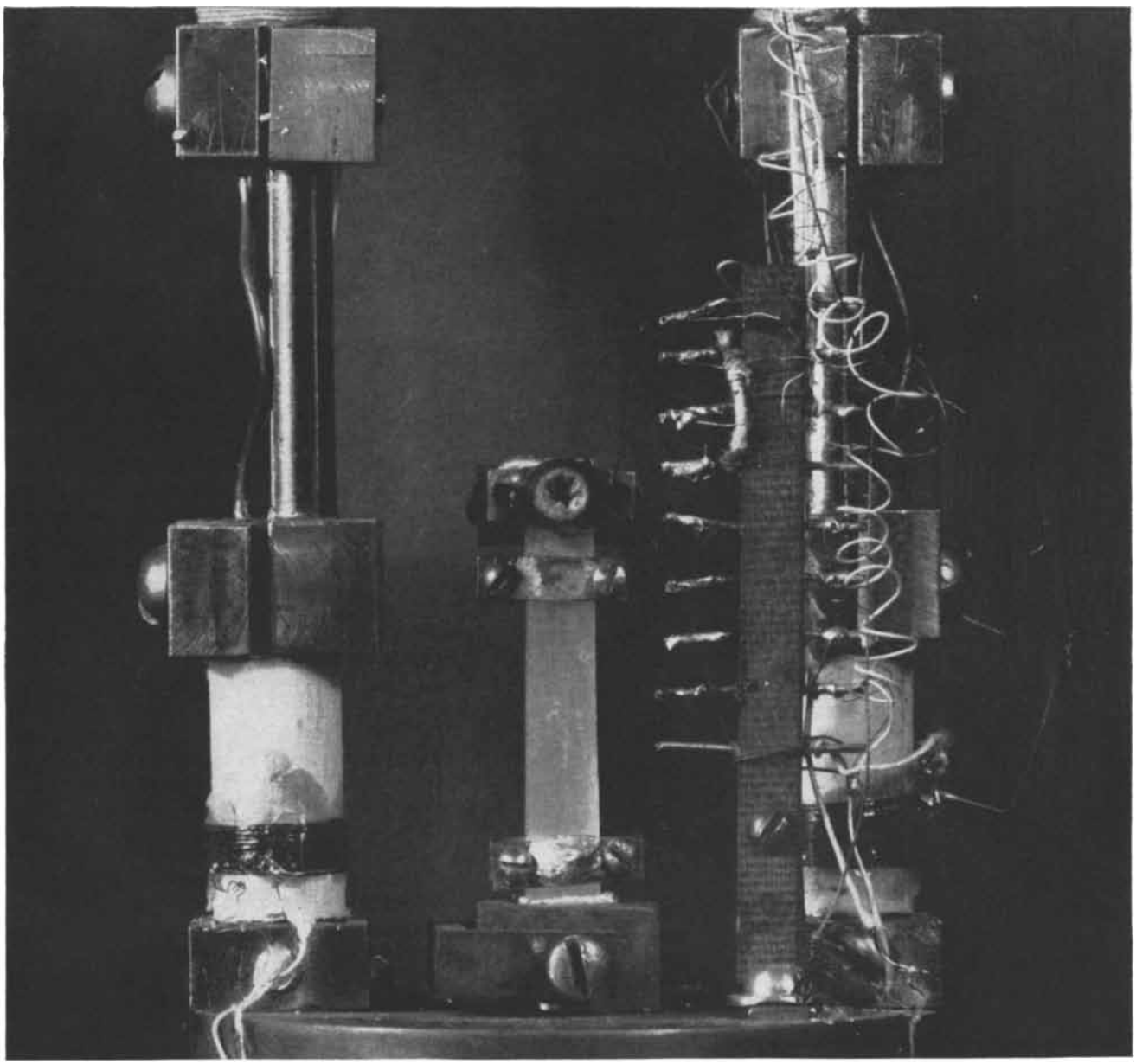
Imperfections in the crystal, represented by the substitution of atoms of a different kind for atoms of the pure metal, or by the restless thermal motion of the atoms around their "home" positions in the perfect-crystal lattice, scatter electrons and impede the flow of heat. Again the process can be compared to the incorporation of impurity atoms into an otherwise transparent glass: the impurities absorb light, and they color and even blacken the glass by means of this absorption. Thus the length of the path of an electron proves to be shorter in brass, in which zinc atoms have been added to copper, than it is in pure copper. The path length is also shorter at higher temperatures, because the random motion of the atoms at higher temperatures makes the substance more "turbid" to electron movement.

This discussion of the importance of the average length of the path traveled by the electron between collisions applies to the pushing of electrons by an electric field as well as to the pushing of electrons by a temperature difference. A good metallic conductor of electricity is therefore a good conductor of heat. Silver wins both races for the best conductor, with copper, gold and aluminum close behind. In fact, the thermal conductivity for all metals at the same temperature turns out to be equal to the electrical conductivity of the metal multiplied by a constant.

The two properties, however, do not vary equally with change in temperature. As the temperature rises, the electrical conductivity of a metal decreases almost reciprocally with the absolute temperature. This is true because the atomic vibrations become larger in proportion to the absolute temperature and the electron paths become correspondingly shorter. The thermal conductivity, on the other hand, executes a neat balancing act that leaves it independent of temperature. The average length of the electron paths decreases, to be sure, as the temperature increases, but the amount of heat carried by each electron is proportional to the temperature. The thermal conductivity is proportional to the product of these two quantities and so remains independent of temperature.

Proceeding now from metals, with their abundant supply of mobile electrons, to semiconductors, with fewer electrons, and ultimately to insulators, with virtually none, one finds that electrical conduction and thermal conduction part company. The electrical conductivity drops as the mobile electron concentration does and reaches remarkably small values for good insulators such as quartz: silver is about 10^{24} times better as a conductor of electricity than quartz is. The thermal conductivity, however, shows no such drop in value. As the electron concentration decreases, the thermal conductivity falls to perhaps a hundredth or a thousandth of the values characteristic of metals and then falls no more. There are, in fact, no good solid heat insulators. An effective heat insulator is not a solid at all but a porous, low-density substance composed mostly of dead air space.

Clearly some process other than conduction by electrons must take over the task of carrying the heat in nonmetals. This process is even more intricate and interesting than conduction by electron motions. It is the conduction of heat by



CRYOSTAT for measuring the thermal conductivity of a crystal (*vertical translucent bar*) at very low temperatures is shown at about twice its actual size. Heat flows into the crystal from the tiny electrical heater attached to the top of the crystal; identical thermometers are clamped near each end. In use the apparatus is enclosed in an evacuated copper can immersed in liquid helium.

the vibrations of the atoms themselves. This process also occurs in metals, but it is covered up by the more effective electron process.

The mechanism of heat transport by atomic vibrations is basically simple. Atoms in a solid are packed tightly together. If an atom is set moving back and forth when part of a solid is heated, the atom nudges its neighbors, which in turn transmit this motion to their neighbors. Atomic kinetic energy is thereby carried from the hot parts of the solid to the cold. On the macroscopic scale this flow of kinetic energy shows up as a flow of heat. The mechanism is identical with the transport of sound waves in a solid, since they too are carried by the pushing of atoms by one another. The typical vibration frequencies of the atoms in thermal motion, however, far exceed those of audible sound. In heat conduction, frequencies of 10^{13} cycles per second are common. This is 35 octaves above middle C!

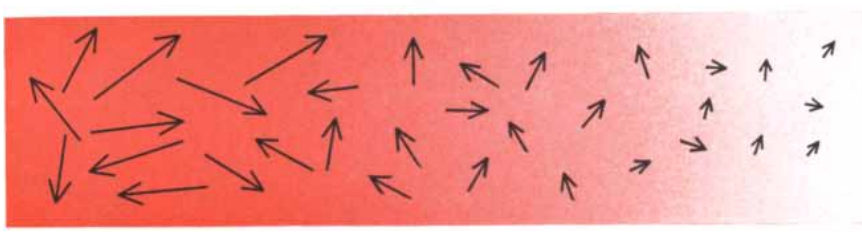
The system of atoms behaves like a system of masses and springs. Each mass is the analogue of a nucleus with its accompanying tightly bound electrons, and the springs are the analogues of the interatomic forces. Each mass in such a system has an equilibrium position that is equivalent to the home position of an atom, and it will vibrate around this position if it is initially displaced. If a mass in one part of the network is shaken, its motion is communicated to the other masses. This is analogous to the flow of heat from a hot to a cold region of a solid. After the external shaking has ceased all the masses will ultimately acquire the same kinetic energy of vibration, just as ultimately all the atoms in a solid arrive at the same temperature, which is a measure of their kinetic energy of vibration.

These atomic vibrations actually occur in tiny bunches called phonons. A phonon is simply a pulse of sound waves, comparable to the pulse of water waves from a stone dropped into water. Its name expresses its similarity to the photon, which is a pulse of light waves. The basic quantum nature of matter insists that energy occurs only in indivisible little lumps—quanta. Phonons and photons are respectively the quanta of sound waves and light waves. Phonons, then, are the carriers of heat in nonmetallic solids.

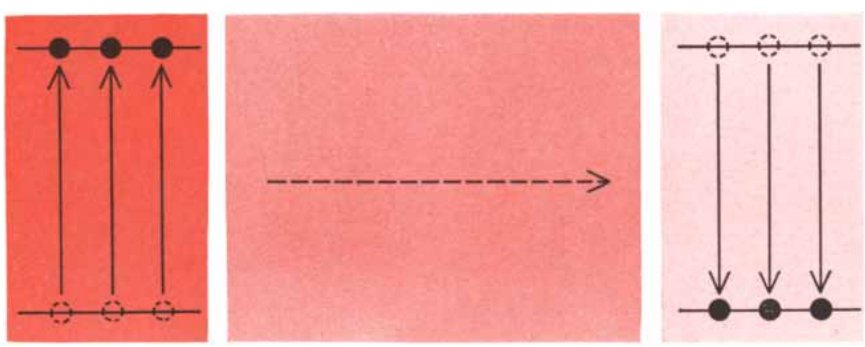
The thermal conductivity of a solid depends in a simple and almost obvious way on the properties of phonons. It is naturally proportional to the number of phonons present, which increases rapidly with increasing temperature. It is proportional to the speed of the phonons, which is equal to the speed of sound waves in the solid and varies only slightly with temperature. Last and most important, the thermal conductivity is proportional to the free path that each phonon travels before it collides with some imperfection in the crystal. Such a collision, like the collisions of electrons with imperfections in the crystal lattice, reflects a phonon back toward the warm end of the solid. It is the variation of this free path from one temperature to another and from one solid to another that, more than any other factor, controls the thermal conductivity of all solids, metals as well as nonmetals.

At ordinary temperatures solids are generously supplied with phonons. There are pulses of atomic vibrations moving in all directions. Paradoxically this abundance decreases the heat conductivity by phonons, which drops steadily as the temperature increases above room temperature. Although the number of phonons increases as the temperature rises, they impede one another's movements so seriously that their path lengths diminish faster than their population expands, in a manner suggesting the overcrowding of a highway or of a cocktail party. When an atom is displaced from its home position by the passage of a phonon, another phonon encountering the misplaced atom is strongly diverted. The phonons themselves impede their own motions as they grow in numbers. At high temperatures phonons move scarcely farther than the distance between neighboring atoms before they are scattered.

The presence of heavy atoms in a solid decreases the heat conductivity by lowering the velocity of sound and by enhancing the scattering of phonons. Designers of thermoelectric materials take advantage of this knowledge by employing heavy elements such as bismuth or tellurium, which have low heat conductivity, in compounds with metals that are rich in free electrons to provide high electrical conductivity. A major portion of the energy of heat, supplied to one end of such a thermoelectric generator, is carried by the free electrons to the other end in the form of electric current. The heavy atoms in the compound meanwhile impede the transfer of energy by the phonons, maintaining the temperature gradient between the hot and cold ends of the generator [see "The Revival of Thermoelectricity," by



ELECTRONS IN METAL have greater speeds (i.e., greater kinetic energy) at higher temperatures. The flow of some of the more energetic electrons (*represented by longer arrows*) to the cooler part transfers their kinetic energy to that part, which is thereby heated.



THERMAL EXCITATION of electrons (*black dots*) in the hotter region of a solid raises them to higher energy levels and releases them from the atoms in which they were bound. Subsequent diffusion of these electrons to a cooler region is followed by the release of the excitation energy when they recombine with other atoms (i.e., fall to lower energy levels). This may be the dominant process of heat flow in nonmetals at extremely high temperatures.

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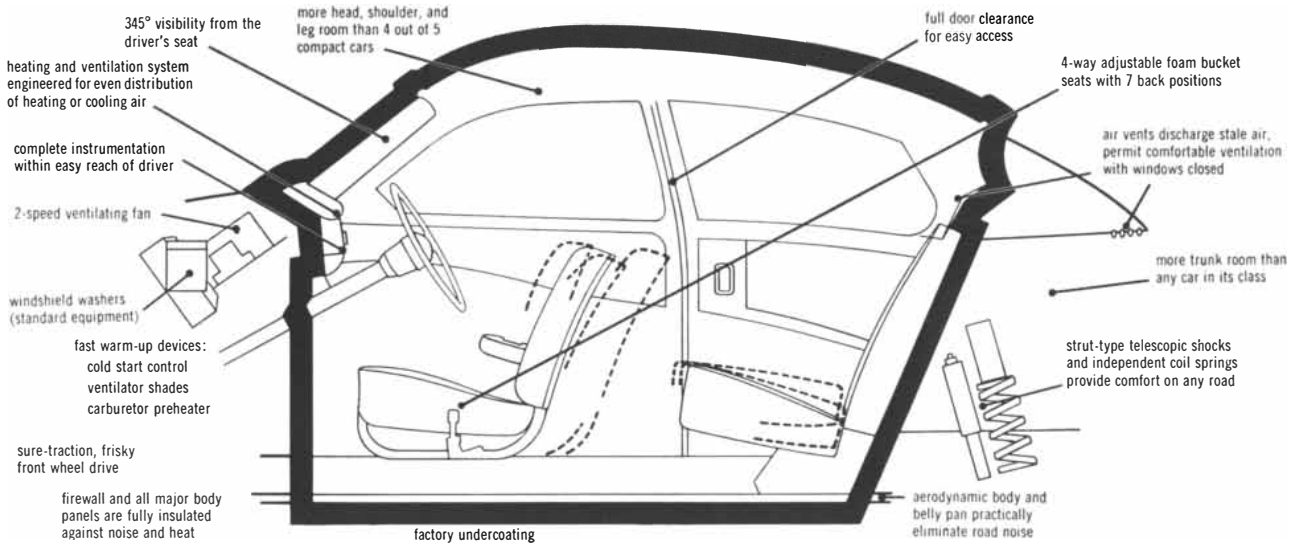

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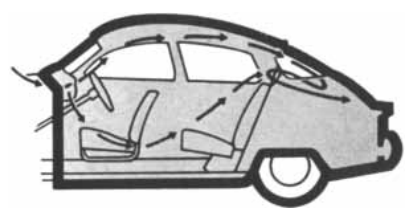

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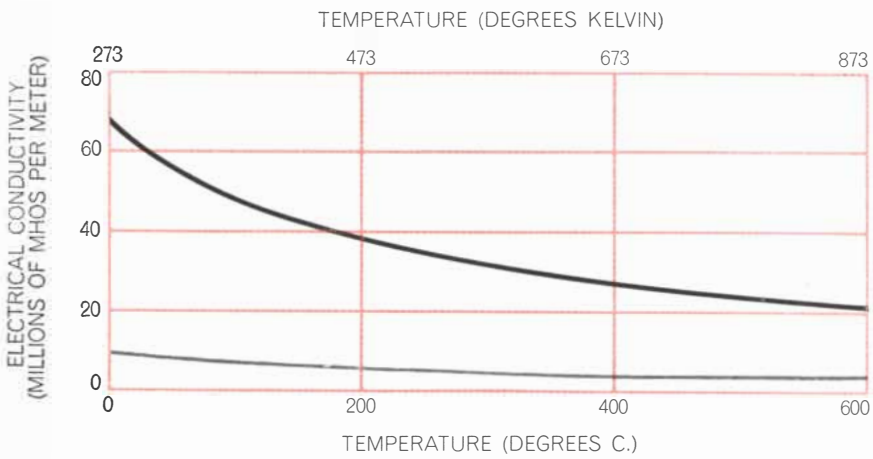
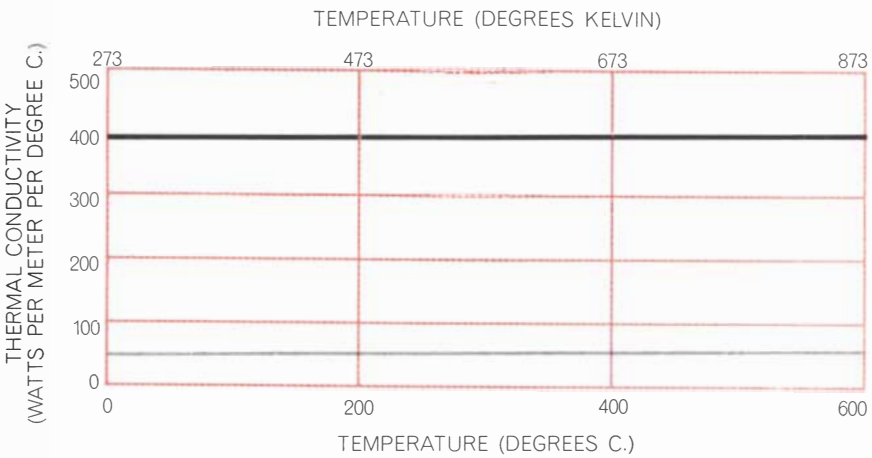


ELECTRICAL CONDUCTIVITY in a metal falls as the temperature increases, because the mean free paths of the heat carriers (i.e., the electrons) are progressively reduced. The two metals represented by these electrical conductivity curves are silver (*black*) and iron (*gray*).



THERMAL CONDUCTIVITY of silver (*black*) and iron (*gray*), or of any metal, remains constant as the temperature rises, because the energy carried by each electron increases sufficiently to compensate for the reduction in the mean free paths of the electrons.

Abram F. Joffe; SCIENTIFIC AMERICAN, November, 1958].

It is at temperatures far below room temperature—temperatures near absolute zero, or minus 273 degrees centigrade—that the most striking phenomena of heat conduction occur. Although measurements in this regime date from the liquefaction of atmospheric gases and of helium half a century ago, only recently was the richness of the field of low-temperature studies of heat flow discovered by Robert Berman and others at the University of Oxford. At low temperatures solids such as rock-salt crystals exhibit heat conductivity that is as much as 400 times greater than it is at room temperature. Furthermore, the thermal conductivity at low temperatures is strikingly responsive to the addition of minute traces of impurities or other imperfections in crystals. Studies of thermal conductivity in this temperature region thus powerfully assist the chemist, the physicist and the metallurgist in their investigations of the approach to perfection in crystals.

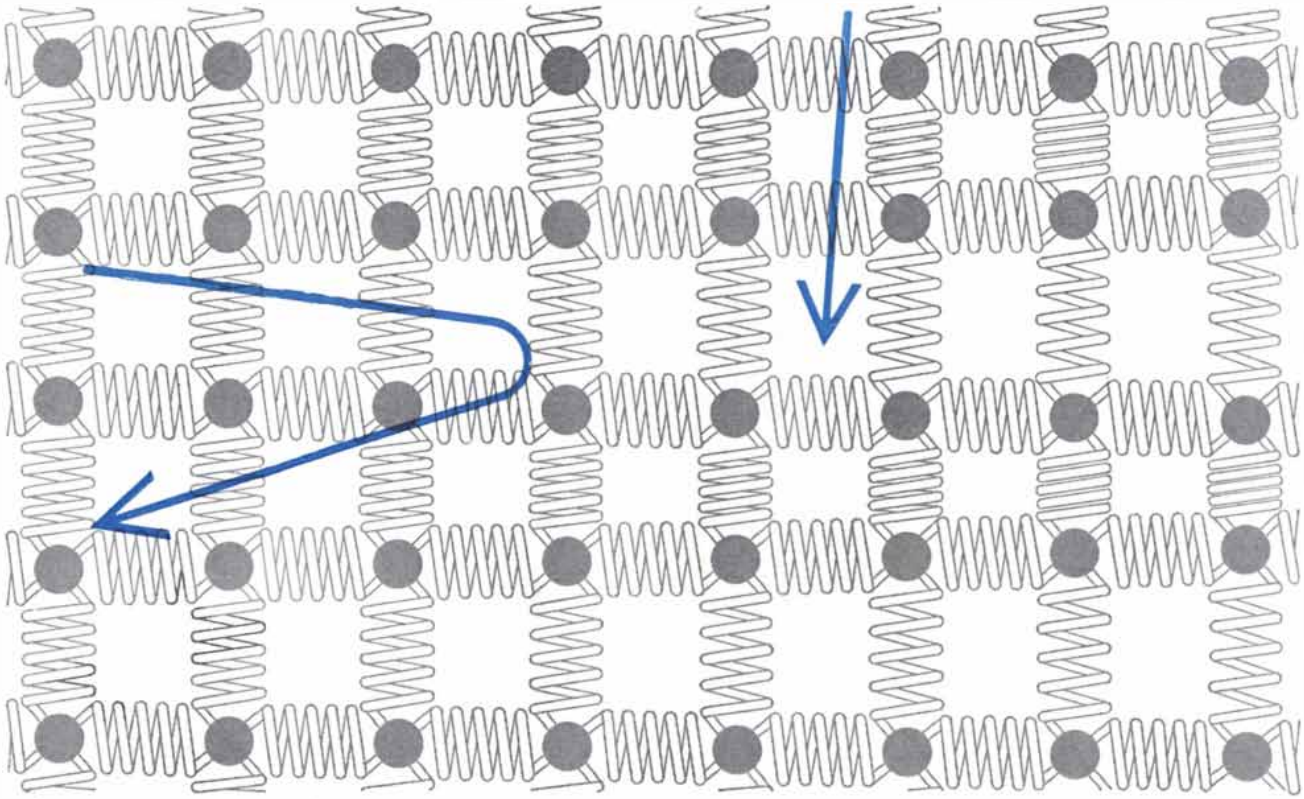
As the temperature drops, the thermal conductivity of nonmetals rises because the free path length of the phonons increases faster than the number of phonons decreases. Eventually a temperature is reached at which this path length —less than a millionth of an inch at room temperature—grows to lengths comparable to the dimensions of the specimen, typically an eighth or a quarter of an inch. Below this temperature the paths of the phonons are terminated by the edges of the crystal, and the phonons are reflected back into the interior of the crystal. The thermal conductivity drops sharply below this temperature; this is because the number of phonons decreases rapidly with further decline in

temperature, while the phonon path length and the phonon speed remain constant.

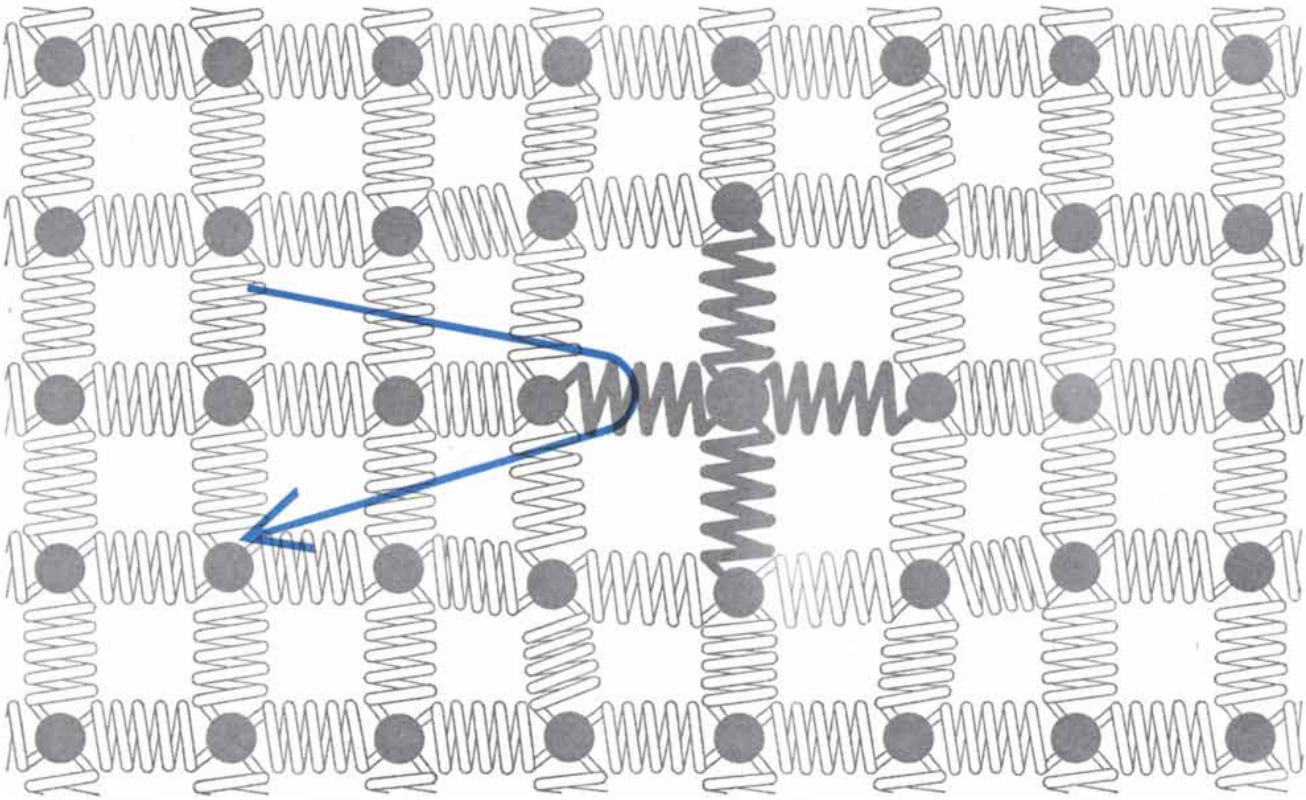
This interpretation of the increase and then the abrupt decrease in the conductivity of materials with decline in temperature was first derived in theory by H. B. G. Casimir of the University of Leiden from early measurements made by W. J. de Haas and Th. Biermasz of the same institution. A convincing demonstration of the validity of the proposed physical process has recently been given by Robert O. Pohl of Cornell University. He cut two specimens of different cross-sectional dimensions from the same single crystal of the salt lithium fluoride and found that the conductivity of the smaller specimen fell off sooner with the fall of temperature, in convincing agreement with Casimir's theory.

Recently Miles V. Klein, now at the University of Illinois but then at Cornell University, provided a dramatic demonstration of the fact that the thermal conductivity at low temperatures is highly sensitive to crystal imperfections. He measured the conductivity of crystals of sodium chloride (common salt) obtained from different sources in the form of large single crystals. Although each crystal was nominally pure and all were much purer than the "pure" chemicals on the shelf of a chemistry laboratory, the measured conductivities differed astonishingly. Since chemical impurity incorporated in a crystal scatters phonons, lower conductivity in certain of the specimens could be taken as evidence of imperfections in their crystal structures. Auxiliary chemical and physical experiments on these specimens indicated that an oxygen-containing radical, such as carbonate ion, was probably responsible for the depression of the conductivity in the less pure crystals. Klein intentionally "doped" crystals with oxygen-containing ions in known concentrations. One of these crystals, with only one part in 3,000 of this impurity, exhibited a conductivity comparable to that of the "pure" crystal with the lowest conductivity of the group. Therefore the purest of the crystals, with a low-temperature conductivity 100 times greater than that of the least pure, must have had less than one part in 300,000 of the impurity.

Under favorable conditions the thermal conductivity at low temperatures is sensitive to impurities even when they are present in concentrations of only one part per million. Since the atoms of



PHONON (*arrow at right*) displaces atoms from their normal positions. In the mechanical model of atoms in a solid depicted here, the atoms are represented by masses (*gray circles*) and the interatomic forces by springs. Another phonon arriving at this time would encounter a region of imperfection; it would be strongly reflected (*curved arrow at left*), its free path terminated and the flow of heat impeded. Such phonon-phonon scattering limits the thermal conductivity of materials at ordinary and high temperatures.

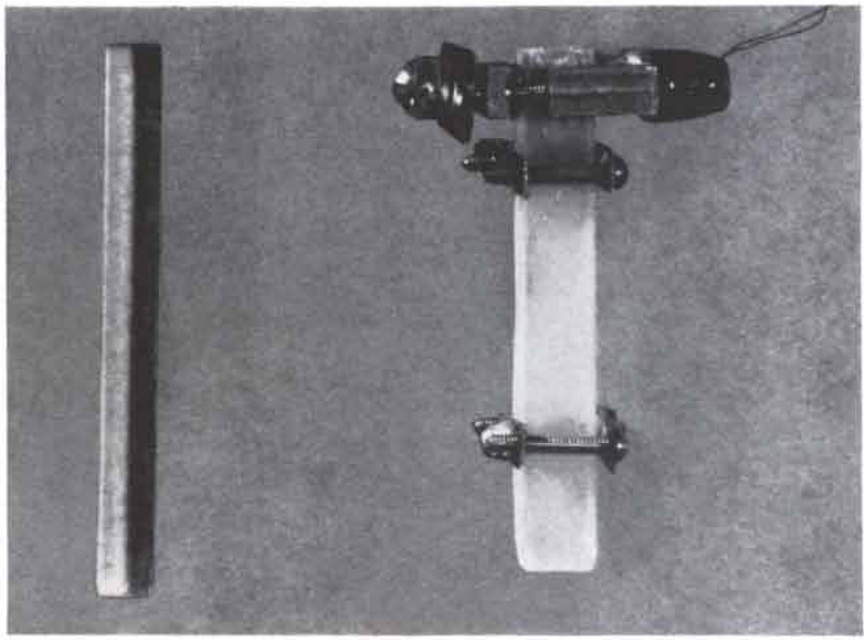


IMPURITY IN CRYSTAL LATTICE introduces a different mass (*large gray circle*) and a different interatomic force (*gray springs*). An incident phonon is strongly reflected (*curved arrow*). Phonon-imperfection scattering is particularly prominent in limiting thermal conductivity at low temperatures; with large impurity concentrations it can be an important factor at room temperatures.

an element in a crystal can be those of two or more isotopes with slightly different masses, the purest crystal may be composed of atoms of varying masses. Glen A. Slack, now at the General Electric Research Laboratory but then at Cornell, first discovered that even this small variation produced an observable depression of the thermal conductivity.

Thermal conductivity measurements are not only sensitive as a method for studying crystal perfection; they are also selective. When different kinds of imperfections limit the phonon paths in a crystal, the thermal conductivity behaves differently as a function of temperature. Pohl has irradiated a lithium fluoride crystal with X rays, thereby creating imperfections known as F-centers, in a concentration of about one F-center for each 100,000 atoms of the crystal. An F-center is a site that would be occupied by a fluorine ion if the crystal were perfect but that is occupied instead by an electron. This imperfection is localized in a very small region of the crystal and approximates a point imperfection. Another group at Cornell has squeezed lithium fluoride crystals in order to introduce "dislocations," that is, imperfections resulting from the slippage of whole rows and planes of atoms during deformation. Comparison of the variations in the thermal conductivity of crystals flawed by point imperfections and by dislocations showed that conductivity in each case varied with temperature in a characteristic way. Thus in addition to the mere detection of an imperfection, it is frequently possible to learn much about the nature of the imperfection in an "unknown" crystal by analyzing the curve of thermal conductivity as a function of temperature.

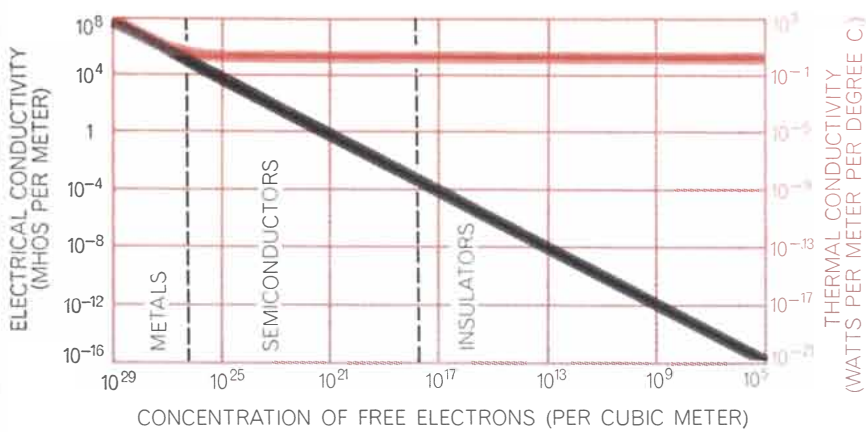
In all of these experiments there are two considerations that compel the use of the low-temperature regime, even though it requires complex apparatus and the handling of liquid helium. At low temperatures, first of all, the limitation of path length by phonon-phonon crowding is not important; path lengths hence become quite long and highly sensitive to the presence of minute concentrations of imperfections. Second, in order to explore temperature dependence it is necessary to cover a wide range of temperature, say a factor of 100 in absolute temperature. Such a range is available only by "dividing" room temperature, that is, by going downward on the temperature scale to within a few degrees of absolute zero; it is impossible to multiply room temperature 10 times



POTASSIUM CHLORIDE CRYSTALS for thermal conductivity experiments are approximately 40 millimeters long. The specimen at right, with an electrical heater (a wire-wound resistor) and two clamps attached to it, is ready to be mounted in the cryostat apparatus.

or so on the absolute scale (from 300 degrees centigrade above absolute zero, say, to 3,000 degrees) before approaching the upper limit of the temperatures at which materials remain solid. Information gained about phonon-transport processes from low-temperature experiments has already advanced the design of materials for use in practical devices at ordinary temperatures.

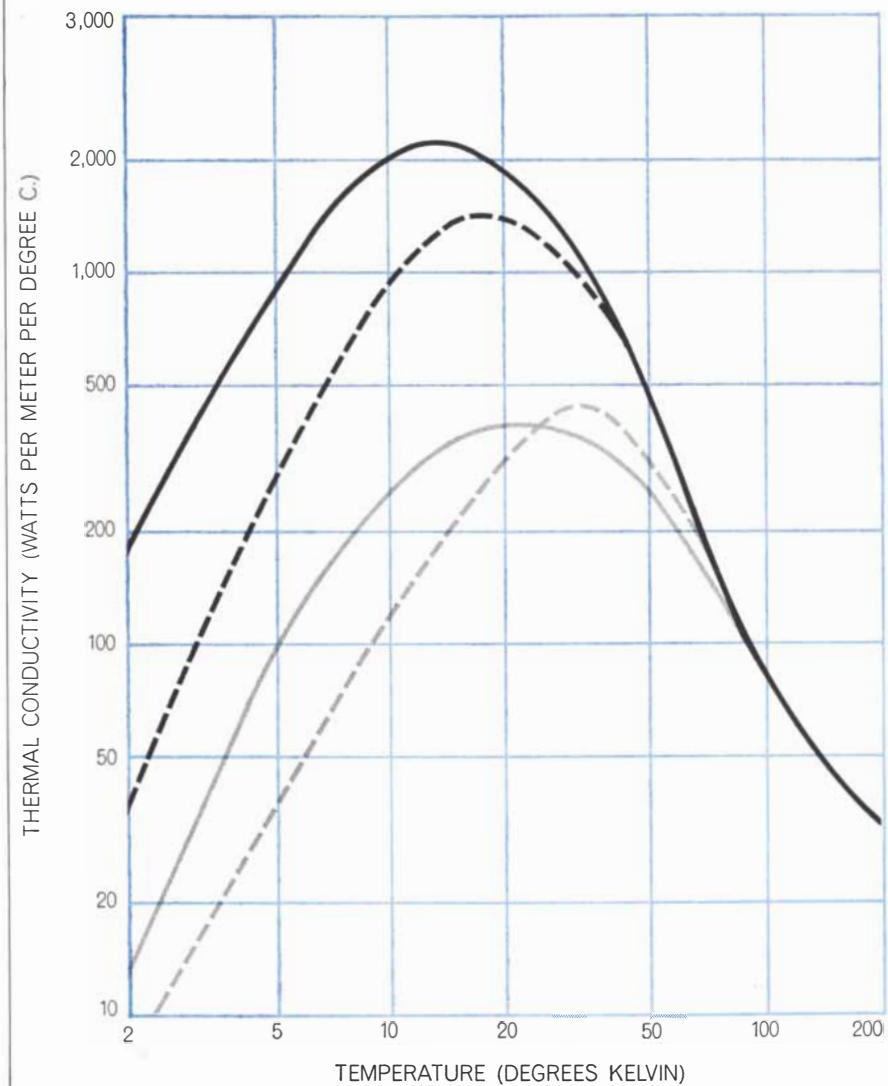
High temperatures nonetheless present intriguing problems in heat flow in nonmetals. Since thermal conduction by phonon transport becomes steadily less effective as the temperature climbs, other heat-transport processes eventually dominate. One such process is ordinary radiant-heat transport: the mechanism by which the sun's heat comes to earth across millions of miles of space and by which an infrared lamp warms its surroundings. This process is simply the transport of photons of visible light or of infrared radiation. The transport proceeds through transparent solids as well as through a vacuum. The heat radiated through a transparent quartz rod when one end is heated to a high temperature vastly exceeds the heat carried by phonons. As glass blowers



CONCENTRATION OF FREE ELECTRONS in a solid directly affects its electrical conductivity; that is, as this concentration decreases (proceeding from metals through semiconductors to electrical insulators), the electrical conductivity (*black curve*) decreases correspondingly. Thermal conductivity (*colored curve*) is similarly affected at first, but heat transport by atomic vibrations soon begins to dominate, preventing any further decrease.

are well aware, the radiant heat is "piped" by internal reflection within the rod; although the walls of the rod may feel only warm, a bad burn results if the radiation emerging from the unheated end falls on one's hand. At sufficiently high temperatures this radiation process becomes important even in an opaque material such as ordinary china. In such a translucent material the free paths of the photons are short but not infinitesimal, and heat is still transferred by radiation.

Another heat-conducting process arises at high temperatures in nonmetals from an electron energy-transport mechanism that is different from free-electron flow. Nonmetals do not have anything like the concentrations of free electrons (several per atom) that metals have. A few electrons, however, can be removed from atoms if the temperature goes high enough. The energy required to pull an electron away from an atom is many times greater than the kinetic energy of motion of a typical free electron. Electrons thermally released from atoms at the hot end of a bar of nonmetallic solid can diffuse toward the cooler end, just as in a metal. At this point they can again combine with atoms, releasing the same amount of energy that was supplied to them at the hot end. Although these electrons have carried some kinetic energy, as in a metal, the far more important burden they have carried is the energy



SIZE AND IMPERFECTIONS affect thermal conductivity differently. The only difference between the crystals represented by the two curves at top is that one (*solid black line*) is larger than the other (*broken black line*). Below about 50 degrees Kelvin the phonon paths are terminated by collisions with the crystal surfaces, giving the smaller crystal a lower conductivity. The chief difference between the larger crystal and those represented by the two curves at bottom is that the latter contain either numerous F-centers (*solid gray line*) or dislocations (*broken gray line*), whereas the former has had no imperfections added.

California Institute of Technology : Case Institute of Technology : University of Chicago : Columbia University : University of Illinois
Massachusetts Institute of Technology : University of Michigan : Pennsylvania State University : Princeton University : Stanford University : Tulane University

Woof

Warp is the threads that run the long way in woven fabric, and woof is the threads that run the short way. When they are interwoven, a strong and useful product results. * Let's say the warp is the Department of Defense and that the fabric desired is an effective national defense. The Institute for Defense Analyses helps to weave in the technical inputs that make the fabric strong. * IDA is an association of eleven universities, formed at the behest of the government to serve as a medium by which the academic and scientific community can provide the technical advice needed in the Department of Defense to develop the fabric of national defense. Many universities that are not Members also participate in the substantive work. * The IDA roster is filled from all sources of scientific and engineering talent from industry, from research laboratories, and from academic faculty and graduates. The IDA staff grapples with problems of great moment, and often of great urgency, in which science is a principal ingredient. * Thus IDA weaves separate but interdependent strands into the protective clothing of the national body. Its work involves the highest level of sophistication in technology, and affects the highest level of responsibility in the national defense. * IDA seeks highly qualified scientific and engineering talent. A permanent career with IDA is a most satisfying possibility for capable people. IDA also welcomes, and due to its unique nature can put to good use, learned and skillful people for comparatively short periods of time. If you feel you are qualified to make a contribution to this vital work, & wish to do so, let's discuss the matter. It's possible that you could be a great help to us.

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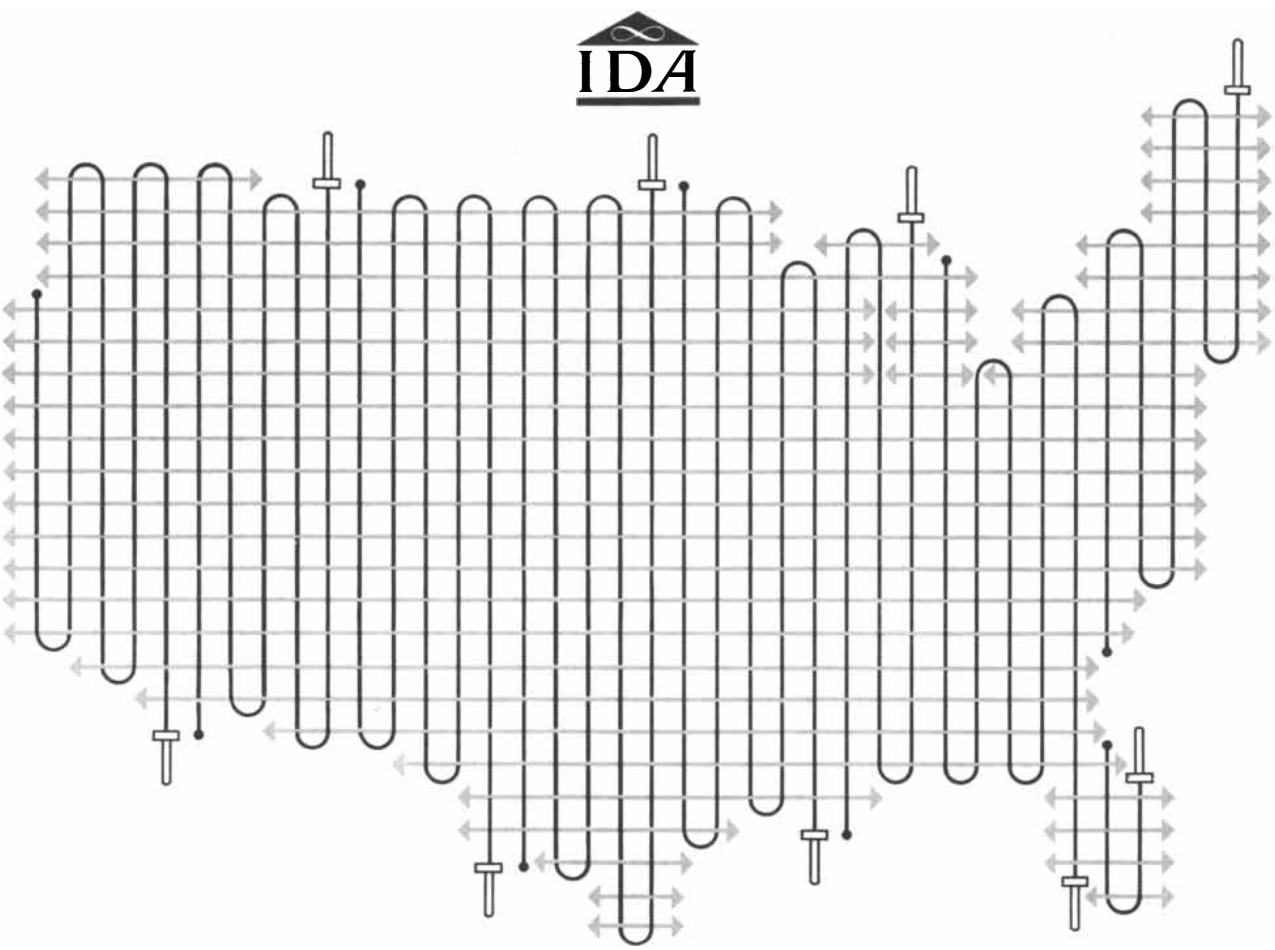
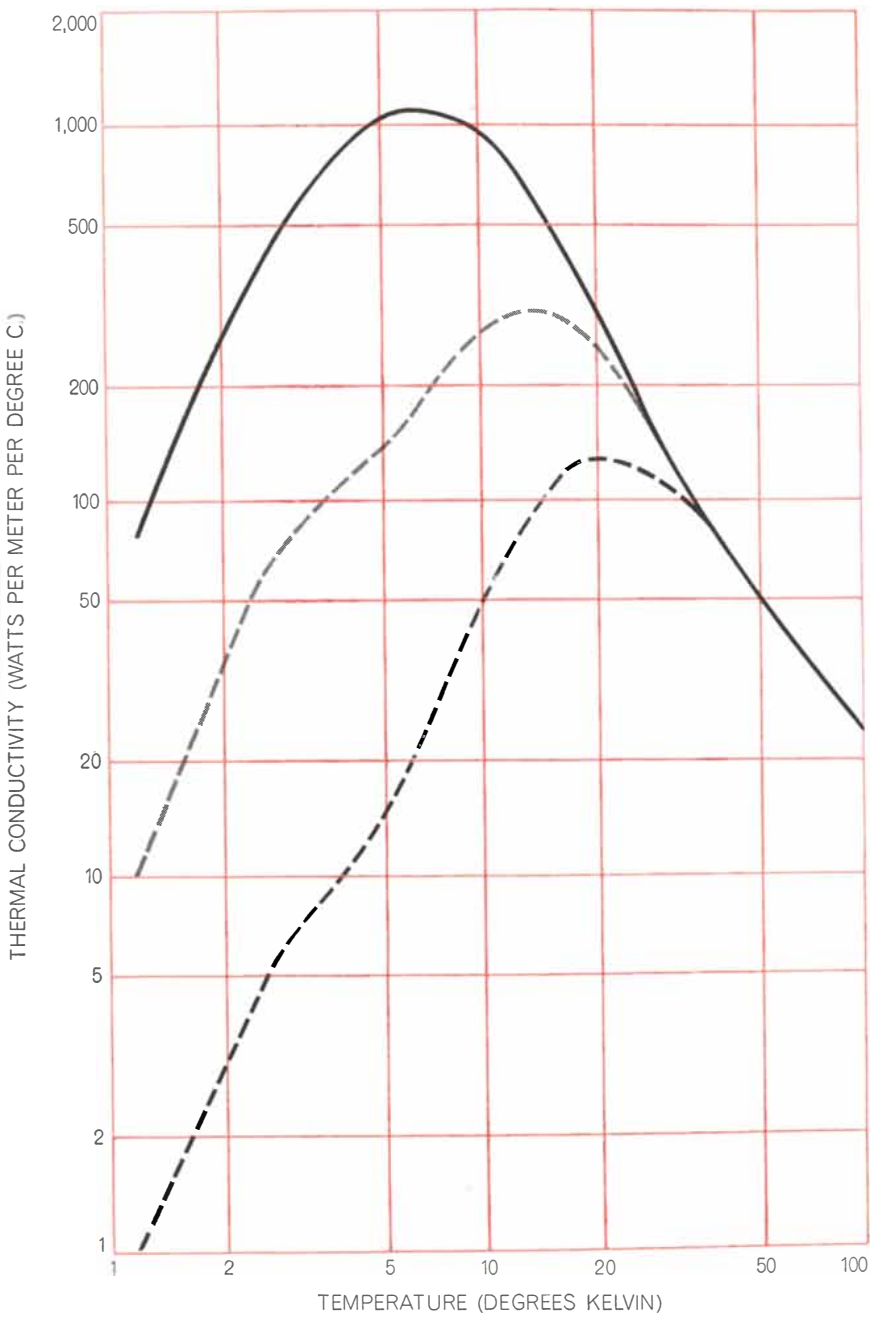


required to release them from atoms. Hence at high temperatures a relatively few electrons in a nonmetal, each carrying this large energy, can be as effective heat carriers as the electrons in a metal.

It is not easy to determine whether radiation or excitation transport is the more important in a given material at a high temperature. Measurements are difficult, largely because of errors induced by radiant heat gain or loss at the surface of the test specimen. Yet more measurements and understanding are urgently needed to design such devices as thermoelectric power generators.

Thus the venerable old experiment of measuring the thermal conductivity of a solid has acquired new vitality. Part of the renewed vigor springs from the need for exotic materials with controlled conductivities at extremes of temperature. But a major part arises from the power and versatility of low-temperature thermal conductivity measurements for the study of physical processes in solids.



THREE SODIUM CHLORIDE CRYSTALS, all chemically pure, nonetheless show considerable differences in their thermal conductivity. Impurities in the two commercially available crystals (*two bottom curves*) depress conductivity by as much as a factor of 100. The third (*solid black curve*) is an experimental specimen grown from highly purified salt.

"zzzzzzzzzz... cyclododecatriene... mumble... mumble"

The wife of a research chemist hears many mumbles — then just sighs and goes back to sleep. She knows her husband and his friends talk, read, write and live a special language. And its vocabulary is often bewildering: cyclododecatriene is a good example.

This Enjay chemical is currently being used to add special properties to plasticizers, resins and lubricants. It is one of the bright new stars in Enjay market development — another example of the way Enjay scientists and marketers move ahead with new ideas, new methods, new products. If you would like help in bringing tomorrow's profits closer to reality, write Enjay, 60 West 49th St., New York 20, N. Y.

ENJAY CHEMICAL COMPANY, a division of Humble Oil & Refining Company

ENJAY

This is the source of new scientific measuring accuracy

PROGRESS

in scientific measurement depends in part on continuing improvement of the oscilloscope, a basic measuring tool that visually displays repetitive or fleeting electrical phenomena.

Dramatic improvements in circuitry have made the oscilloscope a versatile and indispensable tool. Yet, refined and sophisticated as scope circuitry may be, the limitations of conventional cathode ray tubes can create reading errors which only improved CRT design can correct. Hewlett-Packard has combined both electronic and *manufacturing* achievements to produce oscilloscope CRTs that come closer than ever before to eliminating human reading error.

Three basic improvements have been made: a 50% greater picture size on a high-frequency scope, removal of parallax viewing error, and the elimination of reflected glare.

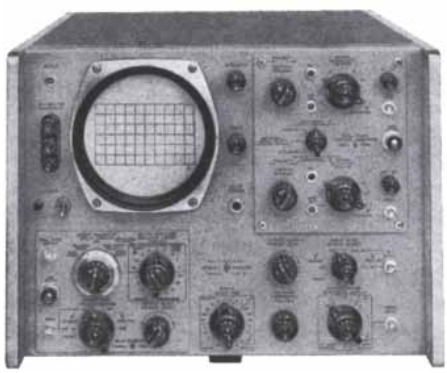
For high speed (50 MC) oscillography, hp has produced an entirely new cathode ray display tube. This new 12,000 volt CRT displays high speed electrical signals on a full 6 cm x 10 cm calibrated screen (50% larger than previously available for high frequencies). Deflection defocusing has been eliminated, and the sensitivity of the CRT has been doubled. Less amplification is needed to swing the electron beam so simpler, more reliable driving circuits can be used. The 50% larger display that stays in focus at full deflection significantly reduces the reading error.

Second, hp developed a manufacturing technique to eliminate a parallax viewing error which, on most oscilloscopes sold today, can be as great as 5% unless every portion of the trace is viewed from precisely in front of that part of the screen. This parallax error was caused by a separation as great as ¼" between the trace, falling on the inside of the CRT face, and the square-centimeter-scribed scaling graticule, placed on the outside surface of the CRT face. hp completely eliminated parallax error by placing the graticule on the inside of the tube, in the same plane as the trace. Readout is now identical from any angle.

Finally, glare and reflections from ambient light have always plagued scope users. Viewing screens blocked out reflected light but limited viewing to one person at a time. Now, an etching process on the surface of the safety glass face plate on hp CRTs eliminates glare, at the same time preserving clear viewing.

Illustrated here is the electron gun against a background of flame from the gas jets of the assembly fixture.

Hewlett-Packard oscilloscope technology includes the continuing improvement of cathode ray tube design and construction for new scientific measuring accuracy.



hp 175A 50 MC Universal Oscilloscope

is the first hp scope to incorporate the new 12 Kv no-parallax CRT as standard equipment, although the no-parallax feature is available as standard or as an optional extra on other hp scopes. The 175A offers a 50 MC main vertical amplifier; plug-in versatility for dual trace viewing to 40 MC, high sensitivity, sweep delay, time marker, X-Y recorder output; simple calibration and maintenance; preset automatic trigger over entire bandwidth; new hp modular packaging for bench and rack mount in a single instrument. $1,325.00 (Basic instrument. Versatile plug-ins optional at extra cost.)

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The Use and Misuse of Game Theory

Can this fashionable technique really be used to solve the problems of human conflict? The author believes that it cannot, but that it can teach us what to do in order to solve such problems rationally

by Anatol Rapoport

We live in an age of belief—belief in the omnipotence of science. This belief is bolstered by the fact that the problems scientists are called on to solve are for the most part selected by the scientists themselves. For example, our Department of Defense did not one day decide that it wanted an atomic bomb and then order the scientists to make one. On the contrary, it was Albert Einstein, a scientist, who told Franklin D. Roosevelt, a decision maker, that such a bomb was possible. Today, in greater measure than ever before, scientists sit at the decision makers' elbows and guide the formulation of problems in such a way that scientific solutions are feasible. Problems that do not promise scientific solutions generally tend to go unformulated. Hence the faith in the omnipotence of science.

The self-amplifying prestige of science among decision makers has been further amplified in this period by the popularization of a scientific aid to the task of decision making itself. This is game theory—a mathematical technique for the analysis of conflict first propounded by the late John Von Neumann in 1927 and brought to wide notice by Von Neumann and Oskar Morgenstern in 1944 in a book entitled *Theory of Games and Economic Behavior*. Now, game theory is an intellectual achievement of superlative originality and has opened a large new field of research. Unfortunately this is not the way game theory has been embraced in certain quarters where Francis Bacon's dictum "Knowledge is power" is interpreted in its primitive, brutal sense. The decision makers in our society are overwhelmingly preoccupied with power conflict, be it in business, in politics or in the military. Game theory is a "science of conflict." What could this new science be but a reservoir of power for those who get there fastest with the mostest?

A thorough understanding of game theory should dim these greedy hopes. Knowledge of game theory does not make any one a better card player, businessman or military strategist, because game theory is not primarily concerned with disclosing the optimum strategy for any particular conflict situation. It is concerned with the logic of conflict, that is, with the theory of strategy. In this lies both the strength and the limitation of the technique. Its strength derives from the powerful and intricate mathematical apparatus that it can bring to bear on the strategic analysis of certain conflict situations. The limitations are those inherent in the range of conflicts to which this analysis can be successfully applied.

No one will doubt that the logic of strategy does not apply to certain conflicts. For example, there are no strategic considerations in a dogfight. Such a conflict is better thought of as being a sequence of events, each of which triggers the next. A growl is a stimulus for a countergrowl, which in turn stimulates the baring of teeth, sudden thrusts and so on. Signals stimulate postures; postures stimulate actions. Human quarrels, where symbolic rather than physical injuries are mutually stimulated, are frequently also of this sort. Conflicts of this kind can be called fights. The motivation in a fight is hostility. The goal is to eliminate the opponent, who appears as a noxious stimulus, not as another ego, whose goals and strategies, even though hostile, must be taken into account. Intellect, in the sense of calculating capacity, foresight and comparison of alternative courses of action, need not and usually does not play any part in a fight.

Game theory applies to a very different type of conflict, now technically called a game. The well-known games such as poker, chess, ticktacktoe and so forth are games in the strict technical sense. But what makes parlor games games is not their entertainment value or detachment from real life. They are games because they are instances of formalized conflict: there is conflict of interest between two or more parties; each party has at certain specified times a range of choices of what to do prescribed by the rules; and the outcome representing the sum total of choices made by all parties, and in each case involving consideration of the choice made by or open to the other parties, determines an assignment of pay-offs to each party. By extension, any conflict so conducted falls into the category of games, as defined in game theory. Nor does it matter whether the rules are results of common agreement, as in parlor games, or simply of restraints imposed by the situation. Even if no rules of warfare are recognized, a military situation can still be considered as a game if the range of choices open to each opponent at any given stage can be exactly specified.

Let us see how chess and poker each fulfill these requirements. In chess the conflict of interest is, of course, implied

Bark and counterbark

in each player's desire to win. The range of choices consists for each player of all the legal moves open to him when it is his turn to move. The outcome is determined by all the choices of both players. The pay-offs are usually in psychological satisfaction or dissatisfaction. In poker the situation is much, but not entirely, the same. The choices are (at specified times) whether or not to stay in; which cards, if any, to throw off; whether or not to raise and by how much and so on. The outcome of each round is the designation of one of the players as the winner. Pay-offs are usually in money.

Poker differs from chess in one important respect. In a poker game there is an extra (invisible) player, who makes just one choice at the beginning of each round. This choice is important in determining the outcome, but the player who makes it has no interest in the game and does not get any pay-off. The player's name is Chance, and his choice is among the nearly 100 million trillion trillion trillion trillion trillion (10^{68}) arrangements of the deck at the beginning of each round. Chance makes no further choices during the round; the rest is up to the players. One can argue that Chance continues to interfere, for example by causing lapses of memory, directing or misdirecting the attention of the players and so forth. But game theory is concerned only with what perfect players would do.

Although Chance may thus play a part, the game as defined by game theory is clearly distinguished from gambling as treated by the much older and better-known mathematics of gambling. The latter has considerable historical importance, since it is in the context of gambling theory that the mathematical theory of probability was first developed some 300 years ago. This theory has since been incorporated into all branches of science where laws of chance must be taken into account, as in the physics of small particles, genetics, actuarial science, economics, experimental psychology and the psychology of mass behavior. For the gambler the mathematical theory of probability makes possible a precise calculation of the odds. This often calls for considerable mathematical sophistication. It is irrelevant, however, to the playing of the game; it is relevant only in deciding whether or not to play. The gambling problem is solved when the odds of the possible outcomes have been calculated. If there are several such outcomes, the gains or losses associated with each are multiplied by the corresponding probabilities and the products are added (with proper signs attached). The resulting number is the expected gain; that is, what can be reasonably expected over a long series of bets when the bets are placed according to the odds offered. A rational gambler is one who accepts or offers the gambles in such a way as to maximize his expected gain. All gambling houses are rational gamblers. That is why they stay in business.

The inadequacy of gambling theory as a guide in a true game is shown clearly in the well-known fact that the rational gambler is likely to meet with disaster in a poker game. The rational gambler will make his decisions strictly in accordance with the odds. He will never bluff, and he will bet in proportion to the strength of his hand. As a result he will betray his hand to his opponents, and they will use the information to his disadvantage.

Gambling theory is of even less use to the ticktacktoe player. Ticktacktoe is a game in which there is a best move in every conceivable situation. Chance, we know, is not involved at all in some games. To be sure, chance is involved in all card games but, as the example of poker shows, something else is involved, namely a strategic skill that is not part of gambling theory at all.

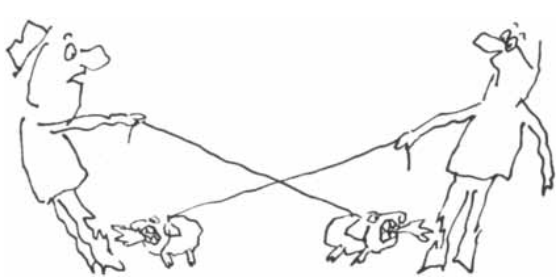
Consider what goes on in the mind of a chess player: If I play Knight to Queen's Bishop's 4, thus threatening his rook, he can reply Rook to King's 2, check. In that case I have the choice of either interposing the Bishop or King

The omnipotent scientist

to Queen's 1. On the other hand, he can ignore the threat to the rook and reply with a counterthreat by Bishop to Knight's 5, in which case I have the following choices . . .

The stronger the player, the longer this chain of reasoning is likely to be. But because of the limitations on how much we can hold in our minds at one time, the chain of reasoning must stop somewhere. For the chess player it stops a few moves ahead of the situation at hand, at a set of possible new situations among which he must choose. The one situation that will actually occur depends partly on his own choices and partly on the choices available to the opponent (over whom the first player has no control). Two decisions are involved in the choice of action: first, which situations may actually occur? Second, which of all those situations is to be preferred?

Now, these questions can be answered without ambiguity if the game is thought out to the end. In a game such as chess, however, it is out of the question to foresee all the alternatives to the end (except where checkmates or clear wins are foreseen as forced). The good chess player then does the next best thing: he calculates the relative values of the various possible future positions according to his experience in evaluating such positions. How then does he know which position will be actually arrived at, seeing that he controls only his own moves, not those of the opponent? Chess players recognize two chess philosophies.



Bite and counterbite

Escalated conflict

Playing the stock market or a slot machine involves no game theory

One is "playing the board," the other is "playing the opponent."

Playing the opponent makes chess akin to psychological warfare. The great chess master José Capablanca tells in his memoirs of an incident that illustrates the drama of such conflicts. In a tournament in 1918 he was matched with Frank J. Marshall, the U.S. champion. Marshall offered an unexpected response to Capablanca's accustomed opening attack, and the play proceeded not at all in line with the usual variations of this opening. Capablanca suspected that Marshall had discovered a new variation in the attack and had kept this knowledge as a secret weapon, to be used only at the most propitious time, namely in an international tournament with the eyes of the chess world on his play against a truly formidable opponent. Capablanca had been picked as the victim of the new strategy.

"The lust of battle, however," Capablanca continues, "had been aroused within me. I felt that my judgment and skill were being challenged by a player who had every reason to fear both (as shown by the records of our previous encounters), but who wanted to take advantage of the element of surprise and of the fact of my being unfamiliar with a thing to which he had devoted many nights of toil.... I considered the position then and decided that I was in honor bound ... to accept the challenge."

He did and went on to win the game. Capablanca's decision was based on taking into account his opponent's thought processes, not only those pertaining to the game but also Marshall's ambitions, his opinion of Capablanca's prowess, his single-mindedness and so on. Capablanca was playing the opponent.

Psychological warfare in chess

Advanced psychological warfare in chess

Although the drama of games of strategy is strongly linked with the psychological aspects of the conflict, game theory is not concerned with these aspects. Game theory, so to speak, plays the board. It is concerned only with the logical aspects of strategy. It prescribes the same line of play against a master as it does against a beginner. When a stragetic game is completely analyzed by game-theory methods, nothing is left of the game. Ticktacktoe is a good example. This game is not played by adults because it has been completely analyzed. Analysis shows that every game of ticktacktoe must end in a draw. Checkers is in almost the same state, although only exceptionally good players know all the relevant strategies. A generation ago it was thought that chess too was approaching the "draw death." But new discoveries and particularly the introduction of psychological warfare into chess, notably by the Russian masters, has given the game a reprieve. Nevertheless H. A. Simon and Allen Newell of the Carnegie Institute of Technology have seriously predicted that within 10 years the world's chess champion will be an electronic computer. The prediction was made more than three years ago. There is still a good chance that it will come true.

Is the aim of game theory, then, to reveal the logic of every formalized game so that each player's best strategy is discovered and the game as a whole is killed because its outcome in every instance will be known in advance? This is by no means the case. The class of games for which such an analysis can be carried through even in principle, let alone the prodigious difficulty of doing it in practice, is only a very small class.

Games of this class are known as games of perfect information. They are games in which it is impossible to have military secrets. Chess is such a game. Whatever the surprise Marshall thought he had prepared for Capablanca, he was not hiding something that could not be discovered by any chess player. He only hoped that it would be overlooked because of human limitations.

Not all games are games of perfect information. Poker is definitely not such a game. The essence of poker is in the circumstance that no player knows the entire situation and must be guided by guesses of what the situation is and what the others will do. Both chess and poker are "zero-sum" games in the sense that what one player wins the other or others necessarily lose. Not all games are of this sort either.

To understand the differences among these various classes of games, let us look at some examples from each class. The essential idea to be demonstrated is that each type of situation requires a different type of reasoning.

An improbably elementary situation in business competition will serve to illustrate the class of games of perfect information. The situation is otherwise a two-person zero-sum game. The Castor Company, an old, established firm, is being squeezed by Pollux, Incorporated, an aggressive newcomer. The Castor people guide their policies by the balance sheet, which is projected one year ahead. The Pollux people also guide their policies by a balance sheet, not their own but the Castor Company's. Their aim is to put Castor out of business, so they consider Castor's losses their gains and vice versa, regardless of what their own balance shows. Both are faced with a decision, namely whether or not to undertake an extensive advertising campaign. The outcome depends on what both firms do, each having control over only its own decision. Assume, however, that both firms have enough information to know what the outcomes will be, given both decisions [*see matrix at left in bottom illustration on page 112*].

From Castor's point of view, a better or a worse outcome corresponds to each of its decisions, depending on what Pollux does. Of the two worse outcomes associated with Castor's two possible decisions, $3 million in the red and $1 million in the red (both occurring if Pollux advertises), clearly the second is preferred. Castor's manager now puts him-

self into the shoes of Pollux' manager and asks what Pollux would do if Castor chose the lesser of the two evils. Clearly Pollux would choose to advertise to prevent the outcome that would be better for Castor ($1 million in the black). Getting back into his own shoes, Castor's manager now asks what he would do knowing that this was Pollux' decision. Again the answer is advertise. Exactly similar reasoning leads Pollux to its decision, which is advertise. Each has chosen the better of the two worse alternatives. In the language of game theory this is called the minimax (the maximum of the minima). This solution is always prescribed no matter how many alternatives there are, provided that the gains of one are the losses of the other and provided that what is the "best of the worst" for one is also the "best of the worst" for the other. In this case the game has a saddle point (named after the position on the saddle that is lowest with respect to front and back and highest with respect to right and left). Game theory shows that whenever a saddle point exists, neither party can improve the outcome for itself (or worsen it for the other). The outcome is forced, as it is in ticktacktoe.

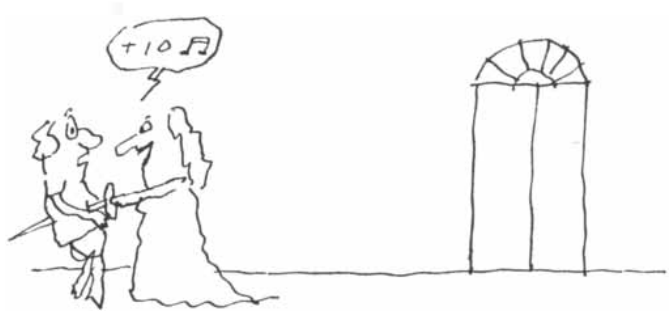
The next situation is quite different. It is a two-person zero-sum game, again involving the choice of two strategies on each side. In this case, however, the choices must be made in the absence of the information that guides the opponent's decision. Appropriately this is a military situation enveloped in the fog of battle.

A commander of a division must decide which of two sectors to attack. A breakthrough would be more valuable in one than in the other, but the more valuable sector is also likely to be more strongly defended. The defending commander also has a problem: which sector to reinforce. It would seem obvious that the more critical sector should be reinforced at the expense of the secondary one. But it is clear to the defending commander that the problem is more complicated. Secrecy is of the essence. If he does exactly what the enemy expects him to do, which is to reinforce the critical sector, will this not be to the enemy's advantage? Will not the attacker, knowing that the important sector is more strongly defended, attack the weaker one, where a breakthrough, even though less valuable, is more certain? Should the defender therefore not do the opposite of what the enemy expects and reinforce the secondary sector, since that is where the enemy, wishing to avoid the stronger sector, will probably attack? But then is not the enemy smart enough to figure this out and so attack the primary center and achieve a breakthrough where it counts?

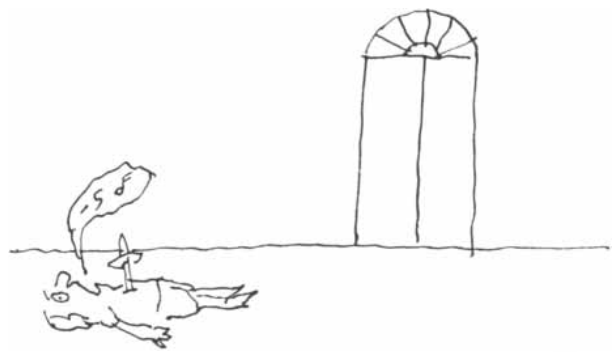
The attacking commander is going through the same tortuous calculations. Should he attack the secondary sector because the primary one is more likely to be strongly defended or should he attack the primary one because the enemy expects him to avoid it?

In despair the attacking commander calls in a game theorist for consultation. If the game theorist is to help him, the general must assign numerical values to each of the four outcomes; that is, he must estimate (in relative units) how much each outcome is "worth" to him. He assigns the values shown in the top illustration on the next page. Working with these figures, the game theorist will advise the general as follows: "Roll a die. If ace or six comes up, attack sector 1, otherwise attack sector 2."

If the defending commander assigns the same values (but with opposite signs, since he is the enemy) to the four outcomes, his game theorist will advise him to throw two pennies and reinforce sector 1 if they both come up heads,



Game theory in "Tosca": Tosca double-crosses Scarpia



Scarpia derives satisfaction from the thought of what is going to happen

Tosca and Cavaradossi discover the double double cross

ATTACKER'S PAY-OFF

A \ D	D_1	D_2
A_1	−10	+30
A_2	+5	−15

DEFENDER'S PAY-OFF

A \ D	D_1	D_2
A_1	+10	−30
A_2	−5	+15

MINIMAX SOLUTION

A \ D	D_1	D_2
A_1	+10 / −10	−30 / +30
A_2	−5 / +5	+15 / −15

TWO-PERSON ZERO-SUM GAME of an attacking (*A*) and a defending commander (*D*), in which neither possesses the information that guides his opponent's decisions, is summarized in these three matrices. The first commander has the choice of attacking a primary sector (A_1) or a secondary sector (A_2). The matrix at left shows the values he assigns to the four possibilities. The second commander has the choice of defending either sector. The matrix at center shows his assigned values. As the number of diagonal lines in each matrix square indicates, the first commander should decide by chance, using two-to-one odds in favor of the secondary sector; likewise for the defending commander, except that the odds are three to one. These results are combined in the matrix at right.

otherwise he should reinforce sector 2.

The solutions seem bizarre, because we think of tossing coins to make decisions only in matters of complete indifference. To be sure, a tossed-coin decision is sometimes used to settle an argument, but we do not think of such decisions as being rational and do not hire experts to figure them out. Nevertheless, the game theorists' decisions are offered not only as rational decisions but also as the best possible ones under the circumstances.

To see why this is so, imagine playing the game of button-button. You hide a button in one hand and your opponent tries to guess which. He wins a penny if he guesses right and loses a penny if he guesses wrong. What is your best pattern of choices of where to hide the button in a series of successive plays? You will certainly not choose the same hand every time; your opponent will quickly find this out. Nor will you alternate between the two hands; he will find this out too. It is reasonable to conclude (and it can be proved mathematically) that the best pattern is no pattern. The best way to ensure this is to abdicate your role as decision maker and let chance decide for you. Coin tossing as a guide to strategy is in this case not an act of desperation but a rational policy.

In the button-button game the pay-offs are exactly symmetrical. This is why decisions should be made by a toss of a fair coin. If the pay-offs were not symmetrical—for example, if there were more advantage in guessing when the coin was in the right hand—this bias would have to be taken into account. It would be reflected in letting some biased chance device make the decision. Game theory provides the method of computing the bias that maximizes the long-run expected gain.

CASTOR AND POLLUX

C \ P	P_Y	P_N
C_Y	−1	+1
C_N	−3	+2

TOSCA'S PAY-OFF

T \ S	S_K	S_D
T_K	+5	−10
T_D	+10	−5

SCARPIA'S PAY-OFF

T \ S	S_K	S_D
T_K	+5	+10
T_D	−10	−5

ZERO-SUM AND NONZERO-SUM GAMES are represented in these three game-theory matrices. The matrix at left is that of the two-person zero-sum game of perfect information discussed in the text. The matrix tabulates the results for Castor Company (in millions of dollars) of any combination of decisions; e.g., if Castor and Pollux, Incorporated, both advertise (*Cy and Py*), Castor loses $1 million. For Pollux, which will decide on the basis of the effect on Castor, this is a positive pay-off. Tosca and Scarpia are involved in a nonzero-sum game (also discussed in the text), that is, a gain for one does not imply a loss for the other. Tosca's line of reasoning can be determined from the matrix at center: if she keeps her bargain with Scarpia (*Tk*), then she loses everything if he double-crosses her (*Sd*); her gain is greatest and her loss least if she double-crosses him (*Td*). Scarpia, as the matrix at right indicates, reasons along the same line, in reverse. They both lose equally; if they had trusted each other, they would have gained equally.

The attacker's game theorist, then, has figured out that the attacker stands the best chance if he allows chance to decide, using two-to-one odds in favor of sector 2. This is the meaning of rolling a die and allowing four sides out of six to determine the second sector. This is the best the attacker can do against the best the defender can do. The defender's best is to let chance decide, using three-to-one odds in favor of sector 2. Game theory here prescribes not the one best strategy for the specific occasion but the best mixture of strategies for this kind of occasion. If the two commanders were confronted with the same situation many times, these decisions would give each of them the maximum pay-offs they can get in these circumstances if both play rationally.

At this point one may protest that it is difficult, if not impossible, to assign numerical values to the outcome of real situations. Moreover, identical situations do not recur, and so the long-run expected gain has no meaning. There is much force in these objections. We can only say that game theory has gone just so far in baring the essentials of strategic conflict. What it has left undone should not be charged against it. In what follows some further inadequacies of game theory will become apparent. Paradoxically, in these inadequacies lies most of the value of the theory. The shortcomings show clearly how far strategic thinking can go.

In the next class of games to be illustrated there are choices open to the two parties where the gain of one does not imply loss for the other and vice versa. Our "nonzero-sum" game is a tale of lust and betrayal. In Puccini's opera *Tosca* the chief of police Scarpia has condemned Tosca's lover Cavaradossi to death but offers to save him in exchange for Tosca's favors. Tosca consents, the agreement being that Cavaradossi will go through a pretended execution. Scarpia and Tosca double-cross each other. She stabs him as he is about to embrace her, and he has not given the order to the firing squad to use blank cartridges.

The problem is to decide whether or not it was to the best advantage of each party to double-cross the other. Again we must assign numerical values to the outcome, taking into account what each outcome is worth both to Tosca and to Scarpia [*see two matrices at right in bottom illustration on opposite page*].

The values, although arbitrary, present the situation reasonably. If the bargain is kept, Tosca's satisfaction of getting her lover back is marred by her surrender to the chief of police. Scarpia's satisfaction in possessing Tosca will be marred by having had to reprieve a hated rival. If Tosca double-crosses Scarpia and gets away with it, she will win most (+ 10) and he will lose most (− 10), and vice versa. When both double-cross each other, both lose, but not so much as each would have lost had he or she been the sucker. For example, the dying Scarpia (we assume) derives some satisfaction from the thought of what is going to happen just before the final curtain, when Tosca rushes to her fallen lover and finds him riddled with bullets.

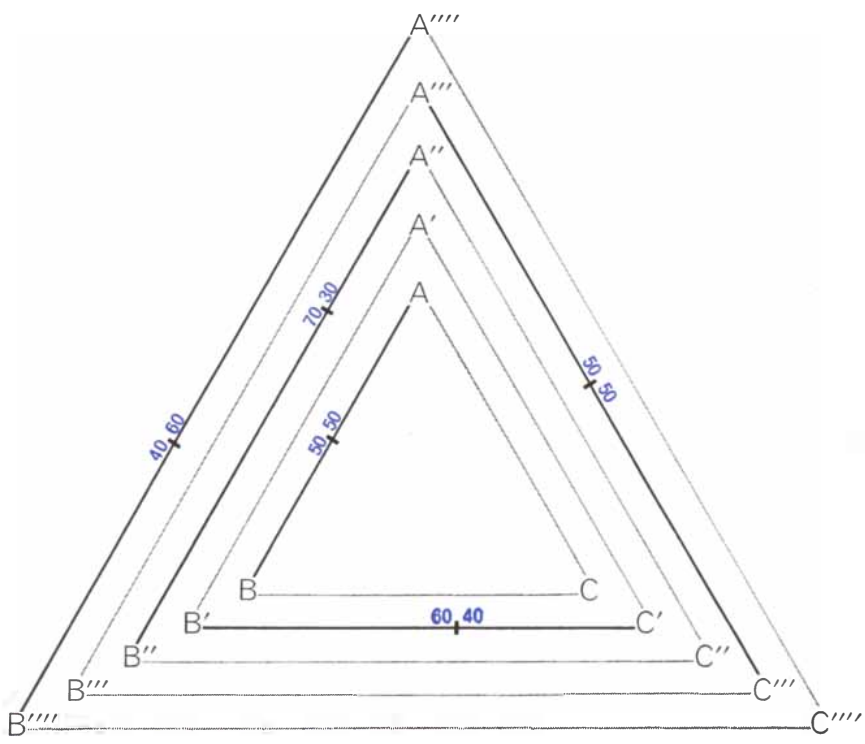
Let us now arrive at a decision from Tosca's point of view: whether to keep the bargain or to kill Scarpia. Tosca has no illusions about Scarpia's integrity. But she is not sure of what he will do, so she considers both possibilities: If he keeps the bargain, I am better off double-crossing him, since I will get Cavaradossi without Scarpia if I do and Cavaradossi with Scarpia if I don't. If he double-crosses me, I am certainly better off double-crossing him. It stands to reason that I should kill him whatever he does.

Scarpia reasons in exactly the same way: If she keeps the bargain, I am better off double-crossing her, since I will get rid of Cavaradossi if I do and have to put up with him if I don't. If she double-crosses me, I certainly should see to it that I am avenged. The execution, therefore, must go on.

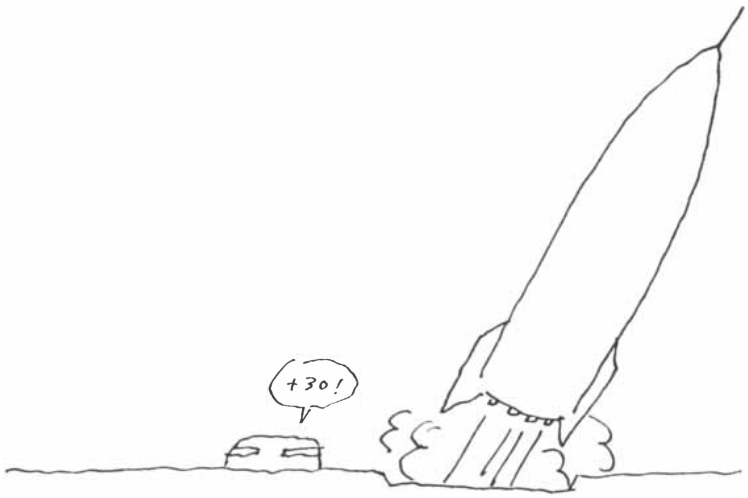
The result is the denouement we know. Tosca and Scarpia both get − 5. If they had trusted each other and had kept the trust, each would have got + 5.

The shortcoming of strategic thinking becomes obvious in this example. Evidently more is required than the calculation of one's own pay-offs if the best decisions are to be made in conflict situations. Game theory can still treat the foregoing case satisfactorily by introducing the notion of a coalition. If Tosca and Scarpia realize that the interests of both will be best served if both keep the bargain, they need not both be losers. Coalitions, however, bring headaches of their own, as will be seen in the next example.

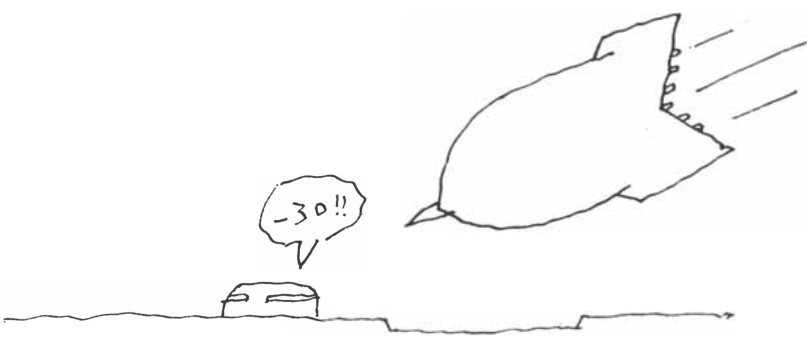
Abe, Bob and Charlie are to divide a dollar. The decision as to how to divide it is to be by majority vote. Abe and Bob form a coalition and agree to split the dollar evenly between them and so freeze Charlie out. The rules of the game allow bargaining. Charlie approaches Bob



COALITION GAME involves splitting a dollar among three individuals; the split is decided by majority vote. Abe and Bob (*A and B*) form a coalition that excludes Charlie (*C*). Charlie then (*C′*) offers Bob (*B′*) 60 cents of the dollar, and so on. Any division is inherently unstable because two can always do better for themselves than can three, and two can enforce any division. No game-theory strategy will guarantee a division satisfactory to all.



Maximum in the military application of game theory



Minimum

with a proposition. He offers Bob 60 cents of the dollar if Bob will shift his vote to freeze Abe out. Abe does not like this arrangement, so he offers Bob 70 cents to shift his vote again to freeze Charlie out. Bob is about to rejoice in his good fortune, which he attributes to his bargaining shrewdness, when he notices that Abe and Charlie are off in a corner. Bob is shrewd enough to guess what they are discussing, and he is right. They are discussing the folly of respectively getting 30 cents and nothing when they have the power to freeze Bob out and split the dollar between them. In fact, they do this. Bob now approaches Abe hat in hand and offers him 60 cents if he will come back. The question is: Should Abe accept the offer?

The game-theory solutions to problems of this sort are extremely involved and need not be pursued here. Instead let us try to summarize in general terms the values and limitations of the game-theory approach to human conflict.

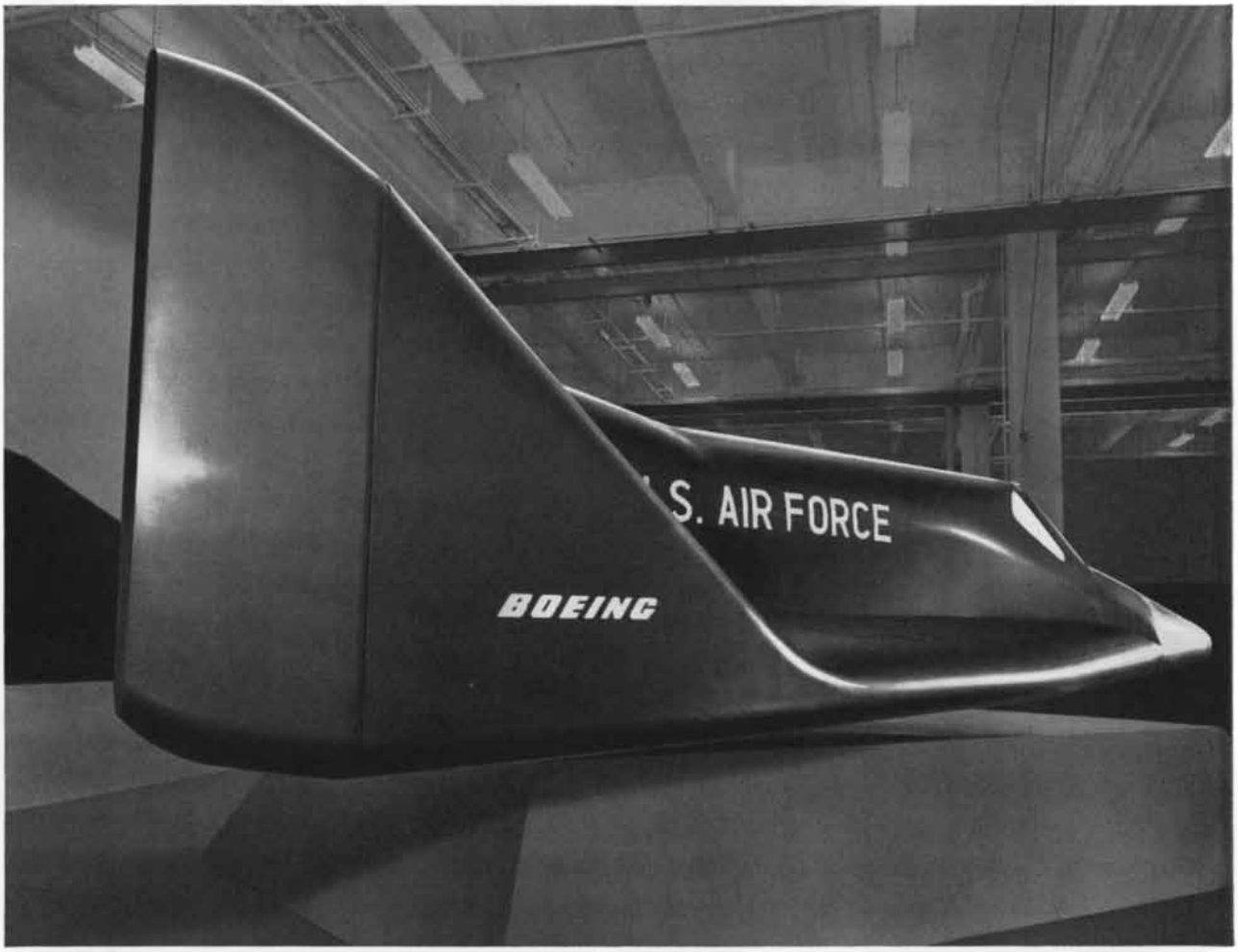
The value of game theory is not in the specific solutions it offers in highly simplified and idealized situations, which may occur in formalized games but hardly ever do in real life. Rather, the prime value of the theory is that it lays bare the different kinds of reasoning that apply in different kinds of conflict.

Let us go back to our examples and compare them. The decisions made by Castor and Pollux were clear-cut, and they were the best decisions on the basis of the knowledge at hand. As we have seen, both firms were guided by the principle of the minimax, choosing the best of the worst outcomes. When both choose the minimax, neither firm can improve its position. Had one of the generals used such a decision, he would have been clearly at a disadvantage. Military secrecy introduces an element of randomness to confound the enemy and brings in a different kind of reasoning. Such reasoning would have been useless in the Castor and Pollux example, because in their case each knew what the other's best decision had to be, and this knowledge made no difference to either. The difference between the two situations is immediately apparent to the game theorist. In the first case the minimax choice of one player is also the minimax choice of the other, in the second case it is not.

Consider the Tosca-Scarpia game. Here both parties have the same minimax choice, which, in fact, they choose. The outcome is bad for both. Why is this? Again the answer is clear to the game theorist. Tosca and Scarpia were playing the game as if it were a zero-sum game, a game in which what one party wins the other necessarily loses. If we examine the pay-offs, we find that this is not the case. Both parties could have improved their pay-offs by moving from the minimax solution to the coalition solution (keeping the bargain and getting + 5 each). Life would be simple if advantage in conflicts could always be obtained by forming and keeping proper coalitions. But the dilemma plaguing Abe, Bob and Charlie deprives us of that hope also. Moreover, both the Tosca-Scarpia game and the divide-the-dollar game reveal that decisions based on calculated self-interest can lead to disaster.

Whether game theory leads to clear-cut solutions, to vague solutions or to impasses, it does achieve one thing. In bringing techniques of logical and mathematical analysis to bear on problems involving conflicts of interest, game theory gives men an opportunity to bring conflicts up from the level of fights, where the intellect is beclouded by passions, to the level of games, where the intellect has a chance to operate. This is in itself no mean achievement, but it is not the most important one. The most important achievement of game theory, in my opinion, is that game-theory analysis reveals its own limitations. Because this negative aspect is far less understood than the positive aspect, it will be useful to delve somewhat deeper into the matter.

The importance of game theory for decision making and for social science can be best understood in the light of the



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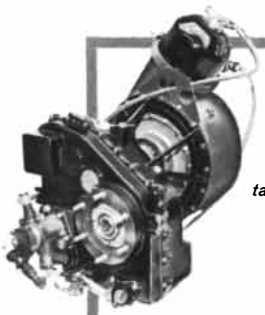

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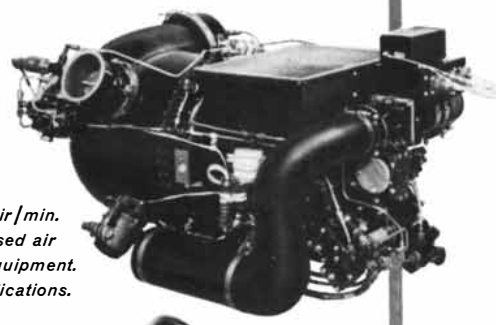

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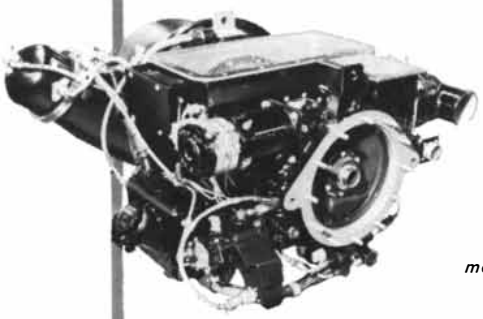

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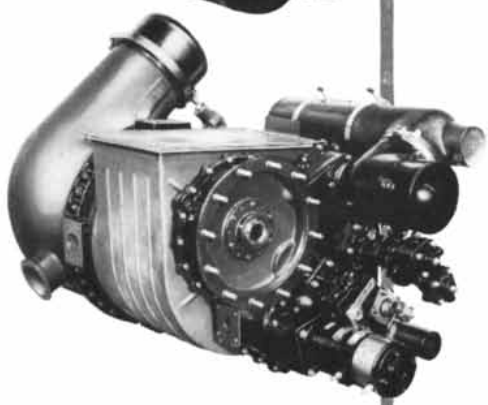

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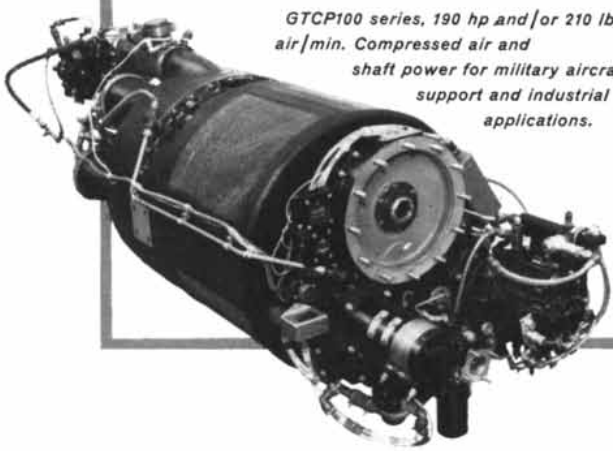

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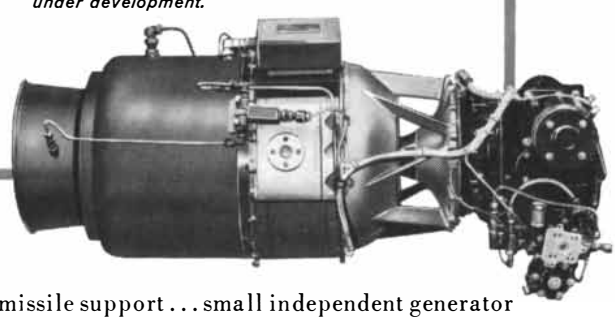

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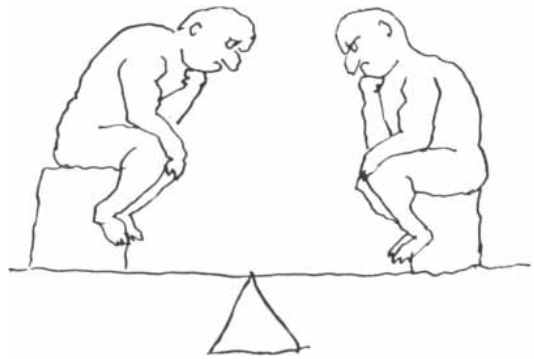
history of science. Scientists have been able to avoid much futile squandering of effort because the very foundations of science rest on categorical statements about what cannot be done. For example, thermodynamics shows that perpetual-motion machines are impossible. The principles of biology assert the impossibility of a spontaneous generation of life and of the transmission of acquired characteristics; the uncertainty principle places absolute limits on the precision of certain measurements conducted simultaneously; great mathematical discoveries have revealed the impossibility of solving certain problems.

Absolute as these impossibilities are, they are not absolutely absolute but are so only in certain specific contexts. Progress in science is the generalization of contexts. Thus the conservation of mechanical energy can be circumvented by converting other forms of energy into mechanical energy. The simpler conservation law is violated, but it is re-established in a more general thermodynamic context. In this form it can again be seemingly violated, but it is again re-established in the still broader context of $E = mc^2$. Angles can be mechanically trisected by instruments more complicated than the straightedge and the compass. Life can probably be synthesized, but not in the form of maggots springing from rotting meat; acquired characteristics can probably be genetically transmitted, but not by exercising muscles.

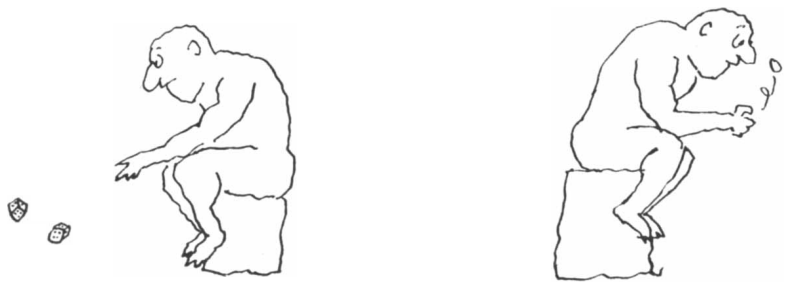
The negative verdicts of science have often been accompanied by positive codicils. The power conferred by science, then, resides in the knowledge of what cannot be done and, by implication, of what can be done and of what it takes to do it.

The knowledge we derive from game theory is of the same kind. Starting with the simplest type of game, for example two-person zero-sum games with saddle points, we learn from game-theory analysis that the outcome of such games is predetermined. This leads to a verdict of impossibility: neither player can do better than his best. Once these bests are discovered, it is useless to play such a game. If war were a two-person zero-sum game with a saddle point, the outcome of each war could conceivably be calculated in advance and the war would not need to be fought. (The conclusion that wars need to be fought because they are not two-person zero-sum games with saddle points is not warranted!)

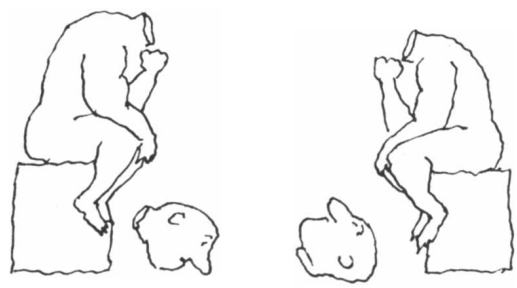
Examining now the two-person zero-sum game without a saddle point, we



Strategic thinking in a two-person zero-sum situation with a saddle point



Strategic thinking in a two-person zero-sum situation without a saddle point



Strategic thinking in a two-person nonzero-sum situation

Strategic thinking in a three-person constant-sum situation with a coalition

Communication is a prerequisite for the resolution of conflict

arrive at another verdict of impossibility: It is impossible to prescribe a best strategy in such a game. It is still possible, however, to prescribe a best mixture of strategies. The meaning of a strategy mixture and the advantage of using it can be understood only in a certain context, namely in the context of an expected gain. This in turn requires that our concept of preference be defined with a certain degree of specificity. To choose the best strategy in a saddle-point game it is necessary only to rank-order the preferences for the possible outcomes. To choose the best strategy mixture an interval scale (like that of temperature) must be assigned to our preferences. Unless this more precise quantification of preferences can be made, rational decisions cannot be made in the context of a game without a saddle point.

I have often wondered to what extent decision makers who have been "sold" on game theory have understood this last verdict of impossibility, which is no less categorical than the verdict on squaring the circle with classical tools. I have seen many research proposals and listened to long discussions of how hot and cold wars can be "gamed." Allowing for the moment that hot and cold wars are zero-sum games (which they are not!), the assignment of "utilities" to outcomes must be made on an interval scale. There is the problem. Of course, this problem can be bypassed, and the utilities can be assigned one way or another, so that we can get on with the gaming, which is the most fun. But of what practical use are results based on arbitrary assumptions?

That is not all. By far the most important conflicts that plague the human race do not fit into the two-person zero-sum category at all. The Tosca-Scarpia game and the Abe-Bob-Charlie game are much more realistic models of human conflicts, namely dramas, in which individuals strive for advantage and come to grief. In these games there are neither pure nor mixed strategies that are best in the sense of guaranteeing the biggest pay-offs under the constraints of the game. No argument addressed individually to Tosca or to Scarpia will convince either that it is better to keep the bargain than to double-cross the other. Only an argument addressed to both at once has this force. Only collective rationality will help them to avoid the trap of the double double cross.

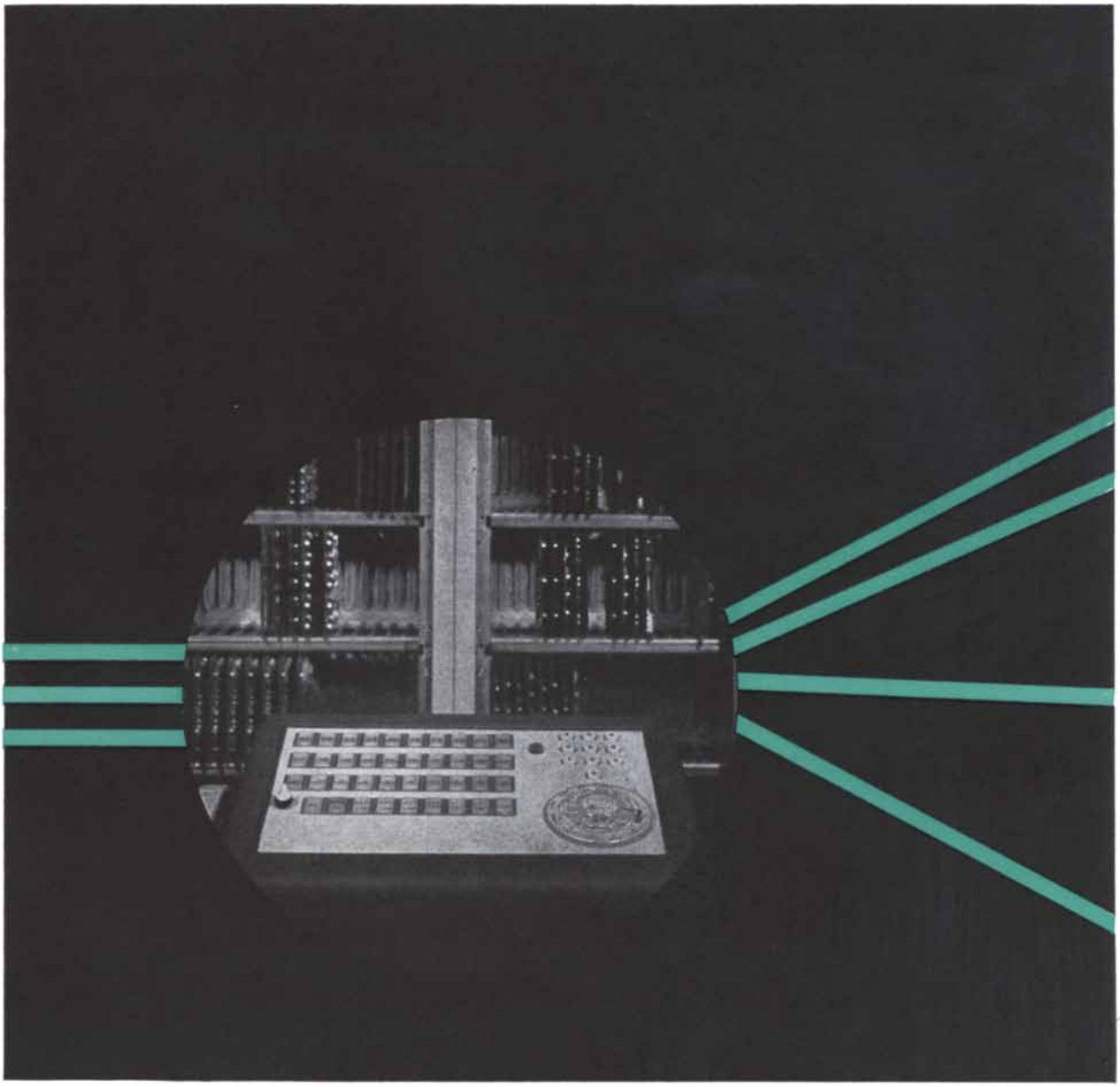
Similarly we can tell nothing to Abe, Bob or Charlie about how to behave to best advantage. We can only tell them collectively to settle the matter in accordance with some pre-existing social norm. (For example, they can take 33 cents apiece and donate one to charity.) This solution is based on an ethical principle and not on strategic considerations.

The role of social norms in games with more than two players was not missed by Von Neumann and Morgenstern. The importance of honesty, social responsibility and kindred virtues has been pointed out by sages since the dawn of history. Game theory, however, gives us another perspective on these matters. It shows how the "hardheaded" analysis of conflicts (with which game theory starts) comes to an impasse, how paradoxical conclusions cannot be avoided unless the situation is reformulated in another context and unless other, extra-game-theory concepts are invoked. Thus acquaintance with these deeper aspects of game theory reveals that the poker game is not the most general or the most sophisticated model of conflict, nor the most relevant in application, as professional strategists often implicitly assume.

Game theory, when it is pursued beyond its elementary paradox-free formulations, teaches us what we must be able to do in order to bring the intellect to bear on a science of human conflict. To analyze a conflict scientifically, we must be able to agree on relative values (to assign utilities). We must learn to be perceptive (evaluate the other's assignment of utilities). Furthermore, in order to engage in a conflict thus formalized, we must be able to communicate (give a credible indication to the other of how we assign utilities to outcomes). At times we must learn the meaning of trust, or else both we and our opponents will invariably lose in games of the Tosca-Scarpia type. At times we must be able to convince the other that he ought to play according to certain rules or even that he ought to play a different game. To convince the other we must get him to listen to us, and this cannot usually be done if we ourselves do not listen. Therefore we must learn to listen in the broadest sense of listening, in the sense of assuming for a while the other's world outlook, because only in this way will we make sense of what he is saying.

All these skills are related not to know-how but to wisdom. It may happen that if we acquire the necessary wisdom, many of the conflicts that the strategy experts in their professional zeal insist on formulating as battles of wits (or, worse, as battles of wills) will be resolved of their own accord.

Another prerequisite is the assignment of utilities to outcomes



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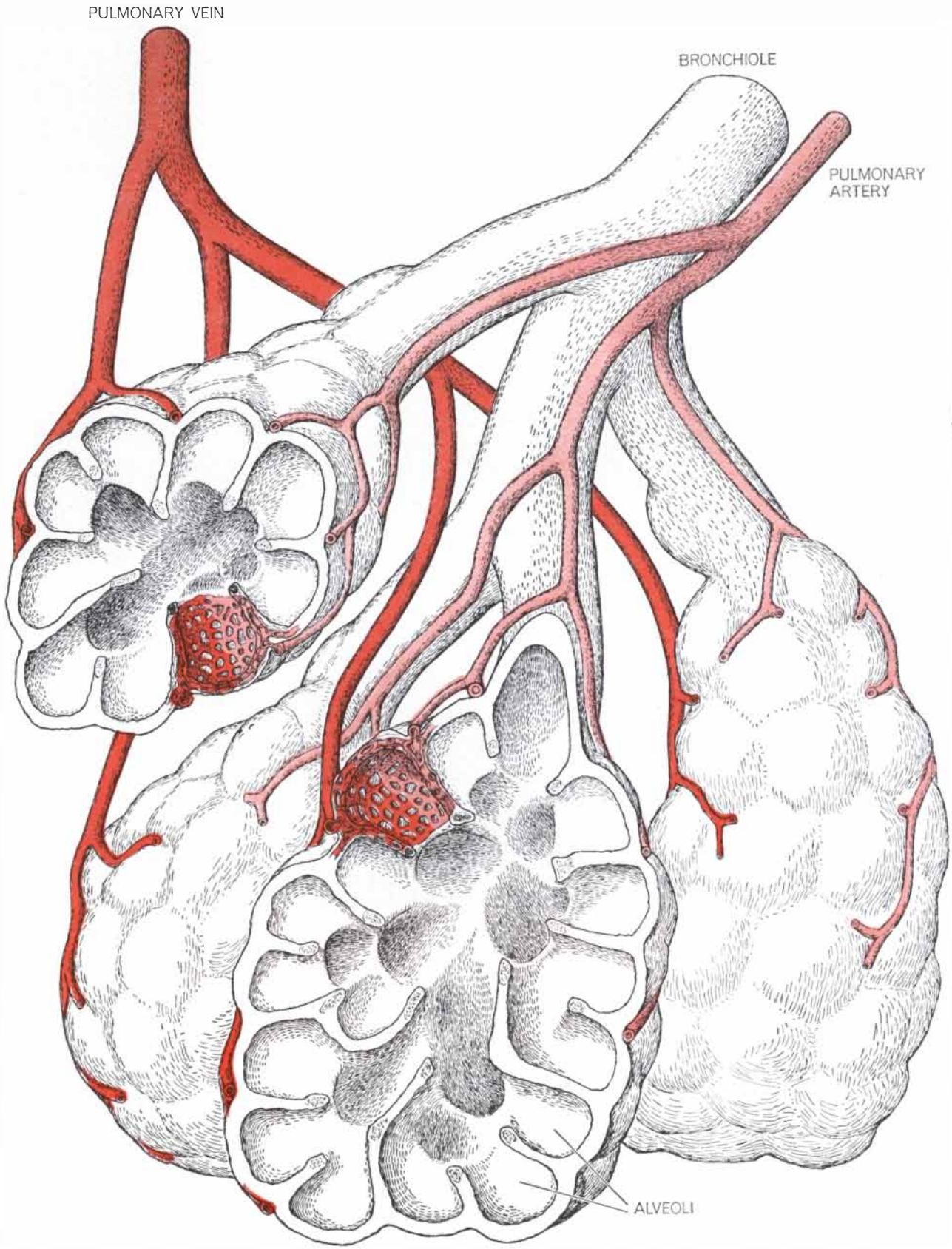


ALVEOLI are the air spaces in the lungs through which oxygen enters the blood and carbon dioxide leaves. A surface-active agent coats the moist alveoli and regulates the elasticity and tension of the lungs as a whole. In this schematic diagram nearly all the smaller blood vessels have been omitted except where capillary networks embedded in the alveolar walls show through from the backs of two alveoli seen in cross section. The average alveolus expands and contracts more than 15,000 times a day during breathing.

SURFACE TENSION IN THE LUNGS

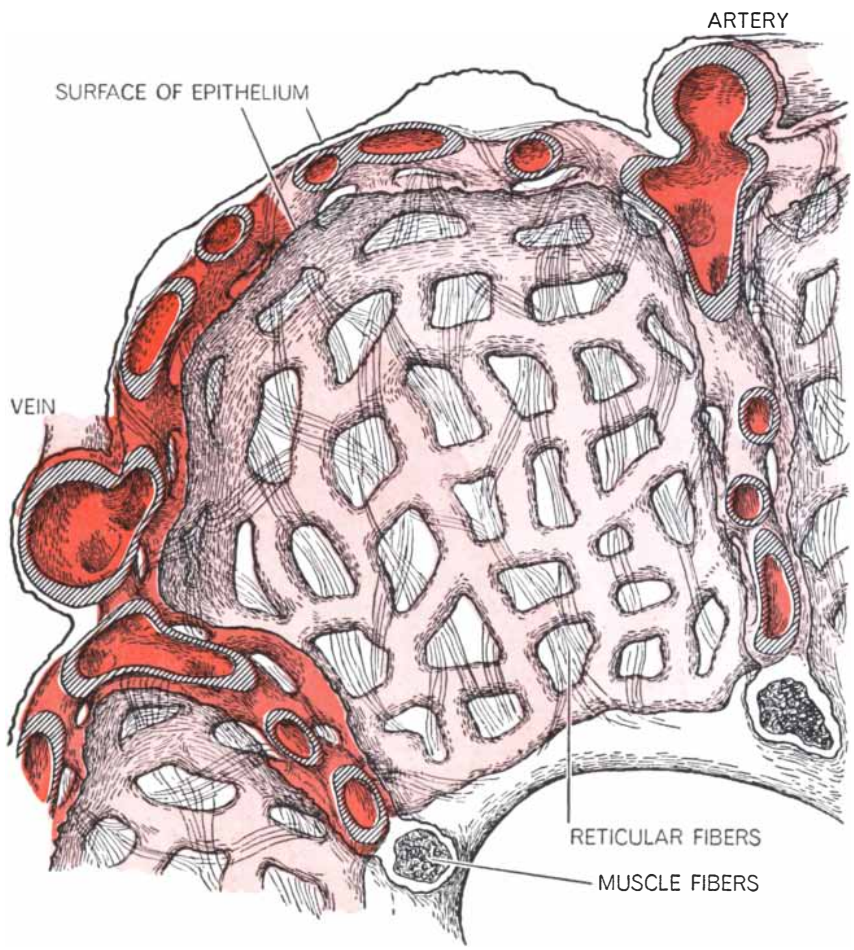
Recent investigations have shown that the air spaces of the lung are coated with a complex substance that lowers surface tension. It now appears that this substance keeps the lungs from collapsing

by John A. Clements

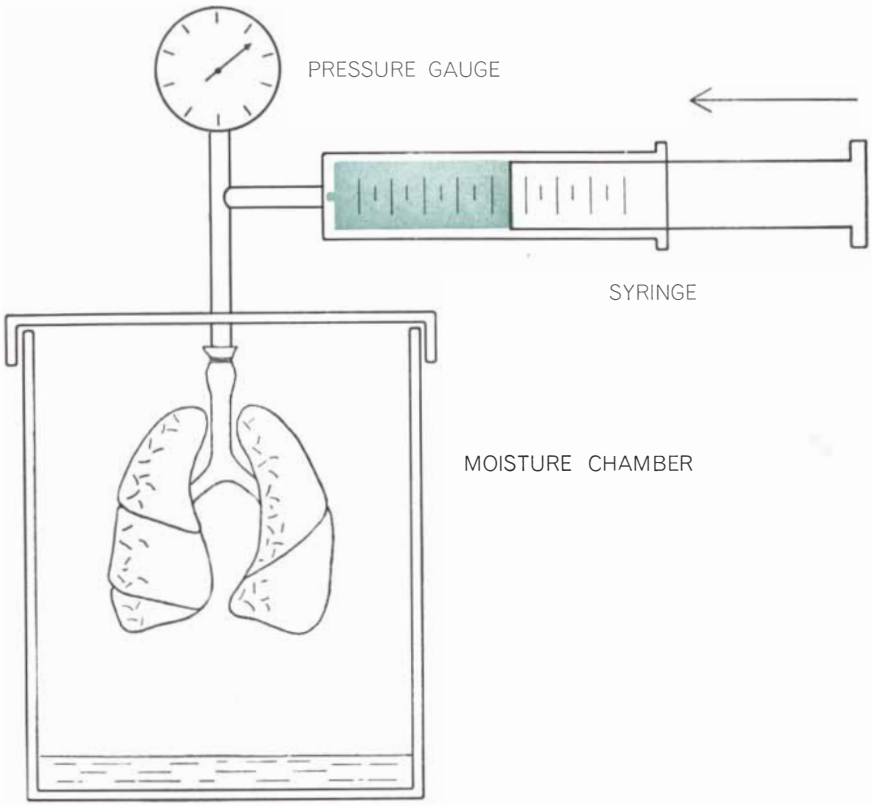
By far the most extensive surface of the human body in contact with the environment is the moist interior surface of the lungs. To carry on the exchange of carbon dioxide and oxygen between the circulating blood and the atmosphere in sufficient volume to sustain life processes requires approximately one square meter of lung surface for each kilogram of body weight. In the normal adult this amounts to the area of a tennis court. Such an area is encompassed in the comparatively small volume of the chest by the compartmentation of the lungs into hundreds of millions of tiny air spaces called alveoli. These air spaces are connected by confluent passages through the bronchial tree and the trachea to the atmosphere and are thus, topologically speaking, outside the body. Within the walls of the alveoli the blood is spread out in a thin sheet, separated from the air by a membrane about one micron (.001 millimeter) thick.

Since the primary function of the lungs is to present the inner surface of the alveoli to the air, it is not surprising to learn that the vital process of respiration is critically dependent on the physical properties of this surface. There is, of course, much more to the anatomy and physiology of the lungs. In recent years, however, the attention of investigators has been drawn increasingly to the role that is played by surface tension: the manifestation of the universal intermolecular forces that is observed in the surfaces of all fluids. The surface tension in the outermost single layer of molecules in the film of tissue fluid that moistens the surface of the lungs has been found to account for one-half to three-quarters of the elasticity with which the air spaces expand and contract in the course of the 15,000 breaths that are drawn into the lungs of the average individual each day.

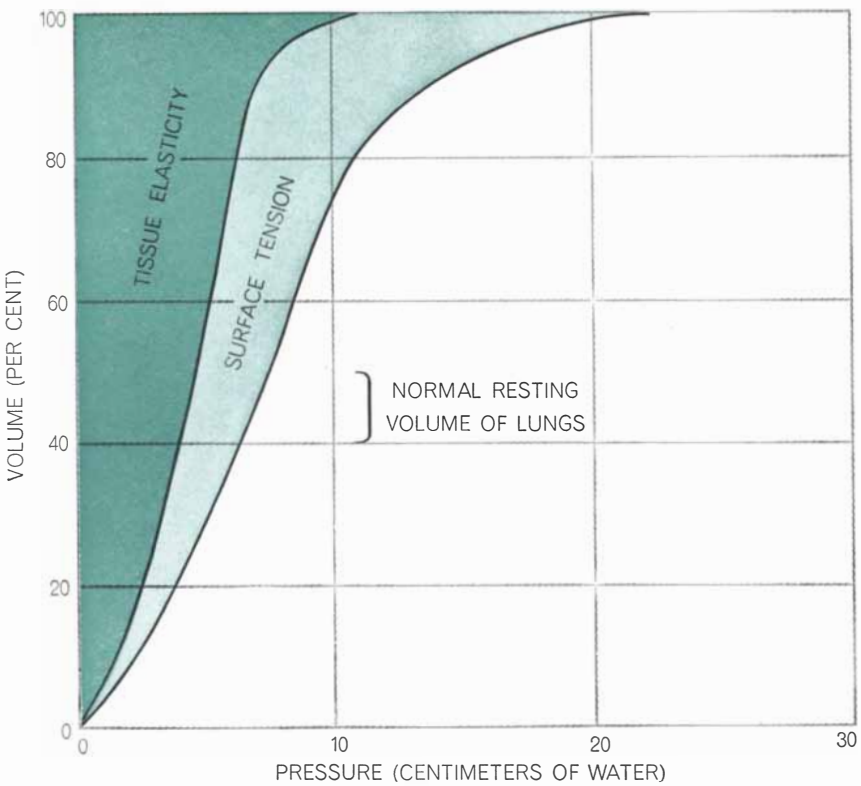
As this knowledge suggests, it has also been found that the body has a way of regulating the surface tension of the lungs. Certain cells in the walls of the alveoli secrete a sort of detergent or wetting agent. This "surface-active" substance tends to weaken the surface tension. Its presence in the monomolecular layer on the surface of the film of moisture coating the air spaces serves to stabilize the dynamic activity of the lungs. It equalizes the tension in the air spaces as they expand and contract; it



SINGLE ALVEOLUS is actually microscopic in size. The alveolar wall has been rendered transparent in this schematic cross section so that the rich network of blood capillaries and fibers that support the alveolus can be seen. The surface-active substance that plays a key role in stabilizing lung function normally coats the epithelium of every healthy alveolus.



LUNG ELASTICITY is measured by using large syringe to fill lungs with a gas or a fluid (*color*). Lungs taken at autopsy are placed in a moist chamber and attached to a manometer, or pressure gauge. Karl von Neergaard of Zurich made the first such measurement in 1929.



ELASTICITY CURVES are obtained by plotting pressure needed to expand the lungs against volume of lungs. The lungs show much less elasticity when filled with fluid than they do when filled with gas. Surface tension plays a significant role only when lungs are filled with gas. The amount of elasticity contributed by surface tension shows up as the difference between the curves at any particular volume of the lungs. It rises as the lungs expand.

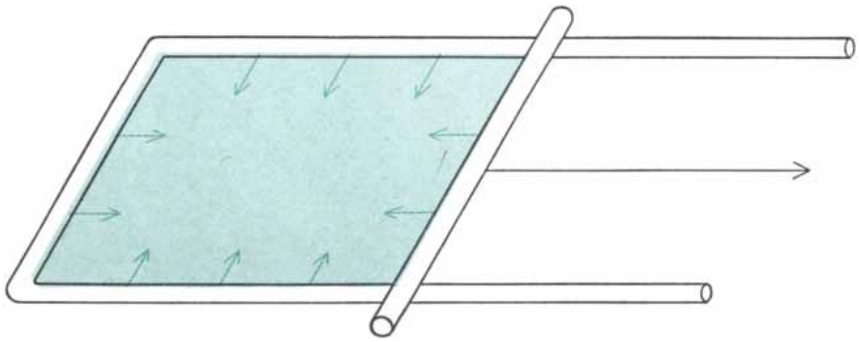
brings about an even distribution of pressure between large and small alveoli, and by decreasing the over-all pressure it reduces the muscular effort required for respiration. This substance has the further function of assisting the osmotic forces acting across the surface of the lungs and so keeping the film of moisture on the surface from drawing fluid into the air spaces.

The critical importance of the surface-active agent becomes apparent when it is not there to do its work. Its absence explains some of the symptoms in the complex organic disease of the newborn recorded variously as fatal respiratory distress, hyaline-membrane disease or atelectasis. The collapse of the lungs and the filling of the air spaces with fluid observed in this disease is promoted by abnormally high surface tension in the alveoli. Some 25,000 newborn infants die of the disease in the U.S. each year. A similar syndrome, although it is not always fatal, has recently appeared as a complication attending heart surgery in some patients whose lungs have been temporarily disengaged from the respiratory function by diversion of the blood through a "heart-lung" machine.

The contribution of surface tension to the elasticity of the lungs was first demonstrated in 1929 by Karl von Neergaard of the University Clinic in Zurich. He distended lung preparations alternately with air and with saline solution and compared the pressures required to do so with each. This experiment, since repeated many times by other workers, showed that it takes a higher pressure to distend the lungs with air. The interpretation of this experiment calls for a more precise definition of a surface: it is an interface between two substances and it is established by the relative cohesion of their constituent molecules. Thus when the fluid on the surface of the lungs forms an interface with air, it exhibits a stronger surface tension than it does at an interface with saline solution. In fact, the tissue fluid forms essentially no interface at all with saline solution of the right concentration and the surface tension is reduced to almost zero. Distention of the lungs with saline solution can therefore be used to measure the elastic properties of the tissue alone, uncomplicated by the effects of surface tension. Since inflation with air yields a measure of both the tissue and the surface-tension components, the effect of surface tension can be derived by subtracting the pressure required to distend the lungs with saline solution from the pressure required to inflate them to the same volume with air.

The technique has recently provided conclusive evidence that surface tension is abnormally high in the fatal respiratory distress of the newborn. After autopsy the lungs of such infants can be expanded at almost normal pressures with saline solution but require three to four times the normal pressure for air inflation. Moreover, the alveoli collapse at abnormally high air pressures during deflation.

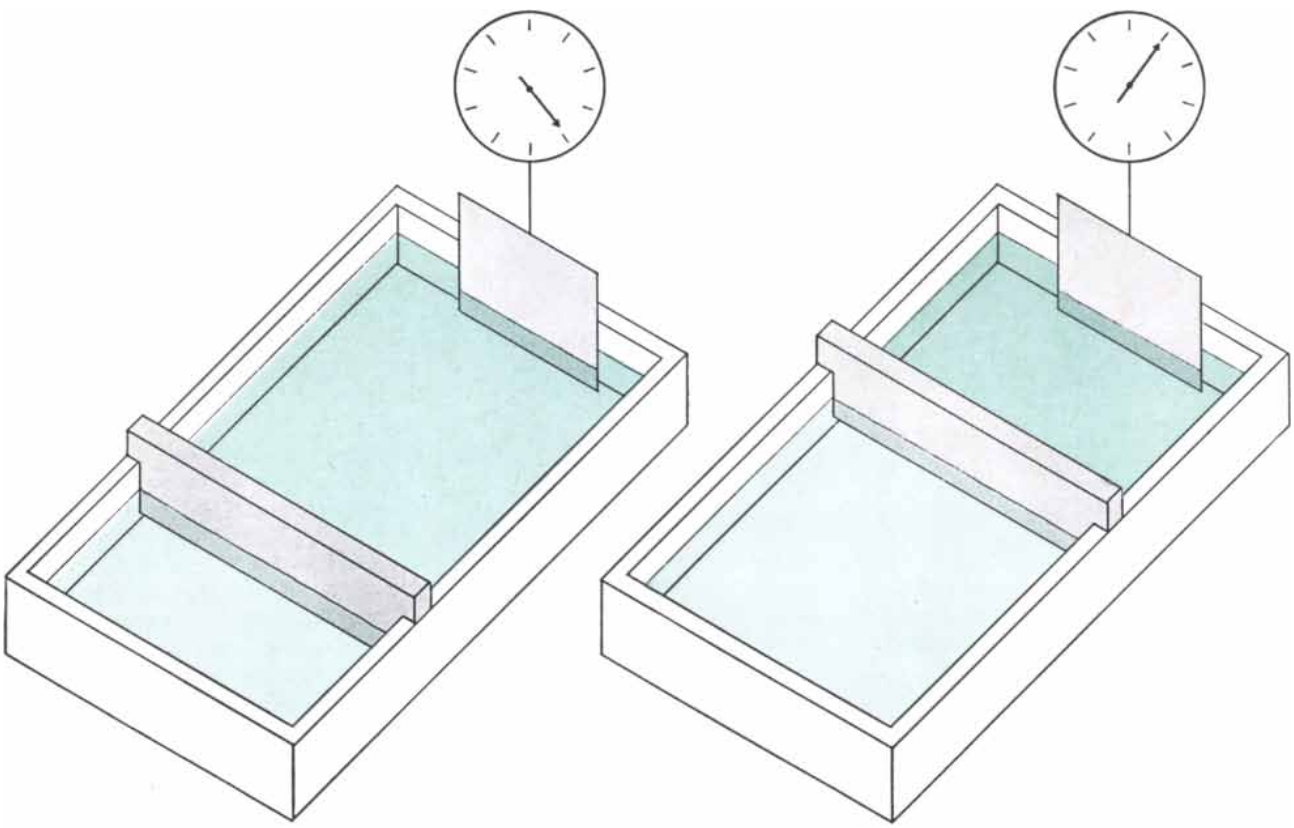
In everyday experience with surface tension there is little to suggest that it has such formidable power. It has barely measurable effects on the properties of solids, showing up for example in the measurement of the elasticity of fine-drawn wires. Its action is more prominent in the behavior of liquids, as in the shaping of raindrops or the providing of a platform for certain aquatic insects. But it seems no more than an incidental effect of the geometry that accounts for it. Whereas the molecules in the bulk of a liquid experience forces of mutual attraction that are balanced in all directions, the molecules at the surface are attracted more strongly to their neighbors below the surface and are attracted only weakly to the sparser population of molecules in the air above the surface.



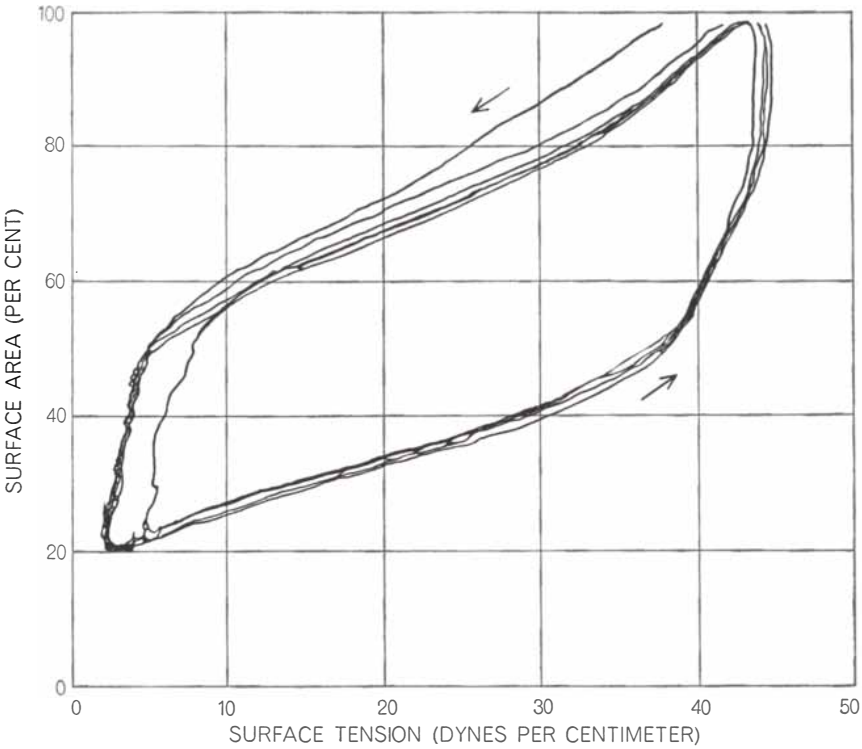
MAXWELL FRAME, used to demonstrate surface tension, consists of U-shaped wire with separate wire across open end. Liquid film (*color*) pulls at cross wire. Force needed to prevent cross wire from moving to bottom of U (*black arrow*) is proportional to the tension.

Because the net pull is downward, the surface particles tend to dive and the surface shrinks to the least possible area.

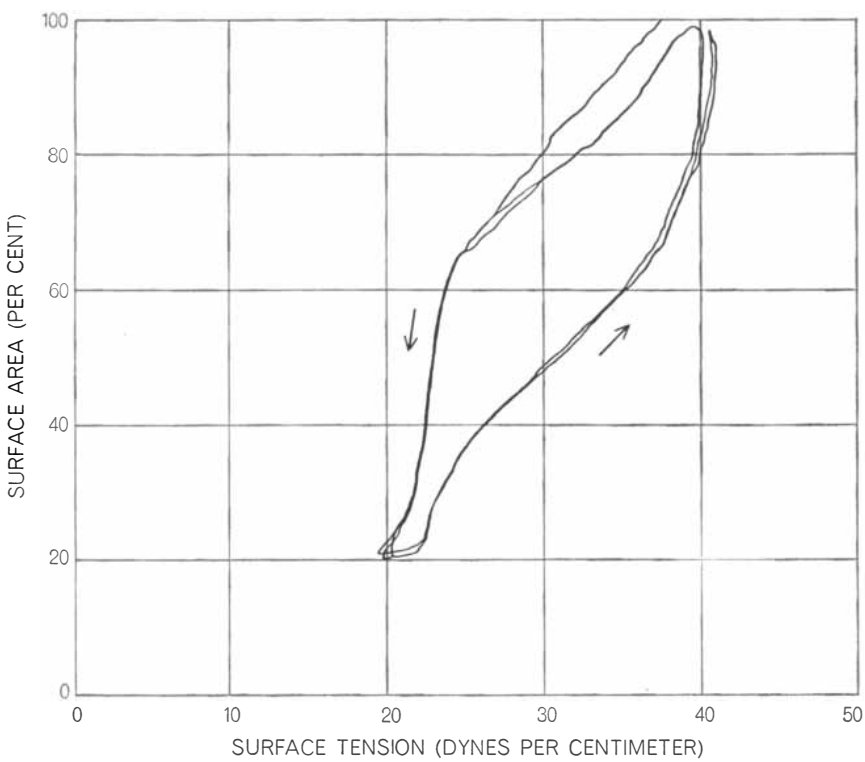
The resultant force of cohesion at the interface between a liquid and the air can be demonstrated with the help of a Maxwell frame, named for the 19th-century physicist James Clerk Maxwell. This is a U-shaped wire, with the open end of the U closed by a cross wire that can slide along the legs of the U. A film of liquid stretched out on the frame tends to pull the cross wire to the bottom of the U. The force necessary to resist this pull—to maintain a constant area of film—provides a measure of the surface tension. Since the film in this experiment has two surfaces, the measured force must be divided by twice the width of the U; the result is usually expressed in dynes per centimeter. (A dyne is the force required to accelerate a one-gram mass one centimeter per second.) The surface tension of pure water at body temperature is equal to about 70 dynes per centimeter; that of blood plasma and



SURFACE BALANCE measures change in surface tension as area of film of surface-active agent on water increases and decreases. Surface tension pulls down on platinum strip (*attached to gauge*). Water alone produces pull of about 70 dynes per centimeter. A detergent in the water makes surface tension about 30 dynes per centimeter but the tension does not change as barrier moves slowly back and forth. Surface-active agent from lungs forms a film on the water and makes the surface tension about 40 dynes per centimeter (*left*). As barrier moves toward strip, compressing the agent, tension drops (*right*). Surface tension rises as the barrier moves back.



CHANGE IN SURFACE TENSION with area, as measured by surface balance, is large when surface-active agent from normal lungs covers the water. Moving barrier made several trips back and forth during test. The tension at first drops rapidly as barrier moves in (*arrow pointing to left*), and it rises rapidly as barrier moves back (*arrow pointing to right*).



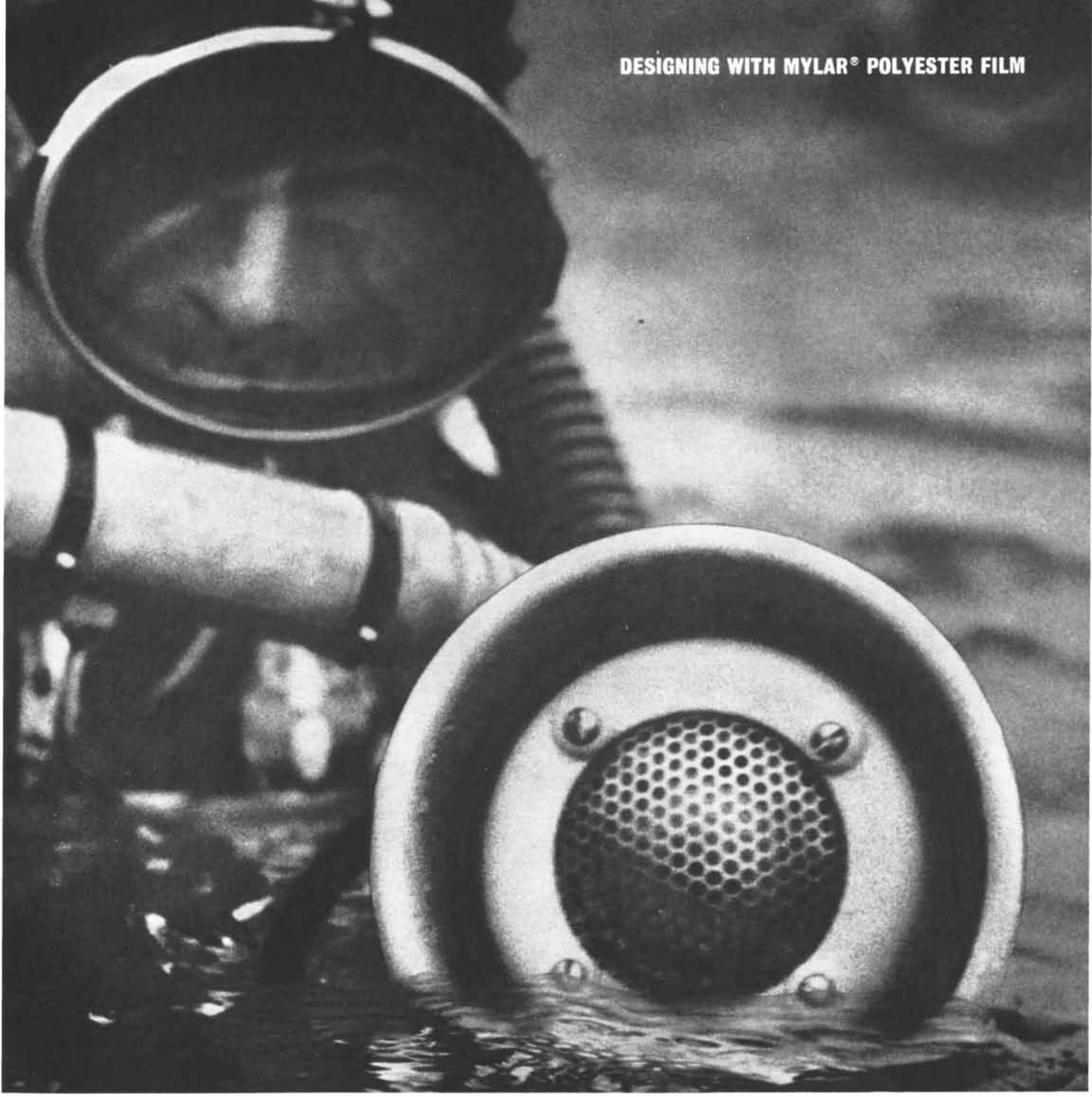
CHANGE IS SMALL when the alveolar coating comes from lungs of newborn infant who succumbed to acute respiratory distress. In such a case the surface tension is about 18 dynes per centimeter. Relative lack of surface activity plays a key role in the fatal disease.

tissue fluid, to about 50 dynes per centimeter.

The results conform with the observation that surface tension does not exert very strong forces. At this point, however, geometry enters the picture again. According to a formula of Pierre Simon de Laplace, the 18th-century astronomer and mathematician, the force exerted in a given surface is equal to twice the tension divided by the radius of the surface. In a flat surface with, so to speak, infinite radius the force is zero. Given the tiny dimensions of the average-sized alveolus, calculation shows that the surface tension of tissue fluid should exert a considerable force. At 50 dynes per centimeter in a surface with a radius of only .05 millimeter, it would produce a force of 20,000 dynes per square centimeter. Expressed as pressure this is equal to 20 centimeters of water.

This computation explains why surface tension influences the elasticity of the lungs so greatly. It does not, however, agree with the actual values for the surface tension in normal lungs obtained by comparison of the pressures required to distend the lungs with liquid and to inflate them with air. At functional or intermediate lung volume, in fact, the calculated effect of surface tension turns out to be from five to 10 times too large. In other words, the surface tension of the tissue fluid would have to be closer to five or 10 dynes per centimeter instead of 50 dynes per centimeter. At larger lung volumes the measured pressure comes into closer agreement with the calculated pressure, indicating a surface tension for the lung tissue of about 40 dynes per centimeter. In short, the surface tension of the tissue is unexpectedly low in the lungs, and it varies with the inflation and deflation of the air spaces.

With these suggestive clues in hand, investigators began to look into the tissue fluid of the lungs for the presence of a surface-active agent. Soaps or detergents are familiar examples of substances of this kind. Their molecules have weaker forces of mutual attraction for one another and for molecules of other species. They tend to accumulate in excess at surfaces and interfaces when mixed in solutions. Acting as bridges between dissimilar substances such as oil and water or water and air, they wet, penetrate and disperse oily substances and stabilize emulsions and foams. The concentration of their weaker attractive forces at an interface reduces the surface tension. At a number of laboratories



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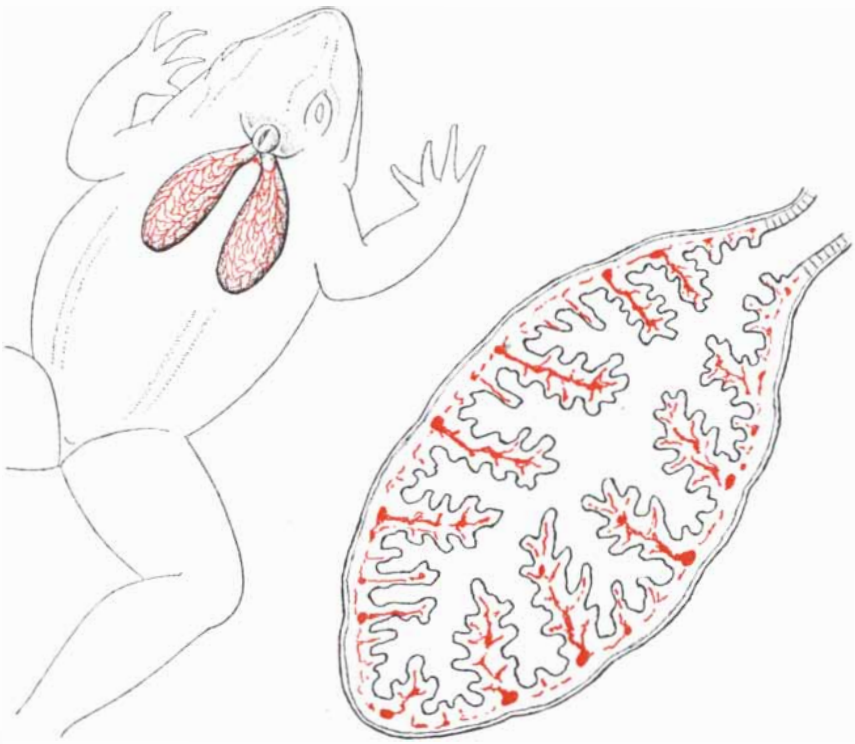
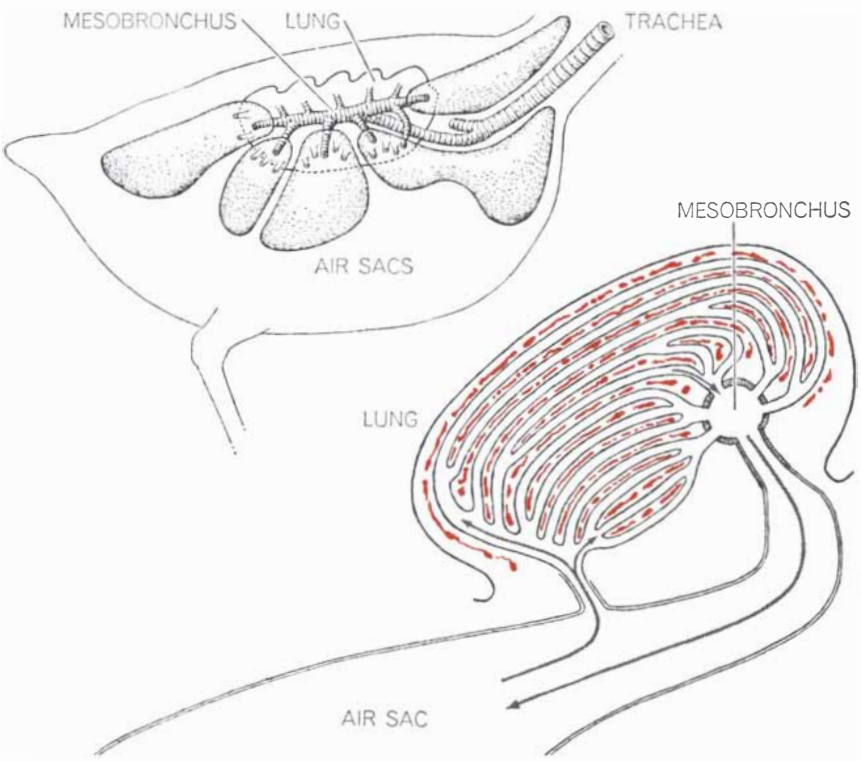


LUNGS OF FROGS contain quite large air spaces that are not threatened by pressure of surface tension created by a liquid that coats the inner lining. Therefore a surface-active agent is not necessary, and none has been found. One lung is shown in longitudinal section at right. Color indicates blood vessels. The diagrams on this page are highly schematic.



LUNGS OF BIRDS contain air capillaries, tiny tubes in which gas exchange with the blood takes place. Air passes through lungs into and out of large air sacs. Since there is little change in lung volume, surface tension does not need to be adjusted. Surface-active agent has not been found in the lungs of birds. A cross section of a bird lung is seen at right.

the presence of a surface-active agent was soon demonstrated in the tissue fluid extracted from the lungs. The extraction can be accomplished in a number of ways: by rinsing the alveoli with saline solution via the air passages; by generating a foam in the alveoli; and by filtration from minced whole tissue. Each of these procedures yields an extract that contains a powerful surface-active agent on which accurate measurements can be made.

The laboratory technique for detecting the presence of this agent and measuring its effect on the surface tension of the tissue fluid provides a nice demonstration of its mode of operation in the alveoli. The extract is placed in a shallow tray and a .001-inch-thick platinum strip is suspended in it from the arm of a sensitive electrobalance or strain gauge. The pull of the surface on the strip provides a measure of the surface tension. A motor-driven barrier slowly sweeps the surface from the far end of the tray, reducing the area of liquid surface in which the platinum strip is hanging to 10 or 20 per cent of its initial size. Since the surface-active agent in the extract spontaneously forms a film at the surface, it is concentrated in the area in front of the barrier. As the concentration builds up, the surface tension falls to low values.

Extracts from normal lungs show a change in surface tension, when measured this way, from about 40 dynes per square centimeter to two dynes per square centimeter—in excellent agreement with the surface tension as estimated in the lung itself. In contrast, the surface tension does not fall below 18 dynes per square centimeter in extracts from the lungs of newborn infants that have succumbed to hyaline-membrane disease.

The change in surface tension with the change in surface area is the key to the action of the surface-active agent in the lung. In an expanded air space the layer of surface-active agent is attenuated, and surface tension is increased accordingly. The increase in tension is partly offset, however, by the increase in the radius of the air space, and the increase in force or counterpressure exerted by the surface tension is diminished. As the air space contracts to perhaps half its expanded size, the increasing concentration of the surface-active agent reduces the surface tension, balancing the Laplace equation in the other direction and again decreasing the pressure in the air space. Similarly, between

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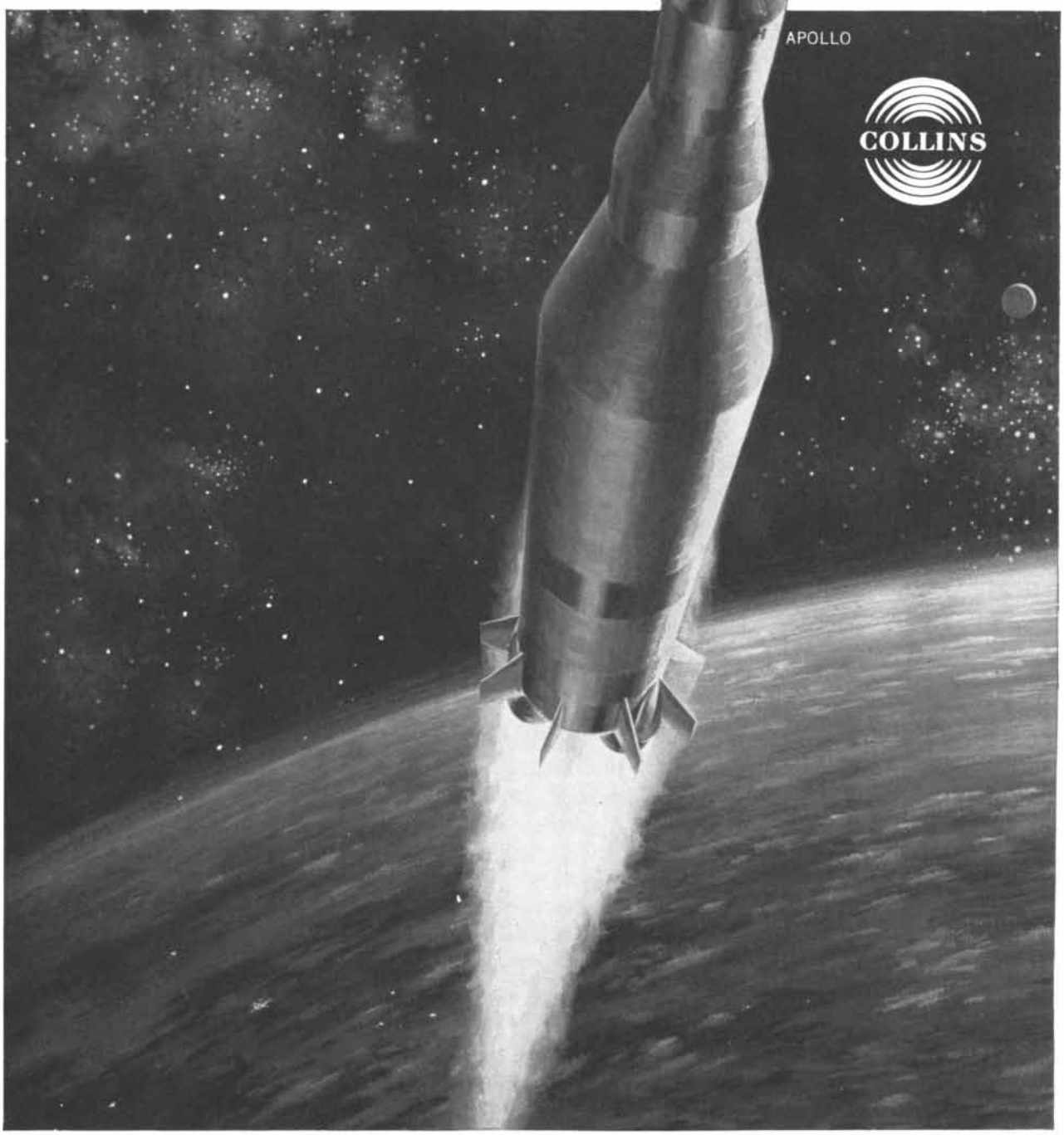
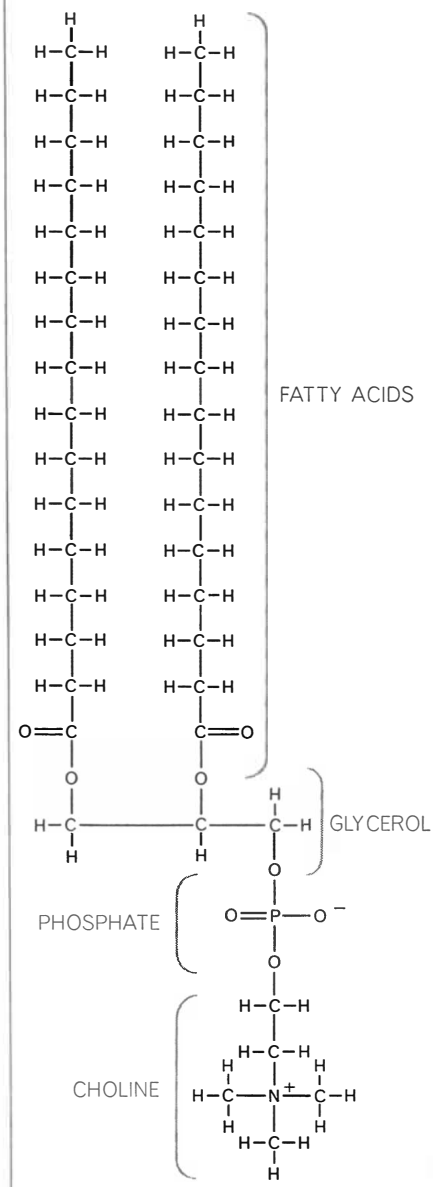


the smallest alveolus and the largest, which may be three or four times larger, differences in the concentration of the surface-active agent in the interface of tissue fluid and air bring about a homogeneous distribution of pressure. The performance of hundreds of millions of alveoli, of random size, is thereby smoothed and co-ordinated.

The action of the alveolar surface-active agent in balancing the forces that otherwise tend to draw fluid out of the capillaries into the alveolar air spaces is also important. The blood pressure in the capillaries, the osmotic pull of the tissue fluid in and on the alveolar membrane, and the surface tension of this fluid all work to move fluids outward. One force, the osmotic pull of the blood plasma, opposes this combination of forces. The maintenance of a favorable balance of forces is assisted by the reduction in surface tension through the action of the surface-active agent. In hyaline-membrane disease, with surface tension sustained at as much as 45 dynes per centimeter, the leakage of fluid from the capillaries blocks the exchange of oxygen and carbon dioxide between blood and air; the process is limited in the end only by engorgement of the air spaces or by their collapse.



LECITHIN MOLECULE consists of long-chain fatty-acid groups that are not strongly attracted to water, as well as glycerol and electrically charged, or polar, phosphate and choline groups that are attracted to polar molecules of water. The fatty acid is thought to stand up out of the water when the molecule is part of a surface layer. Lecithin is strongly surface-active; it is a constituent of the substance that coats the alveoli.

Chemical analysis has shown that the surface-active agent of the lungs is a lipoprotein, that is, a compound molecule made up of protein and fatty constituents. The latter are of an appropriately soapy kind, lecithin being the predominant component. A member of the same chemical family that has been made synthetically, a substance called dipalmitoyl lecithin, shows the same surface activity. Dipalmitoyl lecithin has even been isolated from the lung fluid. It is tempting, therefore, to attribute the surface activity of the lung material to dipalmitoyl lecithin. Against this conclusion, however, it can be shown that the active material isolated from the extract of tissue fluid is the intact lipoprotein molecule. Its activity is destroyed by attempts to segregate the lipids from the protein or to isolate any one of the lipid components from the whole. At present the most reasonable opinion is that the native material is a complex of protein and lipids, particularly dipalmitoyl lecithin, and that both are essential to its activity.

The discovery of this remarkable substance in the lung fluid of man has prompted a search for it in other animals. So far it has turned up in all the other mammals that have been tested (the mouse, rat, guinea pig, rabbit, cat, dog and cow), but not in any amphibian (frog and toad), reptile (snake and crocodile) or bird (pigeon and chicken). There appears to be some rationale for this distribution among species. Amphibians and reptiles depend on their environment to supply a major portion of the heat that sustains their metabolism; weight for weight they do not require as much exchange of respiratory gases as

mammals and therefore do not need as much lung surface. Accordingly they have relatively large air spaces in their lungs, and their lung function is not seriously threatened by the action of surface tension. Birds, on the other hand, have small air spaces, more comparable in size to those in the lungs of mammals. But the bird lung is ventilated in a peculiar way. Instead of the tidal ventilation, which alternately inflates and deflates the air spaces of mammals, the exchange of respiratory gases is accomplished by drawing air through the lungs into large air sacs that are separate from the lungs. In this way the change of volume in the air spaces is minimized. The air spaces can remain at or near their maximum volume, and the lungs are stabilized by the elasticity of the lung tissue itself.

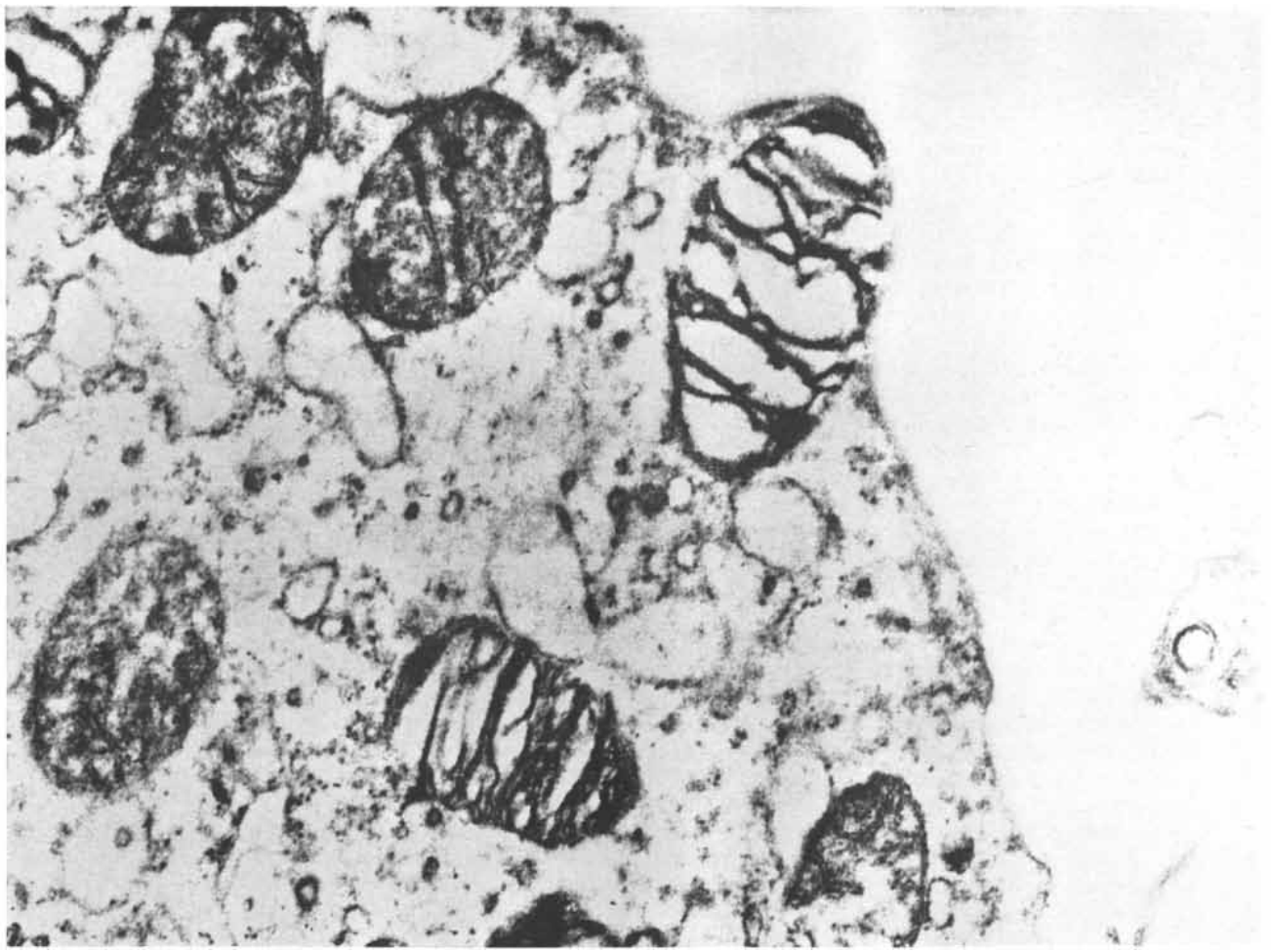
In mammals the lung tissues apparently begin to secrete the critical surface-active material late in embryonic development. This is true, at least, of the two species in which the question has been investigated. In the mouse, which has a gestation period of 20 days, surface activity in the lungs appears suddenly at 17 or 18 days. The lungs of the human fetus develop the activity somewhat more gradually, during the fifth to the seventh month of gestation. This is the interval during which prematurely born infants become increasingly viable.

Since it is now reasonably certain that the secretion of a surface-active material is an adaptation peculiar to mammals, investigators are finding new significance in an observation made in 1954 by Charles Clifford Macklin of the University of Western Ontario. He showed that the walls of the alveoli in mammalian lungs contain special cells that he called granular pneumonocytes. He even suggested that the "granules" discharged by these cells "regulated the surface tension" of the alveoli, but he did not enlarge on this idea further. Under the electron microscope it now appears that the granules of Macklin are cellular particles called mitochondria and possibly the products of mitochondria from certain cells in the alveolar membrane. Mitochondria are associated with the metabolic and synthetic activities of all cells; they appear in high concentration in those tissue cells that have specialized secretory functions [see "Energy Transformation in the Cell," by Albert L. Lehninger; SCIENTIFIC AMERICAN; May, 1960]. Some of the granules can be identified as true mitochondria, with the fine structure that characterizes them in other cells. Others appear to be mitochondria-

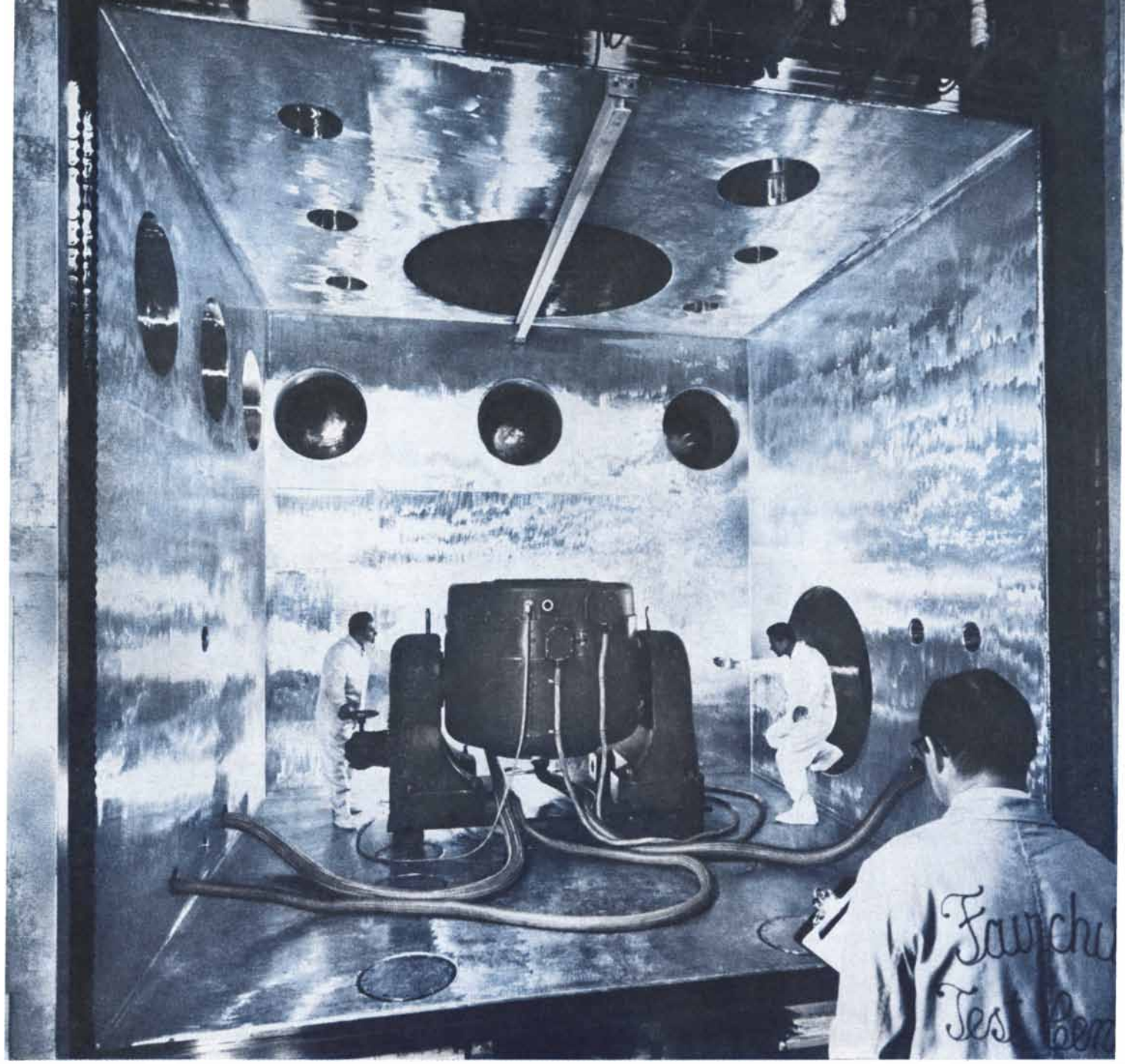
like bodies involved in a process of transformation by which they lose their fine structure and become relatively featureless. Most remarkable of all, the electron-microscope pictures show these same forms passing through the cell membrane from the cytoplasm into the air space. This process could be the means by which the surface-active substance is secreted into the tissue fluid that coats the surface of the alveoli.

Various stages of the process have been observed in the cells of a half-dozen species of mammals but never in the amphibians or birds in which it has been looked for. In mammals, moreover, it has been found that this peculiar transformation of the mitochondria appears in the lung tissues along with surface activity at the same stage of fetal development.

With this background of evidence established by classical physiology and the most modern techniques of cell biology, the way seems to be cleared for investigation of the hormonal, neural, nutritional, environmental and genetic factors that may influence the production, function and elimination of the alveolar surface-active agent. Diabetes, for example, is associated with derangement of lipid, or fat, metabolism. In view of the importance of the lipid fraction of the surface-active agent one wonders if diabetes in the mother may not be a factor predisposing the fetus to respiratory distress at birth, particularly since the syndrome occurs more frequently among infants born to diabetic mothers. The experience with patients in heart surgery suggests another line of investigation. From the rapid decrease in surface activity and the collapse of the lung that sometimes follows the bypassing of the pulmonary circulation, it can be surmised that the production of the agent depends on blood flow and that distribution of the flow affects the distribution of air in the lungs. The question of neural control is raised by experiments with small animals, in which cutting of the vagus nerve is followed by decline in surface activity, the accumulation of fluid and finally collapse of the air spaces. Pure oxygen, atmospheric pollutants and some industrial chemicals have been shown to affect the alveolar surfaces. Animals in which hormonal activity is high—young animals, females in estrus and animals that have been treated with cortisone—are particularly subject to the toxic effects of pure oxygen on the lungs. Occasionally massive collapse of the lungs follows general anesthesia, with no indication of obstruction to the air passages. It is not too much to hope that problems of this kind can be brought within the reach of effective treatment by the next advances in the understanding of the mechanism that regulates the surface tension in the lungs.



MITOCHONDRIAL TRANSFORMATION can be seen in this electron micrograph by Robert E. Brooks of the University of Oregon. It shows part of an alveolar epithelial cell enlarged approximately 45,000 diameters. Toward upper right a transformed mitochondrion seems to be emerging into the air space. To its left is a normal mitochondrion, and to the left of that, one is beginning to change, losing fine structure. Mitochondria probably produce lung agent; transformed mitochondria may carry it to the surface.



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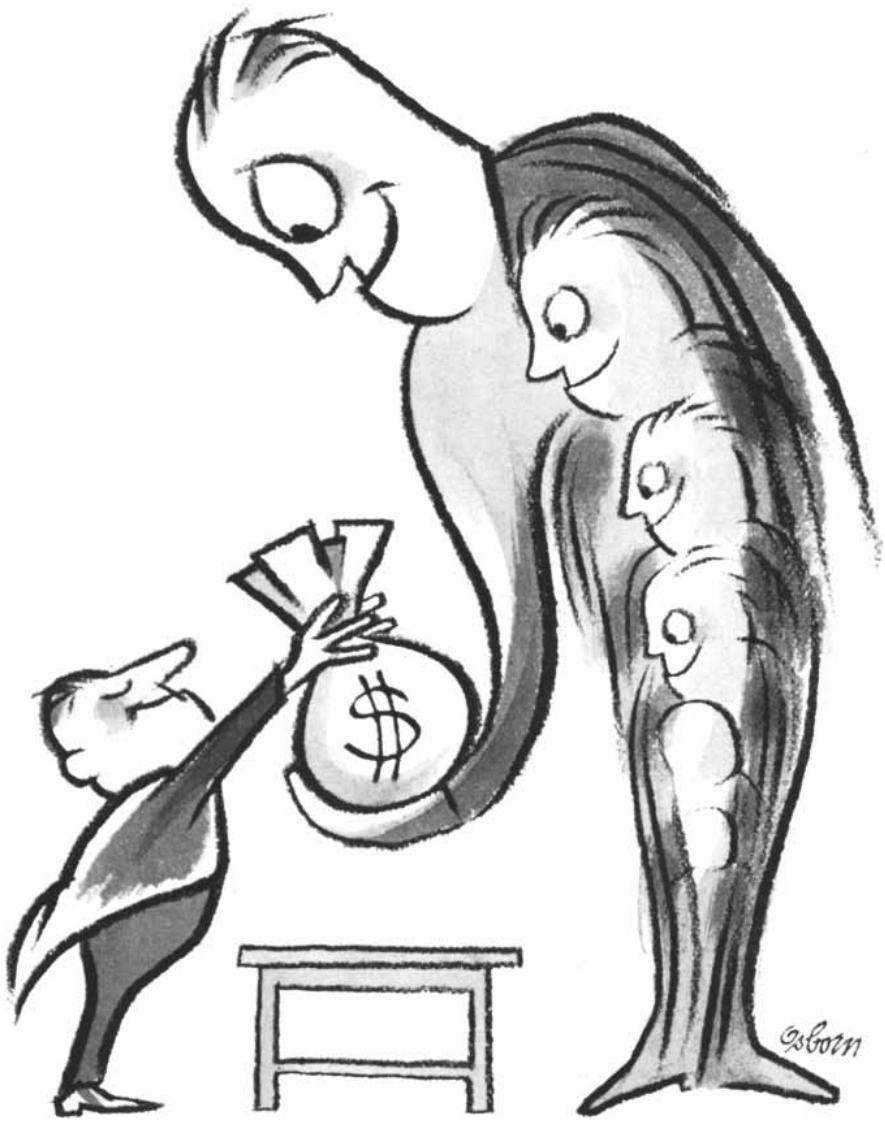
(AND BE REASONABLY SURE OF GETTING IT)



If you ever hope to get rich (or even comfortably fixed), the logical thing to do is to learn *how* to borrow money. And *where*. Like many other things that are important, learning about money takes some intelligence, some practice, some skill – and, often, some help. There's no magic, and luck doesn't have as much to do with it as many people would like to think.

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Here are six easy ways to get started:

First, pick a Full Service commercial bank that's handy to your home or work. (If you have any doubts whether it's a Full Service commercial bank or not, telephone and ask them. If their services include checking accounts, savings accounts and all types of loans, they're a Full Service bank.)

Second, give this bank all your banking business. (This includes your checking and savings accounts, any accounts your wife may have elsewhere. The more business the better.)

Third, get personally acquainted with one of the bank's officers. (Tell him you want to build a good working relationship with his bank because someday you might want to borrow a lot of money.)

Fourth, fill out one of the bank's Personal Financial Statements. (They'll keep it confidential and it will show them that you are deadly serious about building your net worth.)

Fifth, keep your savings account active and growing with regular deposits (even if they're small) and try to maintain some kind of a reasonable balance in your checking account.

Last, borrow a little money for some worthwhile purpose. Pay it back on schedule. Then borrow some more. Pay that back on schedule. Then borrow some more. (You get the picture.)

Get to know your banker before you need him

Almost before you realize it, you'll find that you have earned yourself a priceless banking relationship, a relationship that's built on a reputation for borrowing and paying back exactly as promised. This could be your most precious asset. Guard it zealously.

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Ultraviolet Radiation and Nucleic Acid

The damaging effects of ultraviolet on living things have long been known. Now they are being explained in terms of specific changes in molecules of the genetic material

by R. A. Deering

Ever since the discovery in 1877 that ultraviolet radiation can kill bacteria, workers in several disciplines have been studying the effects of the radiation on living things. Its actions have turned out to be many and varied. Ultraviolet can temporarily delay cell division and can also delay the synthesis of certain substances by cells; it can change the way in which substances pass across the membranes of the cell; it can cause abnormalities in chromosomes; it can produce mutations. Obviously it is a potent tool for the study of living cells, and it has been extensively employed by experimenters. If its exact modes of action at the molecular level were fully understood, the tool would be even sharper and more useful. This article reports the considerable progress that has been made in the past few years toward understanding the biophysical and biochemical role of ultraviolet.

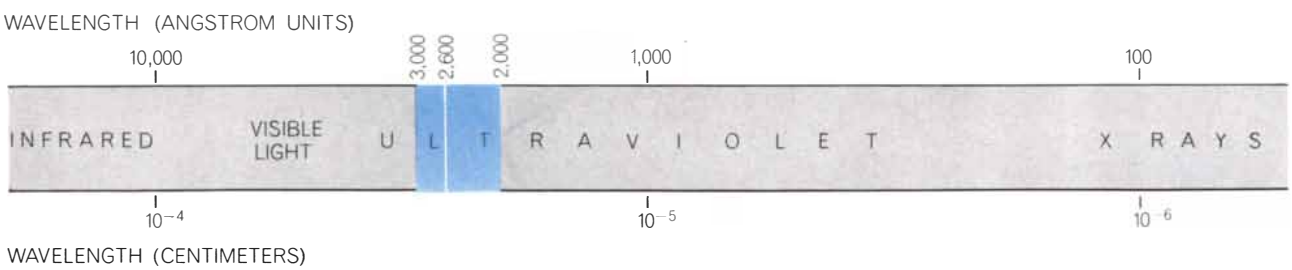
Most of the recent work has concentrated on the interaction of ultraviolet radiation and the molecule of the genetic material deoxyribonucleic acid (DNA), and that is what I shall discuss. There is no doubt that many of the effects of ultraviolet are exerted solely or chiefly by means of changes in DNA. The fact that DNA strongly absorbs ultraviolet, and that its absorption spectrum resembles the ultraviolet "action spectrum" for many biological changes (that is, the biological effectiveness of various wavelengths), show that this must be true. Therefore DNA is the logical starting point in the investigation of the biological activity of ultraviolet radiation.

This radiation falls between visible light and X rays in the spectrum of electromagnetic waves, ranging in wavelength from about 4,000 to a few hundred angstrom units. (An angstrom unit is one hundred-millionth of a centimeter.) The important wavelengths for the biologist are those between 2,000 and 3,000 angstroms. The sun is a powerful emitter of ultraviolet, but a layer of ozone in the upper atmosphere absorbs most of the radiation below 2,900 angstroms. Were it not for the ozone, sunlight would damage or kill every exposed cell on earth.

In the laboratory, working with monochromatic ultraviolet radiation at various wavelengths, investigators have established that the region most potent in its effects on living things is near 2,600 angstroms. When DNA was isolated, it was found to absorb most strongly at just these wavelengths. In the past five years workers in several laboratories have begun to discover what happens to the DNA molecule when it absorbs ultraviolet energy.

Natural DNA, as the readers of this magazine are well aware, normally consists of a double-strand helix. The helices proper—the twin "backbones" of the molecule—consist of an alternation of sugar (deoxyribose) and phosphate groups. Attached to each of the sugars is one of four nitrogenous "bases," generally adenine, guanine, thymine and cytosine. The bases on the two backbones are joined in pairs by hydrogen bonds, the adenine on one chain always being paired with thymine on the other, and the guanine with cytosine. The hydrogen bonds that join the base pairs are weaker than ordinary chemical bonds. Simply heating double-strand DNA breaks the bonds and partially or completely separates the two backbones into two strands of "denatured" DNA.

Ultraviolet radiation falling on DNA is absorbed primarily by the bases, which exhibit about the same absorption peak at 2,600 angstroms as the whole DNA molecule does. This being the case, the first approach was to study the effects of ultraviolet radiation on the isolated bases. It soon turned out that thymine and cytosine, which belong to the class



ULTRAVIOLET portion of the electromagnetic spectrum lies between visible light and X rays. The wavelengths between 2,000 and 3,000 angstrom units are of primary biological importance. DNA, the genetic material, absorbs most strongly at 2,600 angstroms.

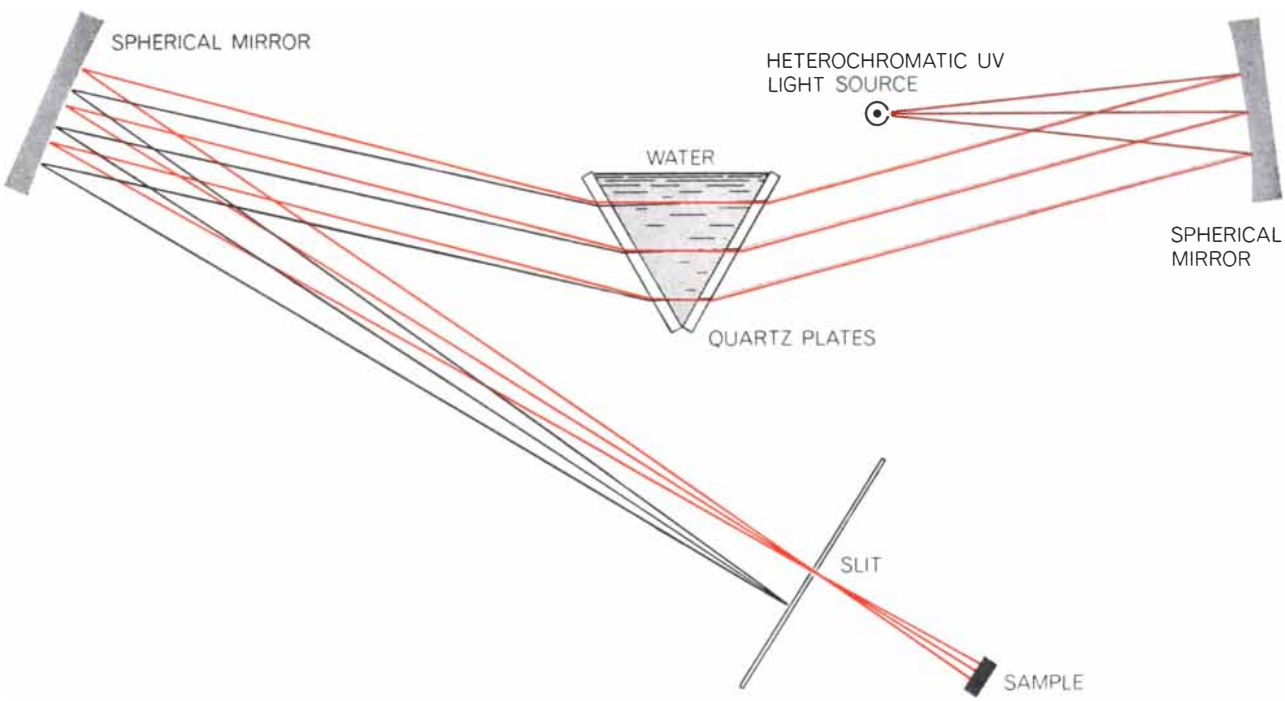
of substances called pyrimidines, are far more sensitive to ultraviolet than are adenine and guanine, which are purines. About one in every 100 quanta of ultraviolet energy absorbed by pyrimidines alters the molecules; for purines the ratio is one in 10,000. (In general only a few of the quanta absorbed by a molecule will be effective in producing permanent changes.) The search was therefore narrowed to the pyrimidines.

The first effect to be discovered was that ultraviolet acts on cytosine molecules or the cytosine units of DNA in water solution, adding a water molecule across a double bond [*see middle illustration on page 138*]. Heating the altered cytosine, even to the temperatures required for biological growth, or acidifying it, partly reverses the reaction. Therefore the hydration of cytosine did not seem likely to be of major biological importance.

For some years, however, this hydration was the only sensitive, ultraviolet-induced change in the bases that could be detected. Heavy doses of radiation did produce complex rearrangements, but these doses were far in excess of the smallest ones known to have biological effects. About three years ago a breakthrough in the photochemistry of DNA came when R. Beukers, J. Ijlstra and W. Berends of the Technological University of Delft in Holland and Shih Yi Wang, now of Johns Hopkins University, discovered that although in a liquid solution thymine is not particularly sensitive to ultraviolet, in a concentrated, frozen aqueous solution it is extremely sensitive. It developed that irradiation of the frozen solution causes thymine molecules to combine and form two-molecule chains, or dimers. As in the case of the cytosine conversion, a double bond changes to a single, and new bonds between carbon atoms link the two thymines [*see bottom illustration on page 138*]. Unlike the altered cytosine, the thymine dimer is stable to heat and acid. But when the solution is melted, irradiation can convert the dimer back into the two original thymine molecules. What the freezing does is to hold the thymines close together in a crystalline or semicrystalline configuration, making it possible for the dimer bonds to form between two neighboring thymines when they absorb ultraviolet. It seemed likely that such a conversion would also occur in DNA, where thymine units are sometimes adjacent to each other on a helical strand and are held in relatively fixed positions. In 1960 Adolf Wacker and his associates at the University of Frankfort found thymine dimers in DNA extracted from irradiated bacteria.

In order to get more complete information on the formation and splitting of thymine dimers in polymer chains such as DNA, Richard B. Setlow and I carried out experiments on some model polymers at the Oak Ridge National Laboratory. Similar experiments were performed independently at the California Institute of Technology by Harold Johns and his collaborators. The compounds we used were short polymers—in effect short single strands of DNA in which all the bases were thymine. Some of our test molecules contained only two backbone units and two thymines; others had 12 or more. Since the sugar-phosphate backbone holds the thymines in fairly close proximity, we anticipated that ultraviolet radiation should form dimers between adjacent thymines in a chain even in a liquid solution. And we expected that once the dimers had formed they would be subject to breakage by ultraviolet, as were the isolated thymine dimers. When thymine loses a double bond in changing to a dimer, it also loses its ability to absorb light at 2,600 angstroms. Therefore measuring the change in 2,600-angstrom absorption gives an indication of the ratio between thymine monomers and thymine dimers in the solution.

When we irradiated our polymers, dimers were in fact produced. Since the rate of formation did not vary with thymine concentration, we concluded



MONOCHROMATOR provides ultraviolet light of a single wavelength for experiments. Light of mixed wavelengths is rendered parallel by a spherical mirror and passes through a quartz-and-water prism. (Glass would not transmit the desired wavelengths.) The prism splits the light into many components of different wavelengths, only two of which are indicated here, and the beams are refocused by a second mirror. The sample to be irradiated is positioned behind a slit that excludes all but the desired wavelength.

that they were formed within, rather than between, individual polymers. Dimers also broke up into monomers, but not at the same rate at which they formed. The process is analogous to a reversible chemical reaction in which forward and backward reactions proceed at different rates, with an equilibrium eventually being reached between the reactants and the products. We found that for every wavelength of ultraviolet there is at high doses an equilibrium between the number of dimers being formed and the number being broken [*see top illustration on page 142*]. At each wavelength and intensity there is a certain rate for dimer formation and a different one for breakage; the equilibrium level is determined by the relative rates of the forward and backward reactions. At 2,800 angstroms the equilibrium state is on the dimer side: most of the thymines are dimerized. At 2,400 angstroms the opposite is true: most of the thymines are monomers. The relative number of monomers and dimers in the polymer solutions can be controlled by changing the wavelength of the incident ultraviolet.

When the data from a number of experiments are plotted [*see bottom illustration on page 142*], the resulting curves show the ability of each wavelength to make and break dimers in these model polymers. The curves approximately parallel the absorption spectra of the monomer and dimer respectively, indicating that it is difference in absorption capacity that accounts for the different action of various wavelengths. The "quantum yield," or number of molecules altered by each quantum, does not change greatly with wavelength; for dimer formation in the polymers containing only thymine it is of the order of .01 and for breakage it is near 1.

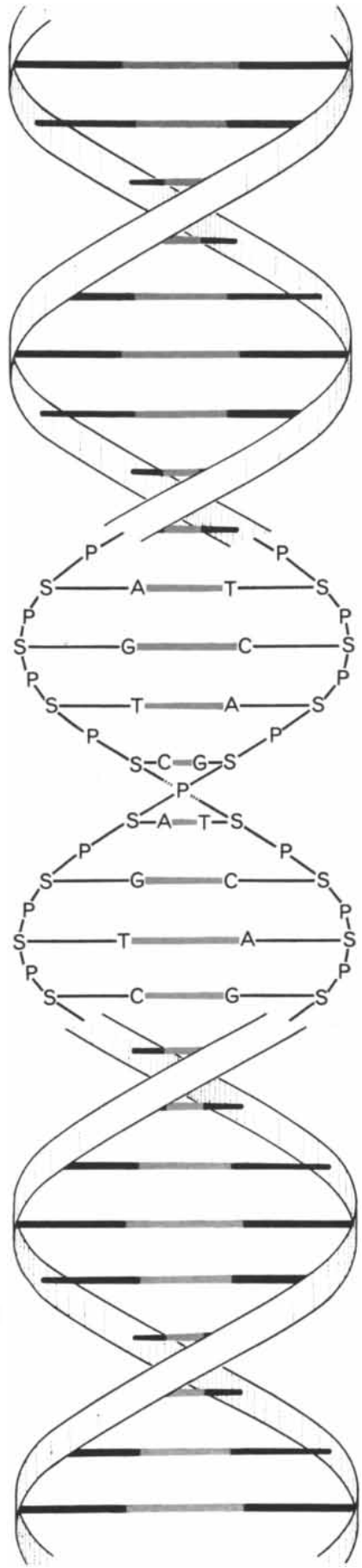
The next step was to relate molecular changes to changes in the properties of DNA and in its biological activity. Julius Marmur and Lawrence Grossman of Brandeis University have shown recently that when double-strand DNA is exposed to ultraviolet, the two strands become more strongly linked, apparently by chemical bonds rather than by the original weak hydrogen bonds. Marmur and Grossman believe the strong link is the result of interchain dimerization, that is, the formation of dimers between thymine units on opposite strands of the double helix.

At Oak Ridge, Frederick J. Bollum and Setlow found that ultraviolet can induce dimer linkages between adjacent thymine units in single-strand DNA. They suspect that the same thing can happen between adjacent thymines in natural DNA, but in this case some of the hydrogen bonds in a local region may have to be broken before dimerization is possible. Marmur and Grossman have shown that irradiation does indeed disrupt hydrogen bonding between strands of natural DNA.

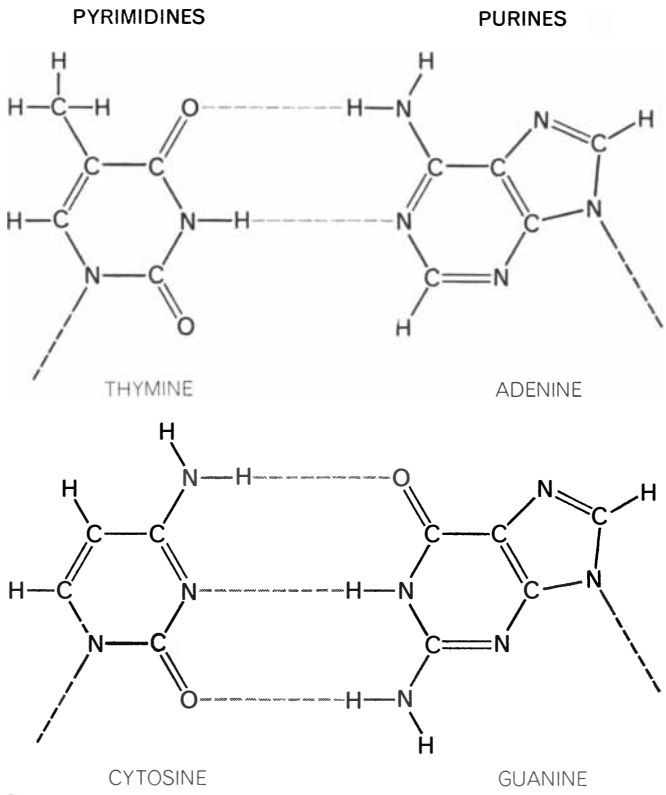
Another effect of ultraviolet on isolated DNA that has been clearly identified is a breaking of the sugar-phosphate backbone, but this occurs only at uninterestingly high doses. Among the sensitive reactions only the cytosine and thymine conversions are understood well enough for their biological implications to be assessed. There are surely other important effects, but they remain to be discovered.

Although the biological significance of the cytosine hydration has generally been discounted because it reverses at body temperature or lower, the reversal may be slower in intact DNA than in the isolated base. There is no direct evidence that the hydration product would be detrimental to the biological activity of DNA, but it might affect the hydrogen bonding in a segment of the helix and thereby give rise to the broken bonds observed by Marmur and Grossman.

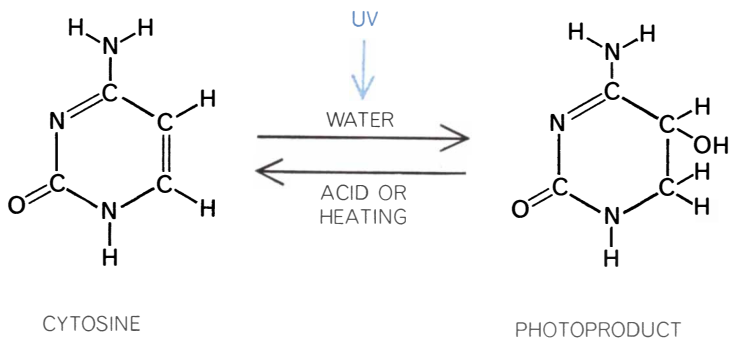
The formation of thymine dimers should in theory be of great biological significance. When DNA makes a replica of itself, according to the widely accepted hypothesis, the hydrogen bonds break and a new complementary chain forms along each of the old strands. A dimer cross link between strands would interrupt the separation, blocking replication. Dimers between adjacent thymines on the same strand would interfere with proper pairing of the bases. Normally an adenine should come into position opposite each thymine on the parent strand. The joining of two adjacent thymines would probably change matters enough to impair the proper incorporation of adenine; replication might stop short at



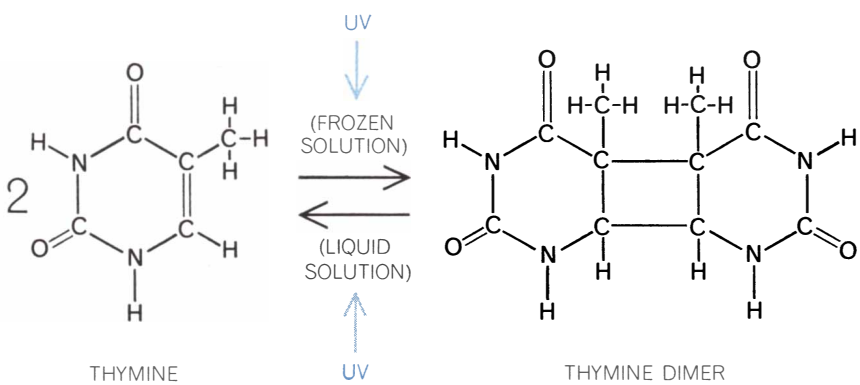
DNA MOLECULE is a double helix, diagramed here schematically. (One strand is actually displaced along the axis of the helix with regard to the other.) The backbone strands are composed of alternating sugar (*S*) and phosphate (*P*) groups. Attached to each sugar is one of four bases, usually adenine (*A*), guanine (*G*), thymine (*T*) and cytosine (*C*). Hydrogen bonds (*gray*) between bases link the strands. Adenine is always paired with thymine, guanine with cytosine. Genetic information is provided by the sequence of bases along a strand.



FOUR BASES are diagramed as they are paired in DNA. Adenine and guanine, the larger molecules, are purines; thymine and cytosine are pyrimidines. The broken black lines show points of attachment to sugar groups; the broken gray lines are interchain hydrogen bonds.



CYTOSINE in a water solution is altered by irradiation with ultraviolet. A water molecule is added across the double bond between two carbon atoms, the double bond changing to a single bond. When the cytosine solution is heated or acidified, the process is reversed.



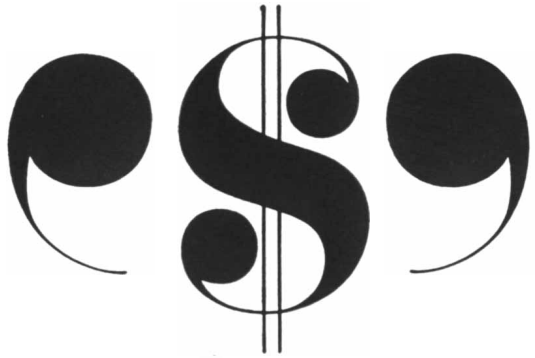
THYMINE in a frozen solution undergoes the reaction shown here when it is irradiated. The double bond between carbon atoms changes to single and two thymines are linked in a double molecule, or dimer. When the solution is melted, irradiation breaks the dimer.

that point or might proceed incorrectly, with an altered base sequence on the newly formed chain. On subsequent replication this altered strand would replicate itself, producing a molecule with the wrong base sequence in both strands —in other words, a mutated gene.

Recent work at Oak Ridge has provided direct experimental proof that thymine dimerization is one of the important ways in which the biological activity of DNA is altered by ultraviolet. Setlow and Bollum studied the ability of irradiated single strands of DNA to serve as a template in the manufacture of new DNA in a variety of cell-free test-tube preparations. Irradiation at 2,800 angstroms cut down the priming ability of DNA, the reduction being proportional to the adenine-thymine content of the various preparations. Subsequent irradiation at 2,400 angstroms partially restored template activity. Presumably irradiation at 2,800 angstroms formed dimers between adjacent thymines on the template DNA, blocking or slowing down the normal synthesis of new DNA strands. Irradiation at 2,400 angstroms evidently broke some of the dimers, partially restoring template activity.

In another series of experiments Setlow and his wife Jane K. Setlow worked with a form of DNA called "transforming principle," studying its ability to carry specific bits of genetic information from one cell to another. The measure of the biological activity of the DNA in this case was its effectiveness in transforming a given trait in the new cell. The Setlows found that irradiation at 2,800 angstroms destroyed the transforming ability of a portion of the DNA molecules. Again, when the irradiated DNA was exposed to 2,400-angstrom radiation, some of its molecules regained their transforming ability. The experimenters could account quantitatively for their results by assuming that about 50 per cent of the inactivation of the transforming DNA was due to thymine dimerization. They do not know what changes account for the rest.

When some types of cells that have been damaged by ultraviolet are exposed to ordinary blue light, a great deal of the damage is reversed; even bacteria that appear to have been killed are revived [see "Revival by Light," by Albert Kelner; SCIENTIFIC AMERICAN, May, 1951]. Claud S. Rupert and his associates at Johns Hopkins University had shown that this photoreactivation takes place through light-mediated enzyme reactions, but the details were not known. Recently Daniel L. Wulff and



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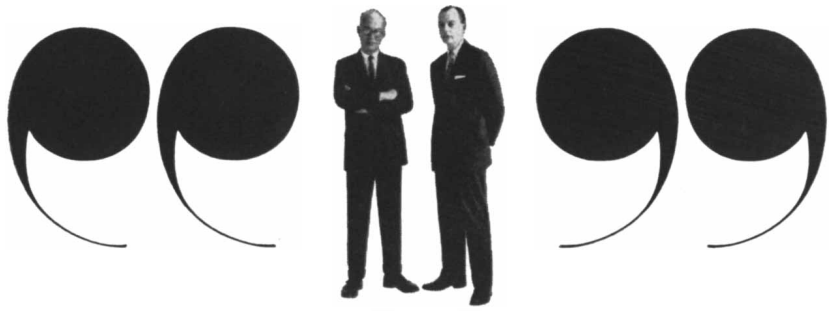

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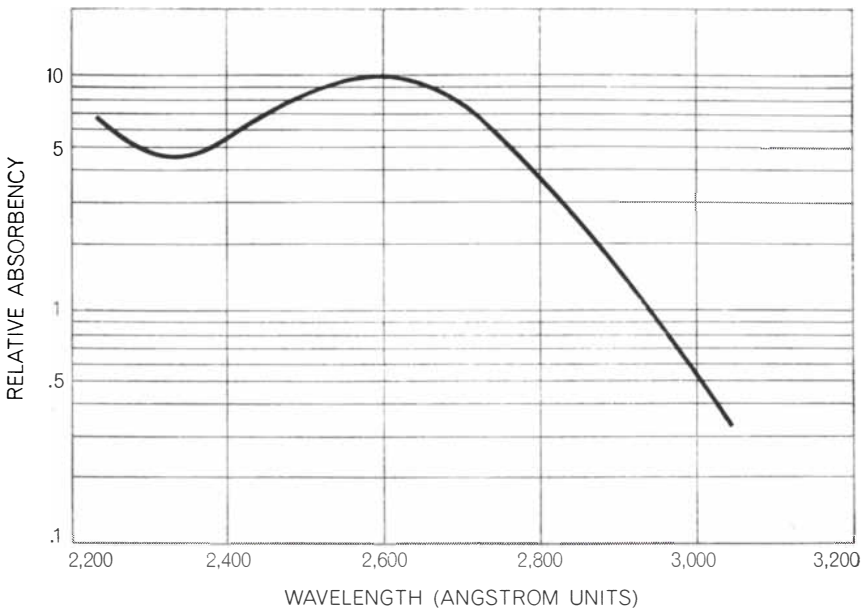
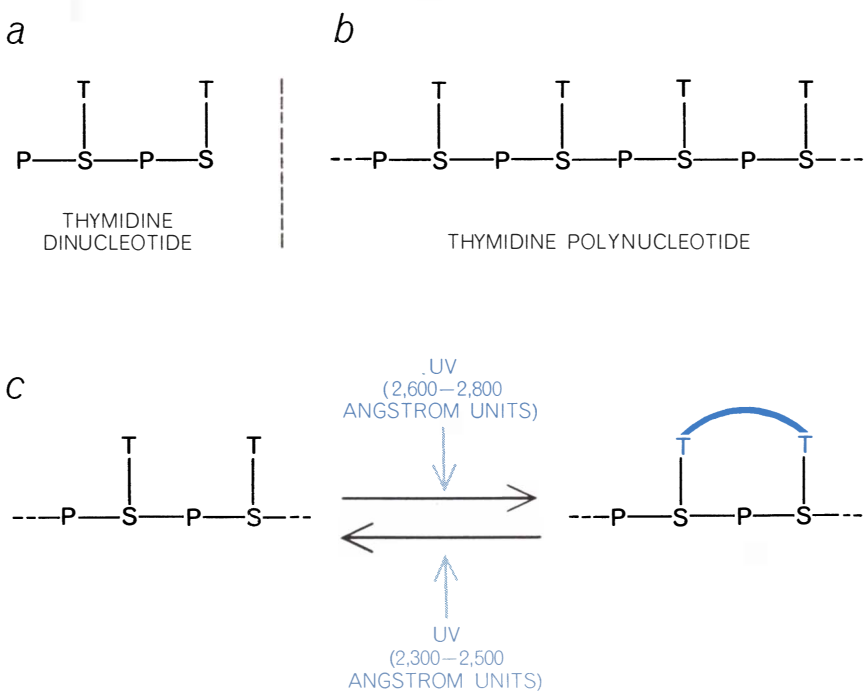


ABSORPTION SPECTRUM of DNA shows its ability to absorb ultraviolet of various wavelengths. The peak is at 2,600 angstroms, the wavelength known to be most harmful to cells.

Rupert have identified one mechanism of reactivation: a particular enzyme preparation, in the presence of blue light, can break up to 90 per cent of the thymine dimers in irradiated DNA. Marmur and Grossman have also shown that the enzyme system can break the ultraviolet-induced cross links between two DNA strands, thereby strengthening the idea that these links result from interchain thymine dimers.

Some bacteria apparently can produce enzymes that repair ultraviolet-damaged DNA without the need for visible light. The extreme resistance to ultraviolet displayed by certain bacteria may



MODEL POLYMERS exposed to ultraviolet were synthetic all-thymine DNA strands composed of either two nucleotide (phosphate-sugar-base) units (*a*) or 12 or more units (*b*). Irradiation both formed and broke dimers between adjacent thymines (*c*). Irradiation with high doses of the longer wavelengths led to an equilibrium condition in which most of the thymines were dimerized; exposure to shorter wavelengths tended to break the dimers.

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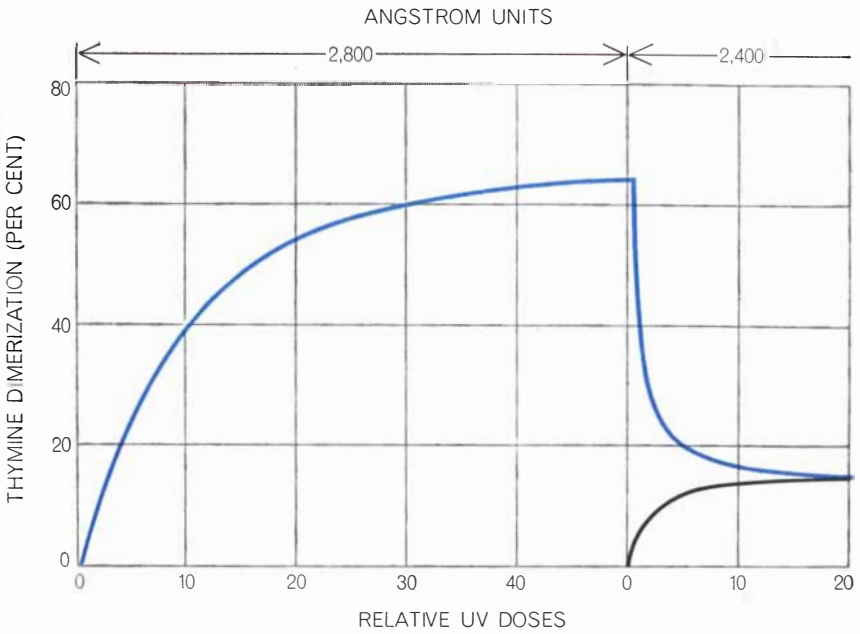
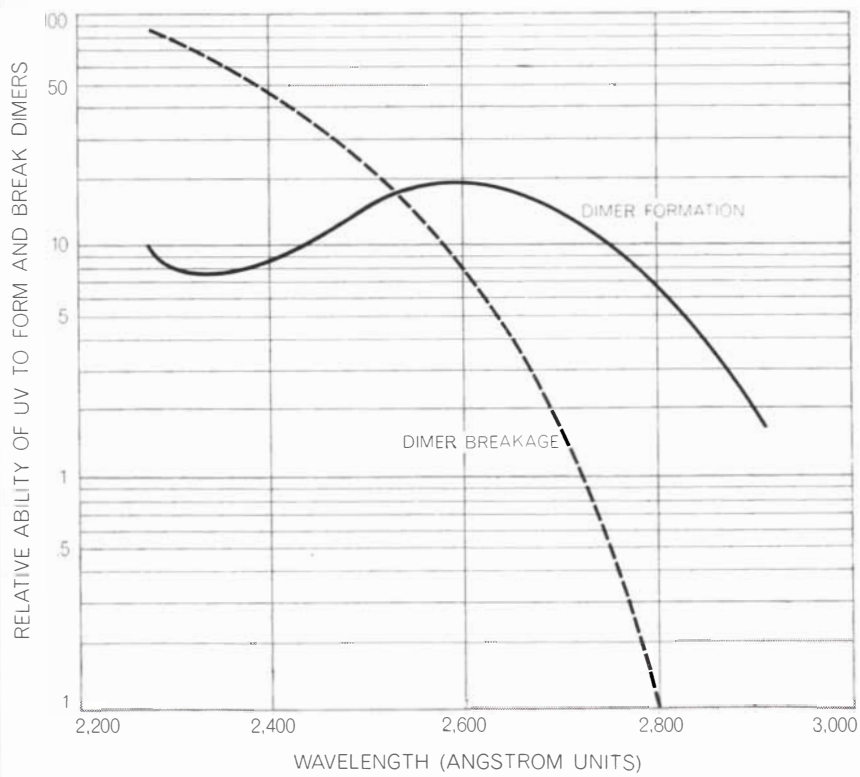


DEGREE OF DIMERIZATION varies with wavelength and dose. Increasing the exposure at 2,800 angstroms increases the proportion of thymine units that are dimerized until an equilibrium state is attained with 65 per cent of the thymine units as dimers (*colored curve*). Irradiation at 2,400 angstroms of the same sample, or of a different sample (*black curve*), results in a new equilibrium level with about 17 per cent of the thymines dimerized.

come from an ability to produce large amounts of these repair enzymes.

To sum up, it is clear that ultraviolet can change DNA in specific ways and can partially reverse those changes. Moreover, both the forward and backward alterations are reflected in DNA function. There is considerable evidence that much of the damage that ultraviolet radiation inflicts on cells and viruses is caused directly by its effects on DNA.

In the case of viruses this may be the whole story. When they infect a cell to



VARIOUS WAVELENGTHS differ in ability to form and break dimers. Those over 2,540 angstroms are more able to form dimers; the reverse is true of the shorter wavelengths.

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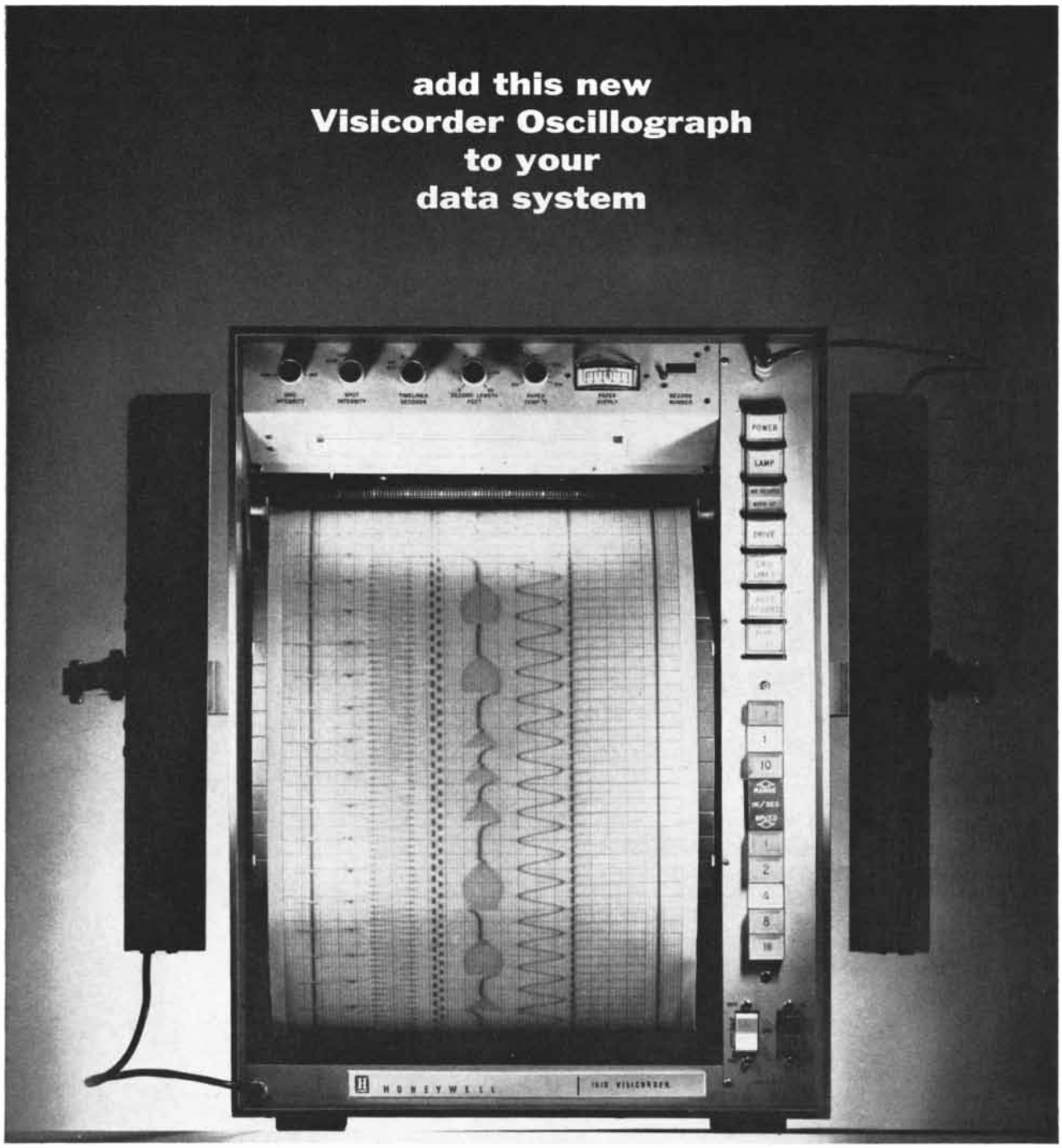

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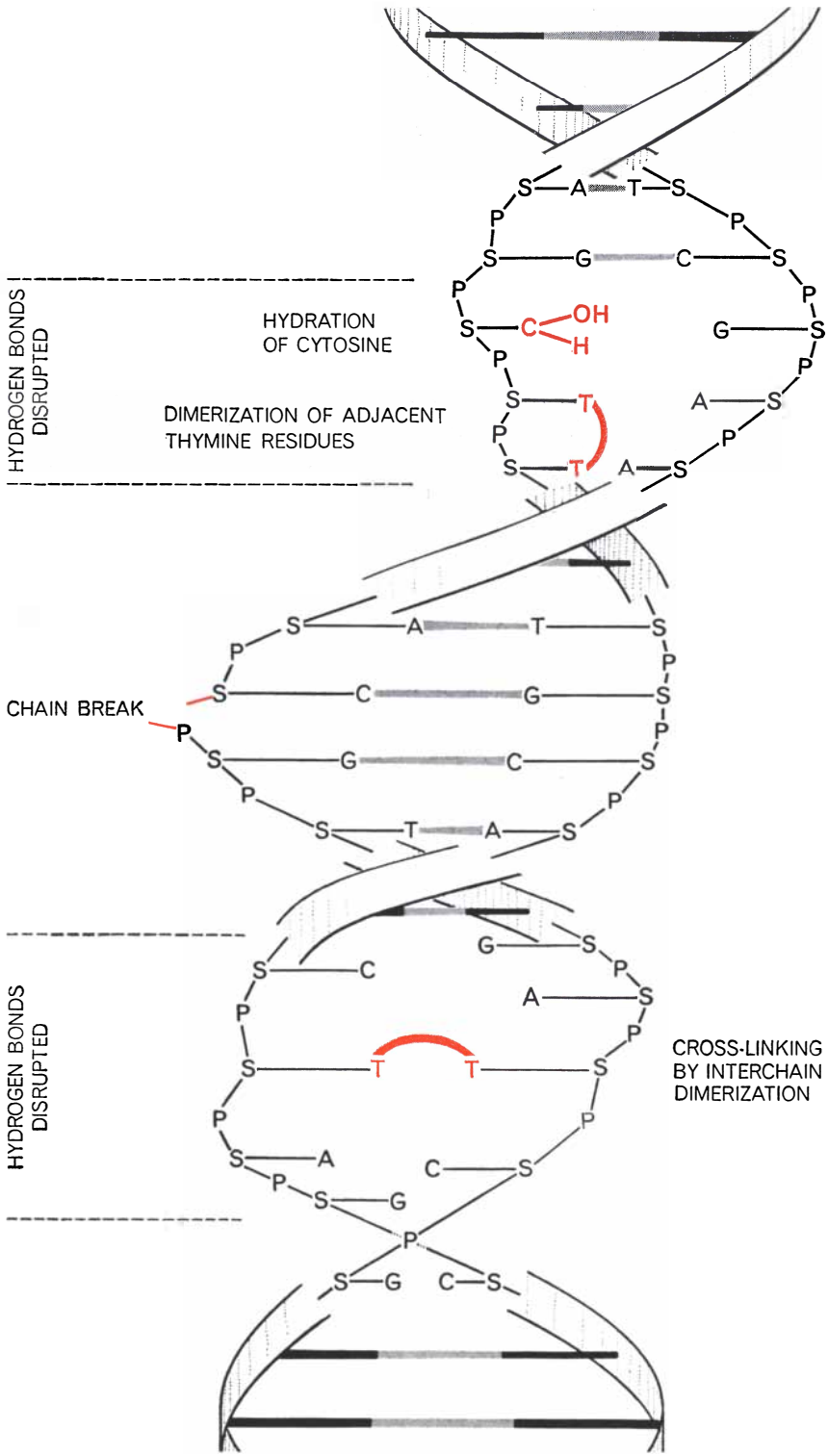
replicate themselves, only their nucleic acid is injected into the cell. Therefore damage to DNA must be directly reflected in the ability of the virus to take over the cell's metabolism and multiply. In cells, however, one cannot assume that the only important effects of ultraviolet are those involving DNA. The radiation is absorbed by proteins, by ribonucleic acid (RNA) outside the nucleus and by other substances that play a part in cell metabolism, and it presumably changes their structures too. The task of identifying all the ultraviolet reactions in living organisms has been well begun, but there is much to learn.



ALTERATIONS IN DNA caused by ultraviolet irradiation are diagramed here. The formation of thymine dimers is the change most likely to do damage to living cells and viruses.

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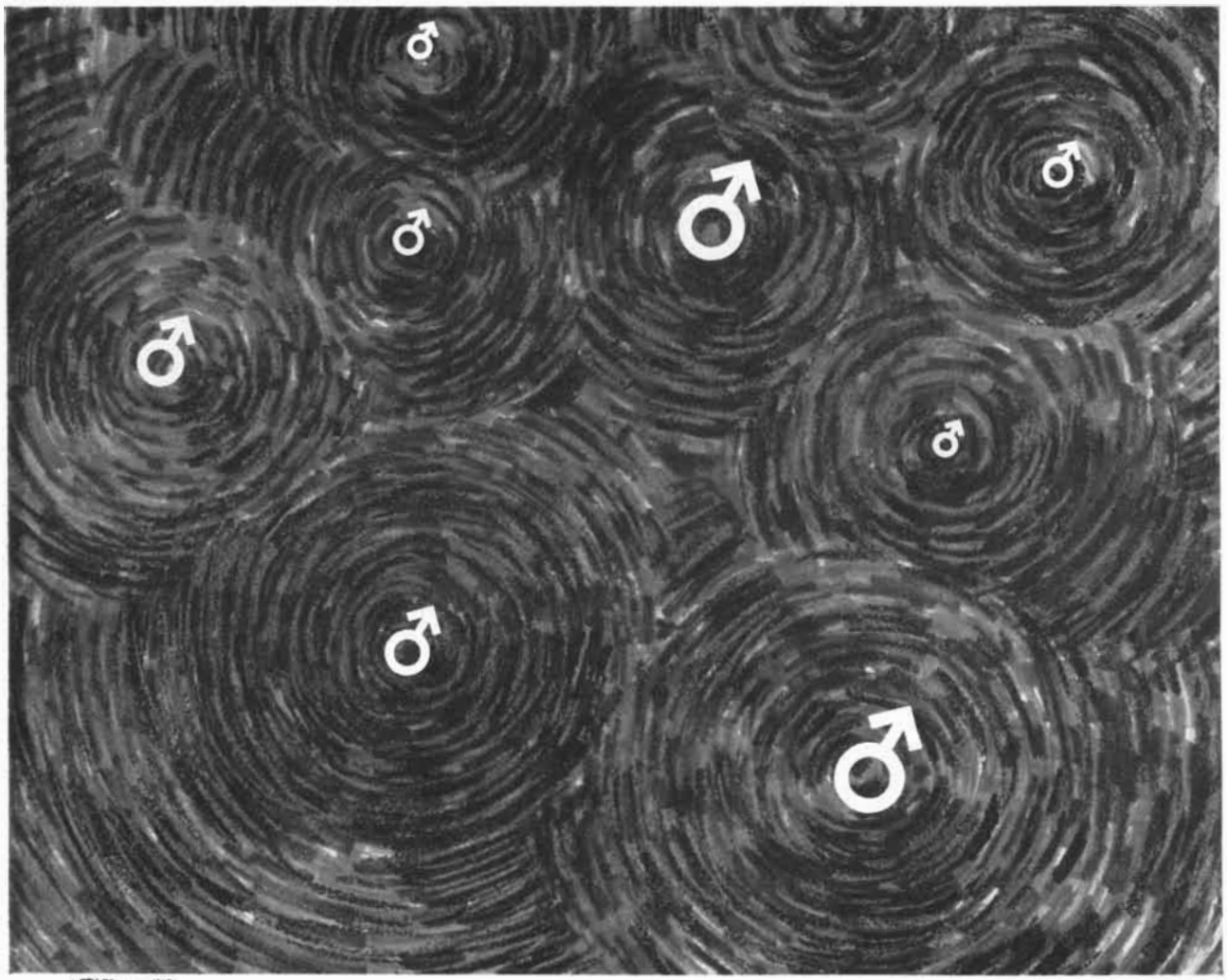

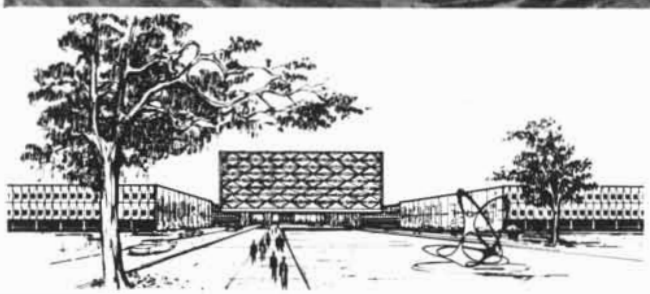

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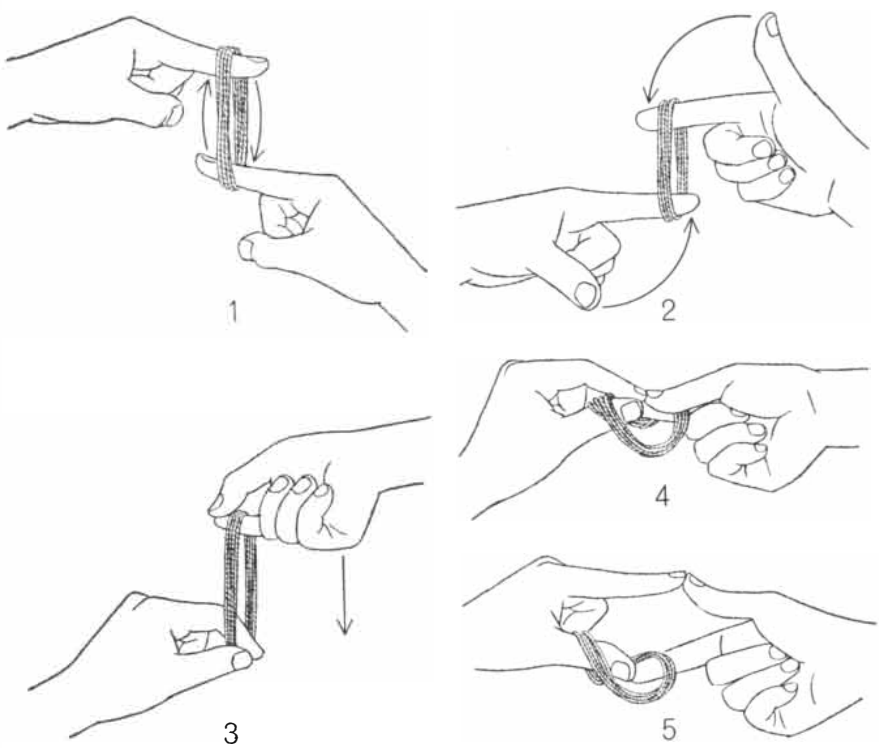
by Martin Gardner

"Jane Ellin Joyce bubbled into our big new drugstore... She hopped onto a stool at the soda counter and elbowed back a black evening wrap from a low-cut white dress... She was holding up her hands in front of her. There was a long loop of cord between them."

So begins *Leopard Cat's Cradle*, an offbeat mystery novel by Jerome Barry. An anthropologist at Columbia University has initiated Jane Ellin into the mysteries of the string play of primitive cultures. She is practicing for an unusual night-club act in which she tells an amusing story, illustrated by a dazzling series of string patterns that she forms rapidly on her fingers with a golden cord.

Just as the charm of origami, the Japanese art of paper folding, lies in the incredible variety of things that can be done with a single sheet of blank paper, so the charm of string play lies in the incredible variety of entertaining and even beautiful things that can be done with one loop of cord. The string should be about six feet long and knotted at the ends. The loop is, of course, a model of a simple closed-space curve. Only the length of the cord and its topological properties remain invariant, so that in a loose sense one can think of string play as a topological pastime.

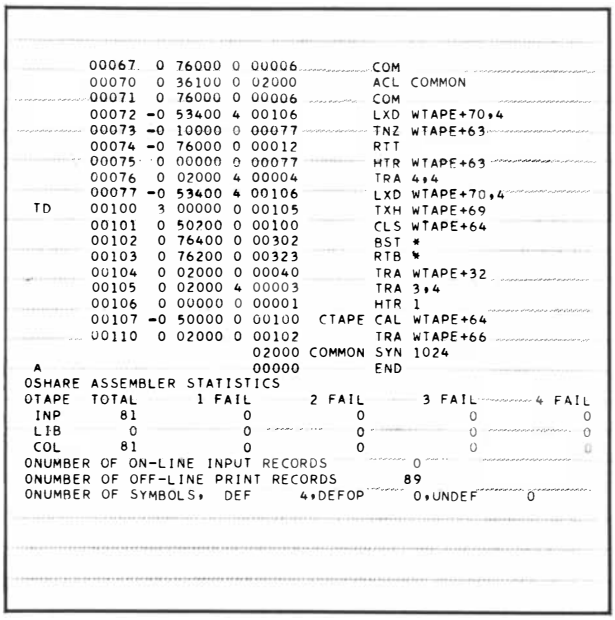
There are two basic categories of string play: releases and catches, and patterns. In stunts of the first category the string appears to be linked or entangled with an object but, to everyone's surprise, is suddenly pulled free; or, alternatively, the loop unexpectedly catches on something. For example, the



A loop-release trick

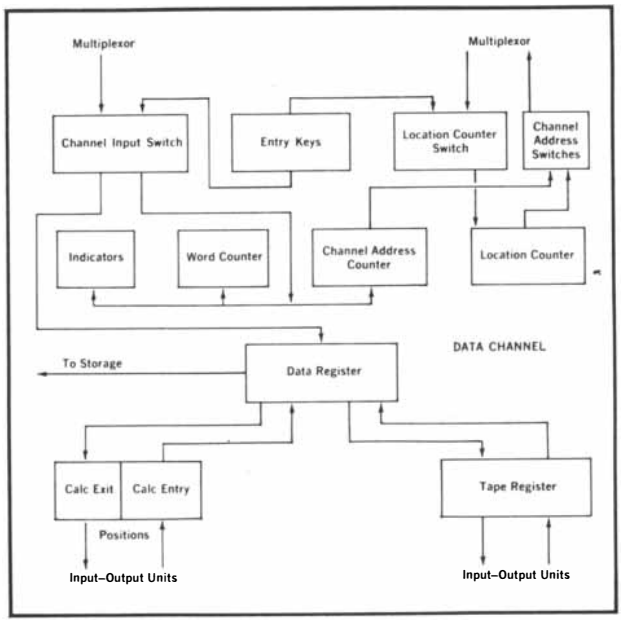
IBM asks basic questions in machine organization

How efficiently can we use computers?



```
        00067   0 76000 0 00006          COM
        00070   0 36100 0 02000          ACL  COMMON
        00071   0 76000 0 00006          COM
        00072  -0 53400 4 00106          LXD  WTAPE+70,4
        00073  -0 10000 0 00077          TNZ  WTAPE+63
        00074  -0 76000 0 00012          RTT
        00075   0 00000 0 00077          HTR  WTAPE+63
        00076   0 02000 4 00004          TRA  4,4
        00077  -0 53400 4 00106          LXD  WTAPE+70,4
TD      00100   3 00000 0 00105          TXH  WTAPE+69
        00101   0 50200 0 00100          CLS  WTAPE+64
        00102   0 76400 0 00302          BST  *
        00103   0 76200 0 00323          RTB  *
        00104   0 02000 0 00040          TRA  WTAPE+32
        00105   0 02000 4 00003          TRA  3,4
        00106   0 00000 0 00001          HTR  1
        00107  -0 50000 0 00100  CTAPE   CAL  WTAPE+64
        00110   0 02000 0 00102          TRA  WTAPE+66
                          02000 COMMON   SYN  1024
A                         00000          END
OSHARE ASSEMBLER STATISTICS
OTAPE  TOTAL      1 FAIL      2 FAIL      3 FAIL      4 FAIL
 INP      81           0           0           0           0
 LIB       0           0           0           0           0
 COL      81           0           0           0           0
ONUMBER OF ON-LINE INPUT RECORDS      0
ONUMBER OF OFF-LINE PRINT RECORDS     89
ONUMBER OF SYMBOLS,  DEF     4,DEFOP     0,UNDEF     0
```

This type of written input-output program is relatively time-consuming and costly to prepare, particularly when input-output routines are used repeatedly.



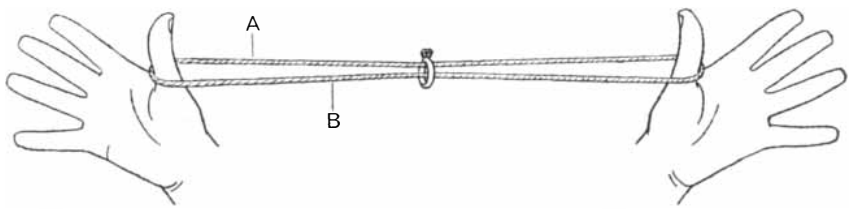
Input of routine data with a unit such as this IBM 7090 data channel reduces program writing, speeds up processing, and cuts the cost per answer.

In an effort to increase efficiency, more and more instructions have been built into computers in the form of circuitry. This means fewer written programs are necessary. However, built-in computer instructions that facilitate the solution of a particular type of problem may limit the computer's capacity to handle a variety of problems. Because of this, IBM is studying new ways of organizing data processing systems. The goal is to improve the speed and proficiency of specialized problem solving without sacrificing the flexibility of general-purpose machines.

Computer architects at IBM are attempting to achieve the most efficient relationship of built-in instructions and programming systems to the range of problems to be solved. They are transferring many input-output and programming operations to built-in circuitry. One example is the IBM 7090 data channel shown above. In addition, they are developing common languages which make it possible to use the same program on different machines. At the same time, they are working to increase over-all speed by developing time-sharing and concurrency techniques that make greater use of the entire system. For example, IBM programmers have developed a method by which a large computer can handle a number of problems at once, thus reducing the cost per answer.

This involves a supervisory program that monitors the execution of the multiple tasks assigned to the central processor. In addition to these multiple problem-solving techniques, an experimental system permits the computer to handle several different programs simultaneously. From developments such as these will come the advanced architectural techniques necessary for a new generation of computers.

If you have been searching for an opportunity to make important contributions in machine organization, optics, solid-state physics, or any of the other fields in which IBM scientists and engineers are finding answers to basic questions, please contact us. IBM is an Equal Opportunity Employer. Write to: Manager of Professional Employment, IBM Corporation, Dept. 659Z, 590 Madison Ave., N. Y. 22, N. Y.



The ring-release trick

string is suddenly released from a buttonhole, or loops are placed around the neck, an arm, a foot—even the nose—and then mysteriously pulled free. In many releases the cord is looped once or more around someone's upright finger and then freed by a series of curious manipulations. In other releases the string is twisted in a hopeless tangle around the fingers of the left hand and a tug pulls it free. There are many variations of an old carnival swindle called the garter trick (it was often performed with a garter in the days when men wore silk stockings), in which the string is formed into a pattern on the table; a spectator puts his finger in one of the loops and then bets on whether the string will or will not catch on his finger when the swindler pulls the cord to one side. Of course the operator has subtle ways of controlling the outcome.

An amusing release that never fails to intrigue all who see it begins with the string doubled three times to form a small eight-strand loop about three inches in diameter. Insert your two forefingers into the loop and rotate it by twirling the fingers in the manner shown in the drawing numbered *1* in the illustration on page 146. After twirling for a few moments, stop at the position indicated by 2, then touch the tip of each thumb to the tip of each forefinger as shown in 3. Lower your right hand and place the tips of thumbs and forefingers together as shown in *4*. Note that the right thumb touches the left finger and the left thumb touches the right finger. (Do not call attention to this. It is the secret of the trick!) Keeping thumbs pressed against fingers, raise your right thumb and left finger as shown in 5. The loop is now lying on the lower thumb and finger. At this point a slight forward toss (keeping intact the circle formed by fingers and thumbs) will throw the loop free of the hands.

Challenge anyone to do what you just did. He will find it astonishingly difficult. Most people assume that thumb touches thumb and finger touches finger. On this assumption it is impossible to free the loop without breaking the circle formed by fingers and thumbs—and such a break is not allowed. Practice until you can do the feat smoothly and rapidly. You will find that you can demonstrate it over and over again without anyone's succeeding in duplicating the moves.

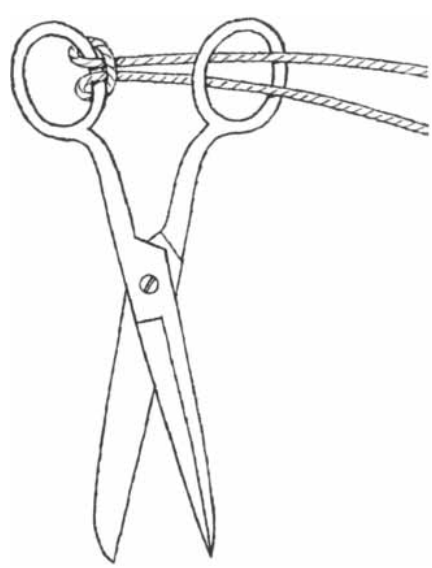
A completely different type of release is that of freeing a ring from the cord. A spectator's upright thumbs hold the string as shown in the illustration above, with the ring riding on both strands. The following is the simplest of many techniques for removing the ring: Place your extended left forefinger over both strands at the point marked *A*. With your right hand pick up the strand nearest you, at point *B*. Draw it upward to the left and place it over the spectator's right thumb (the thumb to your left), moving it from front to back. Curl your left forefinger to retain a firm grip on both strands. Slide the ring to the left as far as you can. Pick up the uppermost strand to the right of the ring, draw it up and to the left and loop it (this time from back to front) over his right thumb.

Pause at this point and ask the spectator to touch the tip of each thumb to the tip of each forefinger. This, you explain, is to make certain that no loop is slipped off either thumb. Grasp the ring with your left hand. Tell him that on the count of three he is to move his hands apart to take up the slack that will form in the cord. When you say "Three," withdraw your left forefinger from the string. As he moves his hands apart the ring comes free. The cord remains on his thumbs exactly as it was at the beginning, without even a twist in it. (As the ring is being released you can slide it along the cord to the right so that it appears to come free near his *left* thumb, where he knows the loop on his thumb is secure.) Children are always delighted by this trick, particularly because it is easily learned and they can show it to friends.

After mastering this release you may wish to try the more sophisticated variation of putting three rings on the cord and removing only the center one. Begin as before, putting the first loop over the spectator's thumb. Slide the first two rings to the left, leaving the third ring near his left thumb. Grasp the upper strand as before, to the right of both rings, but thread it through the first ring before you loop it over his thumb. Hold the middle ring with your right hand and finish as before. Can the reader devise a similar series of manipulations that will put the ring back on the center of the cord again?

The illustration below shows a ring-and-string release in the form of a puzzle. Fasten a pair of scissors to one end of the cord as shown. The other end is tied to the back of a chair. The problem is to free the scissors without cutting or untying the string. The puzzle is too easy to require an answer next month, although many readers may find it harder than it looks.

In the second broad category of string play, various patterns and figures are formed on the hands. This art is part of the folklore of every primitive culture in which string has an important role. For untold generations it has been one of the chief pastimes of the Eskimos, who play it with reindeer sinews and thongs of sealskin. Other cultures in which string figures have reached an advanced stage are those of the North American Indians and of native tribes in Australia, New Zealand, the Caroline Islands, the Hawaiian Islands, the Marshall Islands, the Philippines, New Guinea and the



The scissors-release puzzle

AT RADIATION, IDEAS BECOME REALITY

Example: Telstar's 8 lb/112 channel PCM telemetry system

Bell System's Telstar's continuing success—in a space environment that intersects the Van Allan Belt—not only proves the feasibility of world satellite communications, but also the reliability of a new transmission technique. PCM telemetry has now won its spurs as the most advanced method of checking satellite performance.

Telstar's PCM system, built by Radiation-Melbourne for Bell Telephone Laboratories, weighs only 8 pounds, requires less than 450 milliwatts of power . . . yet provides 112 information channels with highest accuracy available today. Channel allocations: 16-voltage; 40-temperature; 9-current; 27-radiation experiments; 2-pressure; 10-solar aspect; and 8-relay status.

First analysis of Telstar's telemetry data—received by the Radiation-designed and built command-tracking antennas—indicates the canister pressure is still above 5 lb./sq. in., showing that the canister has not been punctured; average temperature inside of 75°F; average skin temperature of 32°F; solar cells delivering 0.5 amp at 13.5 W; and a radiation-induced decrease in current output of 10% (±2) with 20 mils sapphire shielded semiconductors and 5% (±2) with 25 or 30 mils sapphire shielding.

This important new telemetry technique is only one of many advanced projects on which Radiation scientists are now working. If you like to explore advanced concepts, you'll find a stimulating and challenging environment at Radiation . . . where ideas become reality. Send your resume or write for more information. Personnel Director, Dept. SA-12R, Radiation-Melbourne, Melbourne, Florida.

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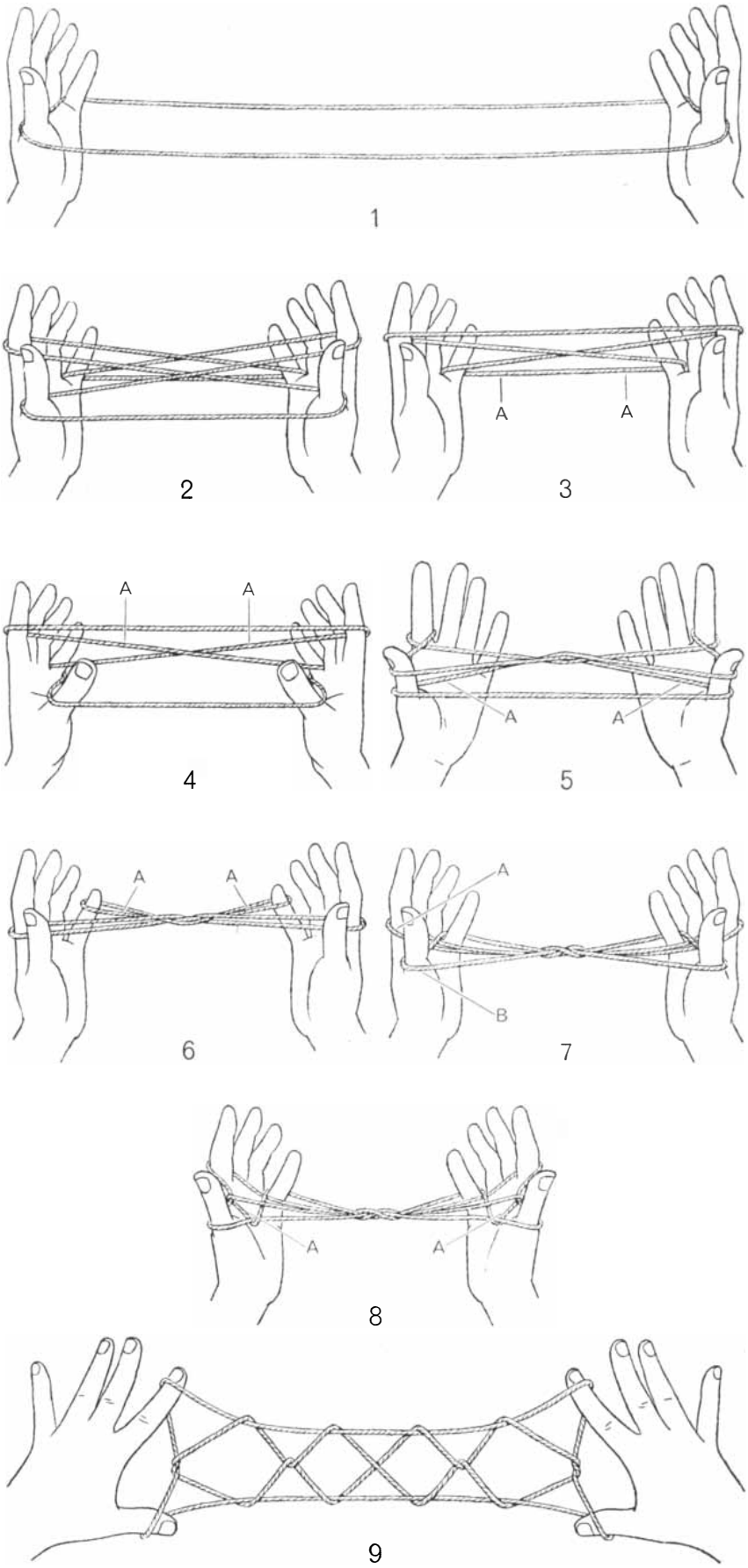


How to make Jacob's Ladder

Torres Strait Islands. Over the centuries these natives—particularly the Eskimos—have developed the art to a degree of intricacy that rivals that of paper folding in the Orient and Spain. Thousands of patterns have been invented, some so complex that no one has yet figured out (from the drawings early anthropologists made of completed patterns) the finger manipulations by which they were formed. A native expert can make the patterns with great rapidity. In most cases he uses only his hands, although occasionally he may bring his teeth or toes into play. Often he chants or recites a story while he works.

Most string patterns have acquired names that reflect a fancied resemblance to an animal or some other natural object, and many of these "realistic" figures can be animated in some way. A zigzag flash of lightning appears suddenly between the hands, a sun goes down slowly, a boy climbs a tree, a mouth opens and shuts, two head-hunters battle, a horse gallops, a snake wriggles from hand to hand, a spear is tossed back and forth, a caterpillar is made to crawl along the thigh, a fly vanishes when one tries to squash it between the hands, and so on. Even among the static patterns there are often touches of remarkable realism. A butterfly, for example, has a section of string that coils into a spiral proboscis. In the mystery novel mentioned earlier each murder victim is found with a string pattern on his or her fingers or attached to a piece of cardboard; in each case the pattern symbolizes in some way the character of the victim.

The traditional cat's-cradle game, the only string play widely known among children of Great Britain and the U.S., belongs to an interesting class of patterns that demand the co-operation of two players. The string is passed back and forth between the players, forming a new pattern at each transfer. So universal is this pastime that, according to David Riesman (in his book *Individualism Reconsidered*, page 216), "our Army advised soldiers and aviators to always carry a piece of string with them and when downed in a Pacific jungle to start playing cat's cradle if a suspicious native approached; the native would sometimes start to play too."

The literature on string figures is almost as extensive as that on origami. The earliest references are passing mentions of the pastime by a few 18th- and 19th-century writers. Captain William Bligh, in his log of the voyage of the *Bounty*, 1787–1790 (the period of the famous mutiny), speaks of seeing na-

Assignment: The Unknown

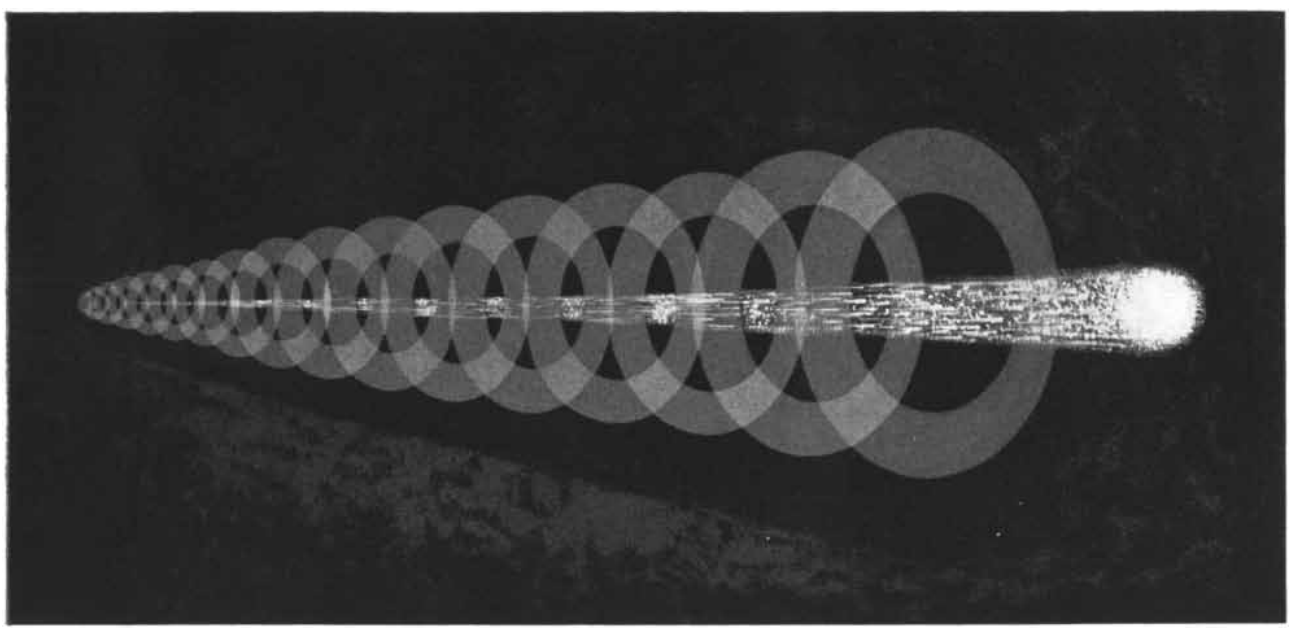
STANFORD UNIVERSITY, as prime contractor to the Atomic Energy Commission, is now building a two-mile electron accelerator — the world's largest machine for probing into the heart of matter. Planned for completion in four years, the Stanford Linear Accelerator Center will take its place among the principal international centers of particle physics research.

Physicists and Engineers interested in working on problems of electron orbit dynamics, including focusing devices and electron beam transport systems, are now finding new challenges at the Linear Accelerator Center situated on Stanford's 9,000 acre campus in the foothills of the San Francisco Peninsula. Experiments in high energy physics are being designed, and problems in applied physics relating to the accelerator are being solved.

Physicists and Engineers with experience in such fields as klystron tube development, microwave measurements, electronic instrumentation, and mechanical design are finding excellent opportunities working on this new scientific venture.

To learn more about these interesting opportunities, please send your résumé to: Mr. G. F. Renner, Stanford Linear Accelerator Center, Stanford University, Stanford, California.

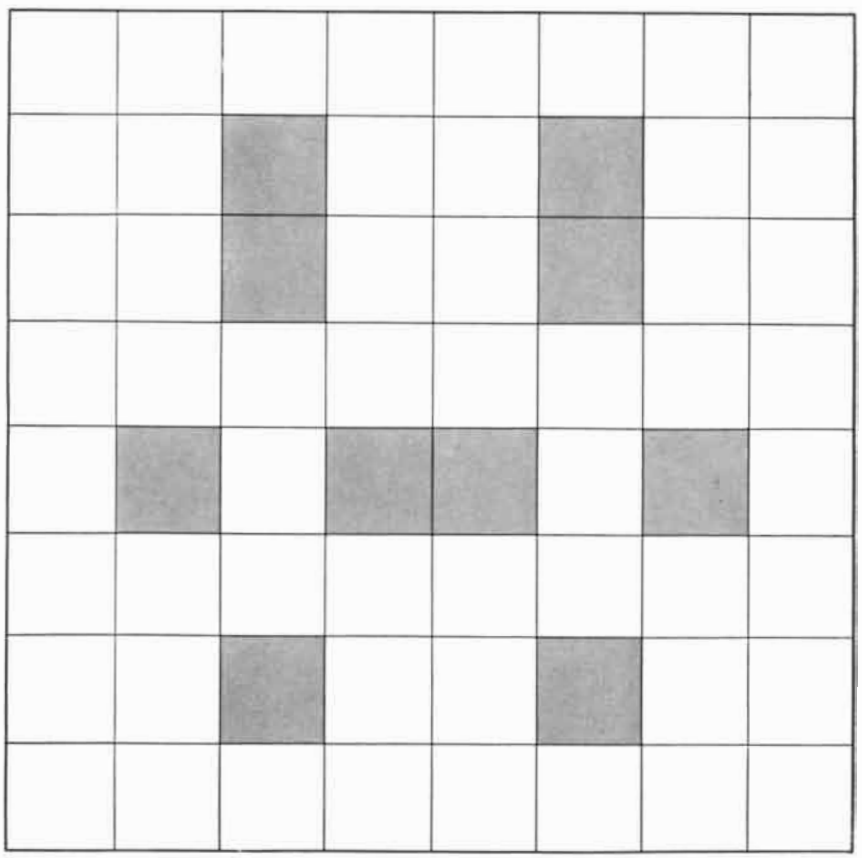
STANFORD LINEAR ACCELERATOR CENTER



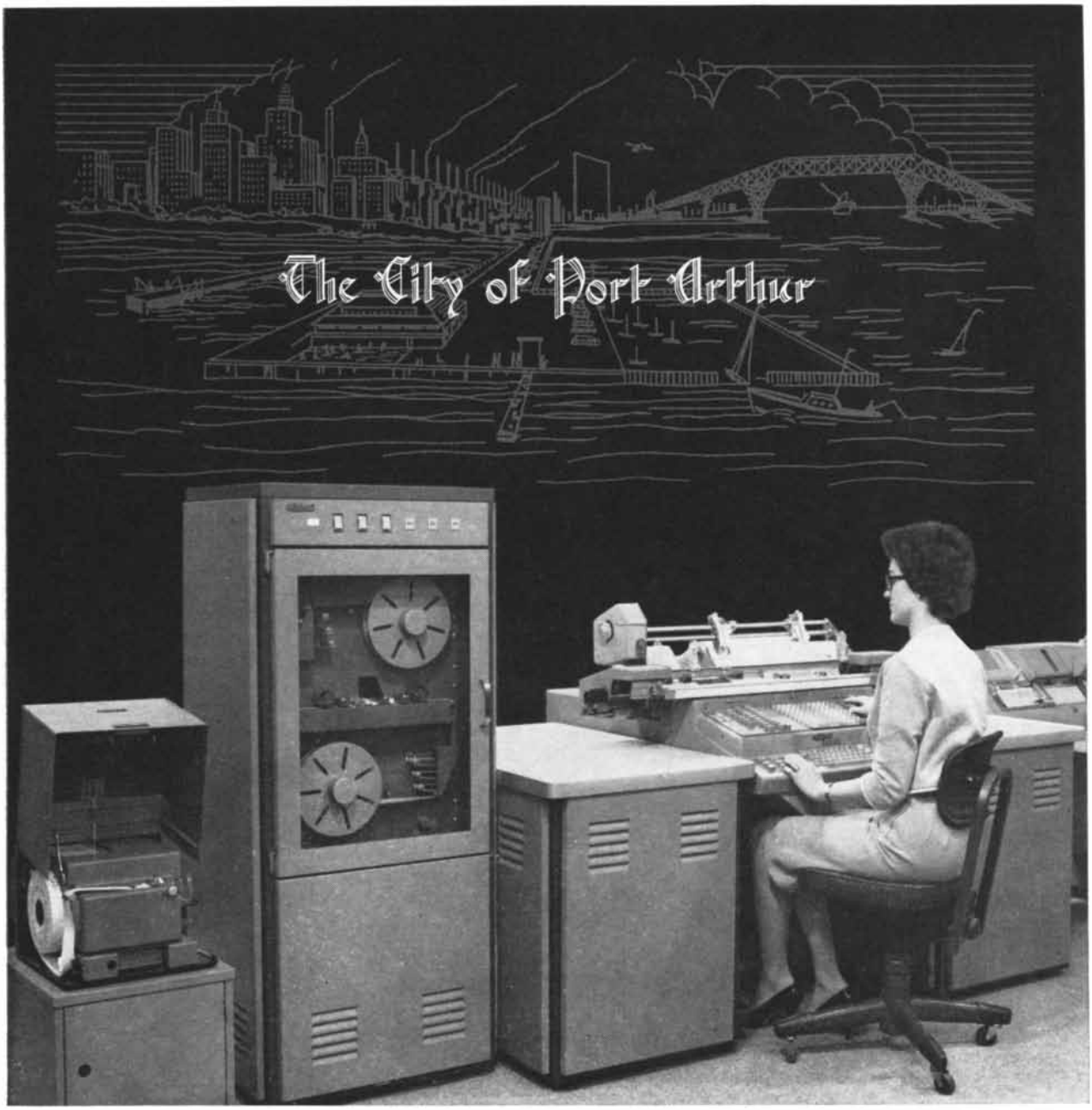
a	*b*	*c*	*d*	*e*	*f*	
	g	*h*	*i*	*j*	*k*	*l*
	m	*n*	*o*	*p*	*q*	*r*
	s	*t*	*u*	*v*	*w*	
		x	*y*	*z*		

Louis Aragon's poem "Suicide"

tives of Tahiti playing with the cord. Charles Lamb recalls string play during his school days. In 1879 the English anthropologist Edward Burnett Tylor called attention to the importance of string figures as culture clues, and in 1888 Franz Boas wrote the first full anthropological description of how a native produces a pattern. A nomenclature and method of describing the making of string figures was published by W. H. R. Rivers and Alfred C. Haddon in 1902. Since then a large number of important papers on string play have



A solution to the Greek-cross problem



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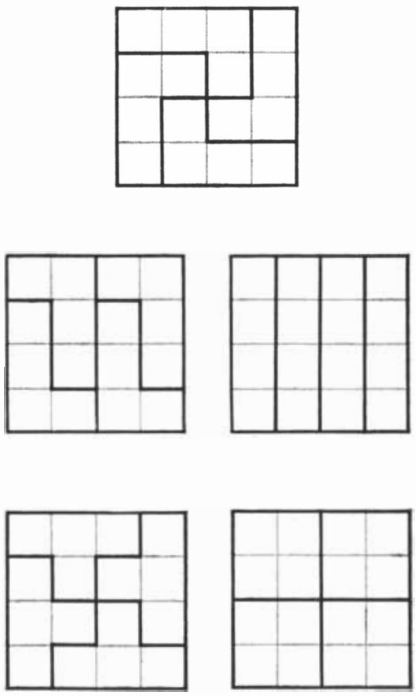
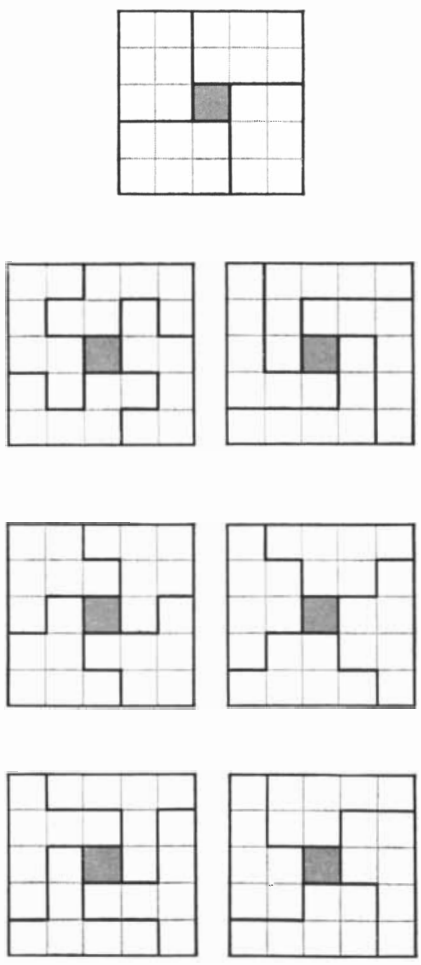


Quartering the 4 × 4 board



Quartering the 5 × 5 board

appeared in anthropological journals, and many books have been devoted to the subject. Most of these books have long been out of print, but Dover Publications this year reprinted one of the most comprehensive: *String Figures and How to Make Them*, by Caroline Furness Jayne, first published in 1906. This richly illustrated compendium of more than 400 pages contains detailed instructions for making some 100 different figures and is an excellent introduction to a fascinating avocation. It is a pity that the art is not more familiar, particularly among teachers of young children, nurses who work with the bedridden and psychiatrists who advise handicraft as therapy.

To whet the reader's appetite I shall explain one of the simplest and most widely known of the diamond patterns. Mrs. Jayne calls it the Osage Diamonds because it was first shown to her by an Osage Indian from Pawhuska, Okla., but it is more commonly known in this country as Jacob's Ladder. The reader is urged to take a six-foot piece of soft cord, knot the ends and see if he can master the figure. With a little practice the diamond pattern can be made in less than 10 seconds.

The figure starts, as do most string patterns, with the cord looped over the thumbs and little fingers as shown in the drawing numbered *1* in the illustration on page 150. Put the tip of your right forefinger under the string that crosses your left palm, and with the back of this finger draw the strand to the right. Do the same thing with your left forefinger, putting it between the strands now attached to the right forefinger. The cord should appear as it does at 2. Withdraw your thumbs and pull the string taut (*3*).

Turn your palms away from you to make it easy to put the tips of your thumbs under the farthest strand at the points marked *A* in *3*. With the thumbs, draw this back and under all the other strands to the position shown at *4*. Bend the thumbs over the strand nearest them and with the backs of the thumbs pick up the next strand at the points marked *A* in *4*. Release the little fingers from their loops. The string should appear as it does in *5*.

Bend the little fingers over the strands nearest them and with the backs of the fingers pick up the strands at the points marked *A* in *5*. Release the thumbs. This brings the cord to the position shown at *6*. Bend each thumb over the two strands nearest it and with the backs of the thumbs pick up the next strands at the point marked *A* in *6*. Return the thumbs. The string pattern should now appear as it does at 7.

With your right thumb and forefinger pick up the string at point *A* (*7*), pull it toward you and place the loop over the left thumb; then take the loop already on the left thumb, holding it at the point marked *B* (*7*), and lift it over the thumb, thereby releasing it. This exchange of loops is known as "Navahoing the loops"—a move that occurs in the making of many string figures. With your left hand Navaho the loops in the same way on the right thumb. (An expert can Navaho both thumbs simultaneously without the help of the other hand, but a beginner had best do it in the manner described.) The string now appears as it does at *8*.

You are ready for the final move. Bend your forefingers, placing their tips down into the small triangles marked *A* in *8*. Withdraw your little fingers from the string, at the same time turning your palms away from you, raising the forefingers as high as you can. (Allow plenty of slack in the string during this final maneuver or the pattern will not open fully.) Draw the cord taut. If the maneuver is done properly, the diamond pattern will form as shown at *9*. This sudden appearance of a pleasing design out of what had appeared to be chaos is one of the delightful features of most string patterns.

Two people who master the figure will find it amusing to produce it cooperatively, the cord then being held by one player's left hand and the other player's right hand. It is not difficult to produce two identical patterns simultaneously in this manner, each on a pair of hands shared by two players. The ultimate test of dexterity is for two players, rapidly and at the same time, to share hands and form two different patterns, but this calls for great skill and co-ordination.

This year's puzzle Christmas greeting is concealed in the top illustration on page 152, a poem written by Louis Aragon, the French writer, during his early association with the surrealist movement. The poem is called "Suicide." I take it to symbolize life as it appears to the despondent: all its rich variety drained away, leaving only an idiotic ordering of meaningless symbols. In brooding on this poem I have discovered that Aragon unintentionally hid within it a two-word exhortation that, in the light of the nuclear arms race, seems an appropriate message for the closing of 1962. To de-

New Clues to Queues

The gravity of RAC's problem-solving responsibilities has demanded a willingness to innovate, to bend research techniques to meet anomalous needs, and to contribute new theoretical knowledge to operations research, overall. As just one example, RAC researchers are now performing extensive methodological research on queuing theory, seeking to improve and extend RAC's research on allocation of resources. The language of queues provides a common denominator for many such problems.

RAC's output is intellectual—the idea or recommendation or suggested solution that applies to an individual problem area confronting top-level decision-makers today. The root problem may be essentially military, political, economic, social, or a combination. In any event it is first formulated, then analyzed, and ultimately solved . . . by a multidisciplinary research team. (No team lacks for breadth of background; 32 different fields of interest are represented on RAC's professional staff.)

RAC is an independent, nonprofit organization of more than 400 people, and its continuing expansion means a constant need for imaginative scientists and engineers with advanced degrees to help tackle problems of international scope and fascinating complexity. The environment is stimulating, and the rewards, tangible and subjective alike, are well worth exploring. For additional information, please send your resume to: Mr. John G. Burke, Professional Staffing, Research Analysis Corporation, 6935 Arlington Road, Bethesda 14, Md. (Residential suburb of Washington, D. C.)
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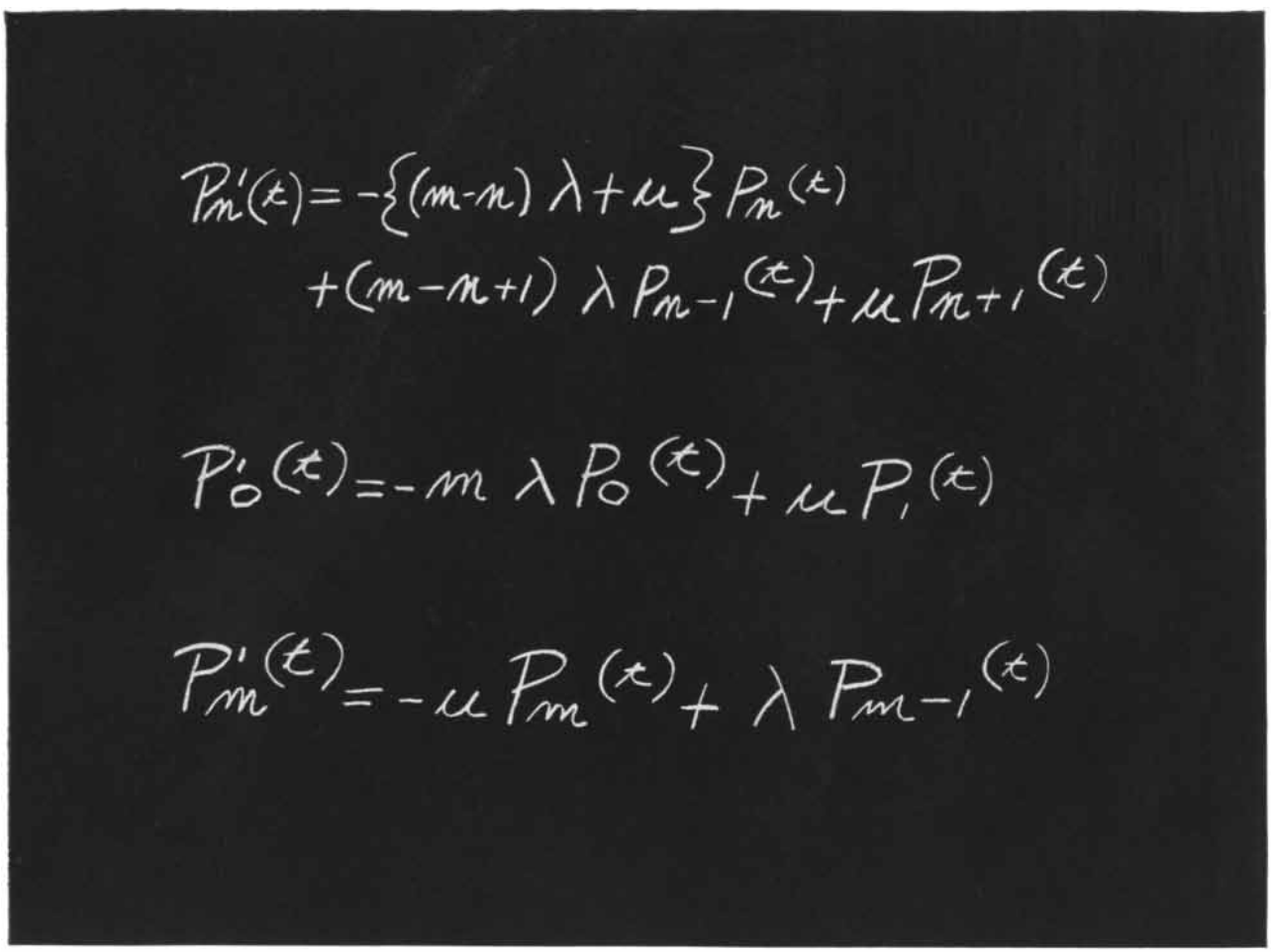


code it place the point of a pencil on a certain letter, then move from letter to adjoining letter, up or down, left or right or diagonally, spelling out the message. (In other words, move like a chess king.) A letter may be counted twice to permit such spellings as "stunning" and "no onions." In spite of severe limitations imposed by the sparsity of vowels, it is possible to obtain fairly long phrases: for example, "No point to hide" and "Put UN on top." The two-word phrase I have in mind, however, is remarkably appropriate when addressed to a world about to cut its own throat; moreover, it has a marvelous ambiguity. The answer will appear in this space next month.

Last month's problems based on checkerboard designs are answered as follows:

A minimum of 10 squares must be removed from an 8×8 board to make it impossible to cut a five-square Greek cross from what remains. There are many solutions. The one shown in the bottom illustration on page 152 was provided by L. Vosburgh Lyons of New York City.

The 4×4 board can be quartered in no more than five different ways, shown at the top of page 154. Half of the second pattern can be reflected, but then two of the pieces will not have the same handedness as the other two. The seven ways of quartering the 5×5 (with center hole) are shown at the bottom of page 154. Patterns for the 6×6 are given in L. A. Graham's *Ingenious Mathematical Problems and Methods*, a Dover paperback (page 165), and by Harry Langman in *Play Mathematics*, published by the Hafner Publishing Company (page 127).

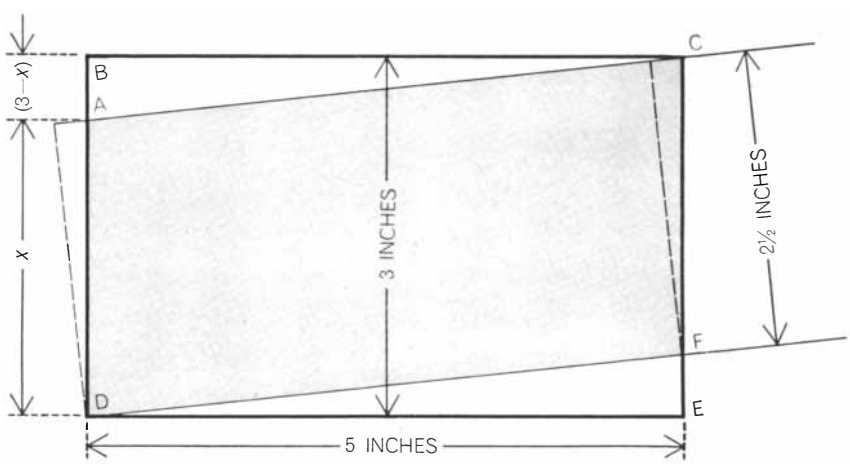
A maximum of 32 knights can be placed on a standard chessboard in such a way that no knight attacks another. Simply place the knights on all squares of the same color. Jay Thompson of New York City writes that a group of chess players at a Middle Western hotel got into such a violent argument over this problem that the night clerk had to get a policeman to pull his chess nuts out of the foyer.

Readers were also asked last month (in the answer to the first problem of the previous month) to determine exactly how much of a 2½-inch strip is covered by a 3×5 file card placed obliquely over the strip as shown in the illustration below.

Let x be the length AD. The length of AB will then be $3 - x$, and AC will have a length of $\sqrt{5^2 + (3 - x)^2}$. The portion of the strip covered by the card is a rhomboid (shown shaded in the illustration), the area of which is obtained by multiplying base by altitude. If the rhomboid is viewed as shown, with the strip's width as its altitude and AC as its base, its area can be expressed: $2.5\sqrt{5^2 + (3 - x)^2}$. Give the illustration a quarter-turn. AD becomes the base, BC the altitude, therefore the area can also be expressed as $5x$. The two expressions are equal:

$$5x = 2.5\sqrt{5^2 + (3 - x)^2}\,.$$

Solving this quadratic equation gives x a value of 2.5118+. The shaded area ($5x$) is 12.559+. When the card is not tilted, it covers an area of 12.5, so that tilting it as shown increases the area by .059+ square inches. Is it possible to cover more than 12.559+ by placing the card in a position different from the one shown? More on this next month.



Solution to the file-card problem

JUST GIVE THE DATA, PLEASE

Today's instruments are reporting every conceivable kind of measurable variable. Temperature. Strain. Liquid level. Pressure. Vacuum. Humidity. Flow. Viscosity. Torque. pH. emf. Voltage . . . and many more. They bring to their jobs an accuracy, perseverance, and freedom from coloration that the most objective city room couldn't begin to match.

The only catch comes in designing them. It's a foregone conclusion that they be reliable. Then they have to measure extremely small or extremely large amounts of change, taking place at very rapid or very slow rates. The data they turn in must be usable, so that it can actuate recording, controlling, or indicating mechanisms, or serve as inputs for data processing equipment. All in all, it's quite a job for Honeywell, and you'll excuse us if we take a discoverer's pride in the successful accomplishment of assignments such as these:

BED OF ZEROS. In many petrochemical processes, gas or vaporized petroleum is passed over a heated bed of finely divided catalyst to crack it into components. But what, exactly, is the heat-transfer mechanism involved? Researchers at a leading Eastern university are seeking the answer, under the sponsorship of the National Science Foundation. To determine the bed's response to sinusoidally varied temperature, the differential temperature below and above the bed is measured, as well as that of the gas leaving. However, the differential signal is so small that equipment used must measure accurately in the microvolt region. Honeywell answered this complex problem by installing a complete pre-tested packaged system, and guaranteed it would work. It consists of a Honeywell 2745 potentiometer for system calibration and zero suppression, three Honeywell Deviation Amplifiers, and six Honeywell T6GA amplifiers, with a Honeywell 906C Visicorder for readout. By recording temperature phase and amplitude change, the gas-particle heat transfer coefficient is calculated for use in setting up new petrochemical processes.

SHIVERING TIMBERS. The Ship Structure Committee, representing various government agencies, assigned Lessells & Associates, Inc. of Boston the task of developing long-range data on ocean wave loading of seagoing vessels.

For the past two years, two oceangoing freighters plying the turbulent North Atlantic trade routes have been recording stress data for the project. They will eventually be joined by other ships in the study. Stress data are picked up by transducers on the hulls, and recorded on Honeywell Magnetic Tape Systems. Since the voyages take from 30 to 40 days, an extremely low recording speed was needed: 0.3 ips. A programmer working through balance and calibration circuits records for 32 minutes every 4-hour watch, and rough seas automatically turn on the recording apparatus. Sea and weather information from the ship's log is correlated with the time-marked tape. Back in Boston, the tapes are reproduced and amplified, played onto a Honeywell Visicorder oscillograph unit and finally, into a probability analyzer. The Ship Structure Committee will make this reduced data available to marine engineers for improving design and increasing safety of projected new vessels.

UNDERGROUND DETECTIVE. Project VELA holds promise of becoming a highly significant factor in international relations if agreement to cease nuclear testing is reached. Established at Geneva in 1958, VELA is concerned with the detection of underground, surface, and atmospheric nuclear explosions.

To detect seismic disturbances of any kind, VELA is simultaneously carrying on research and establishing observation posts around the world. To record accurately one brief moment of seismic history for electronic data processing takes hundreds of hours of continuous recording, and ordinarily, mountains of tape. Honeywell slowed down a standard magnetic tape recorder to 0.3 ips, and by using special tape, three full days' surveillance can be recorded on one roll. One of the most recent orders Honeywell received for seismic research called for the exceedingly slow recording speed of 0.06 ips, a pace that makes an indolent snail look like a speed demon. Honeywell was able to brake down to specification. And at highly satisfactory signal-to-noise ratios, too.

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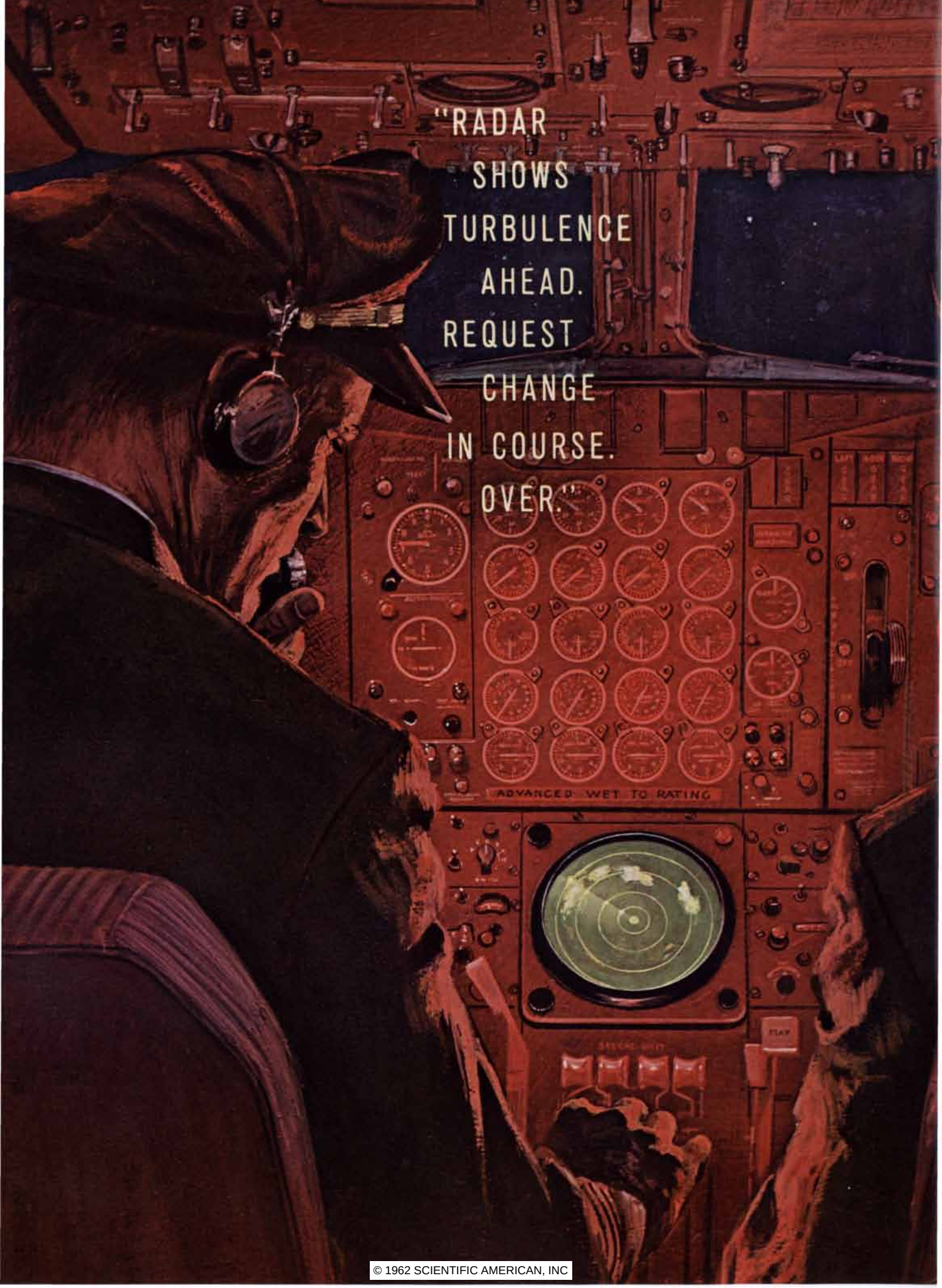

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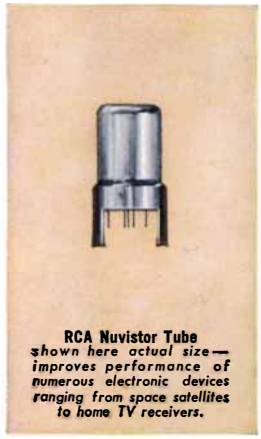
Behind the accuracy and precision of most of these electronic sentinels stands one of the marvels of our scientific age: the RCA electron tube. The electronic impulses that "probe" the storm are generated by an RCA Magnetron electron tube. The "eye" of the radar unit—where a storm pattern is revealed in the pilot's cabin—is an RCA display storage tube. "Heart" of the unit is a tiny NUVISTOR tube—which augments the system's extreme sensitivity. NUVISTORS amplify signals indicating subtle changes in atmospheric conditions—changes that might be lost or distorted with less sophisticated components.

NUVISTORS . . . Display Storage Tubes . . . Magnetrons . . . are just three of the many electron tube categories produced by RCA in its unceasing effort to produce new tubes for new uses—in home entertainment, science, industry, medicine, and national defense.

RCA ELECTRON TUBE DIVISION



RCA Nuvistor Tube *shown here actual size—improves performance of numerous electronic devices ranging from space satellites to home TV receivers.*

RCA Display Storage Tube *—similar in principle to your home TV picture tube—paints a picture of electronic signals in radar systems and industrial test instruments.*

RCA Magnetron Tube *develops tremendous amounts of electronic power for the exacting and important national defense mission of radar surveillance.*

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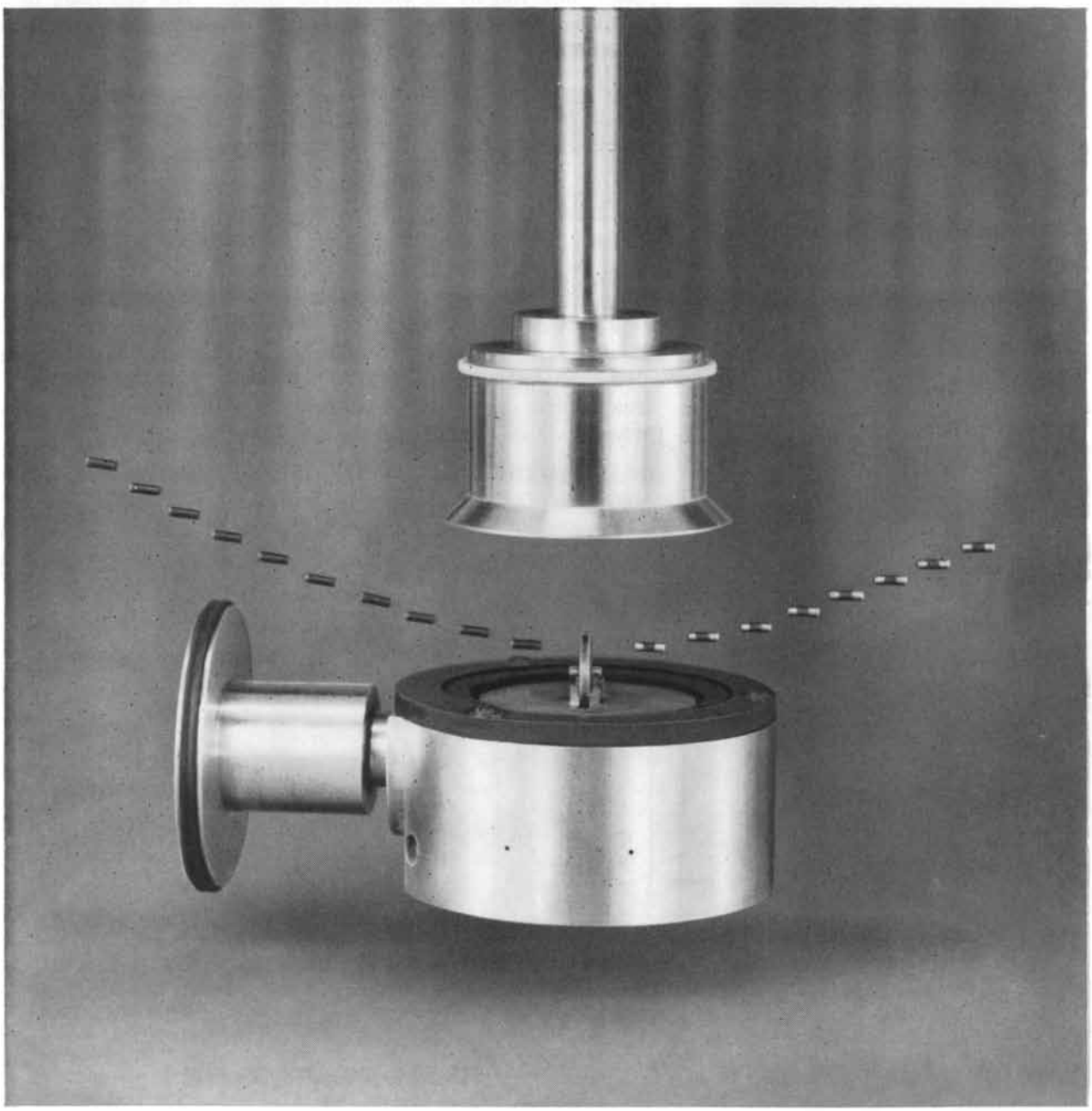
PROCESSES. In the manufacture of deposited carbon resistors, good electrical connections between the carbon film and the metallic cap must be provided. Because Western Electric's new computer-controlled production line was designed to produce high-reliability resistors at the rate of one every 3 seconds, traditional silver pastes requiring hours of baking were unsuitable. Western Electric engineers studied this problem and developed a completely automatic process using high voltage in a near-vacuum argon atmosphere to sputter a thin, uniform film of gold onto the carbon core ends. This new process provides high-conductivity, low-noise terminations—in the short time required by the extremely high production rate. Ultimate result: high-quality deposited carbon resistors produced in the large quantities and at the low cost required for U.S. Government and Bell Telephone System applications. **WESTERN ELECTRIC**



THE AMATEUR SCIENTIST

An apparatus for studying crystallization in solutions frozen on a mercury surface

Conducted by C. L. Stong

Frozen water is accepted so casually in temperate latitudes that only seven words have been coined in the English language for classifying its myriad forms: ice, snow, sleet, hail, frost, hoarfrost and rime. Eskimos take a livelier interest in the material. They recognize scores of different ices and have some 50 names for snow alone. The ices comprise a large family of materials that owe their physical properties in part to such variables as the composition of the freezing solution, the rate of freezing, subsequent heat treatment, the age of the specimen and the extent to which a particular specimen has been worked, or deformed. The effects of these variables are recorded in the polycrystalline structure of ice and can be observed by anyone who has access to a microscope. Last summer Edson L. Blackman devised an ingenious apparatus with which to investigate the effects of dissolved salts on the crystallization of ice. He did the work as a project for a Junior Research Fellowship under Vincent J. Schaefer at a field station of the Atmospheric Sciences Research Center of the State University of New York. His apparatus, which can be assembled easily at home, enables the experimenter to observe not only the fine structure of ices but also the mechanisms of nucleation, the development of electric charge that accompanies the freezing of water and other relatively neglected but fascinating phenomena.

"The crystallization patterns of ice," writes Blackman, "are greatly affected by the nature of dissolved substances in the water and by the environment. It occurred to me that something approaching an ideal environment would be provided by a clean surface of mercury from which air was excluded. The high surface tension of mercury makes many liquids, including water, spread readily when they are placed on it. Since the molecules of mercury are in continuous random motion, they do not present to the freezing solution any rigid lattice pattern that might influence the growth of ice crystals. And since a surface of mercury offers little frictional resistance to moving particles, the forces of crystallization act unhindered and the molecules of water move into the most natural solid configuration.

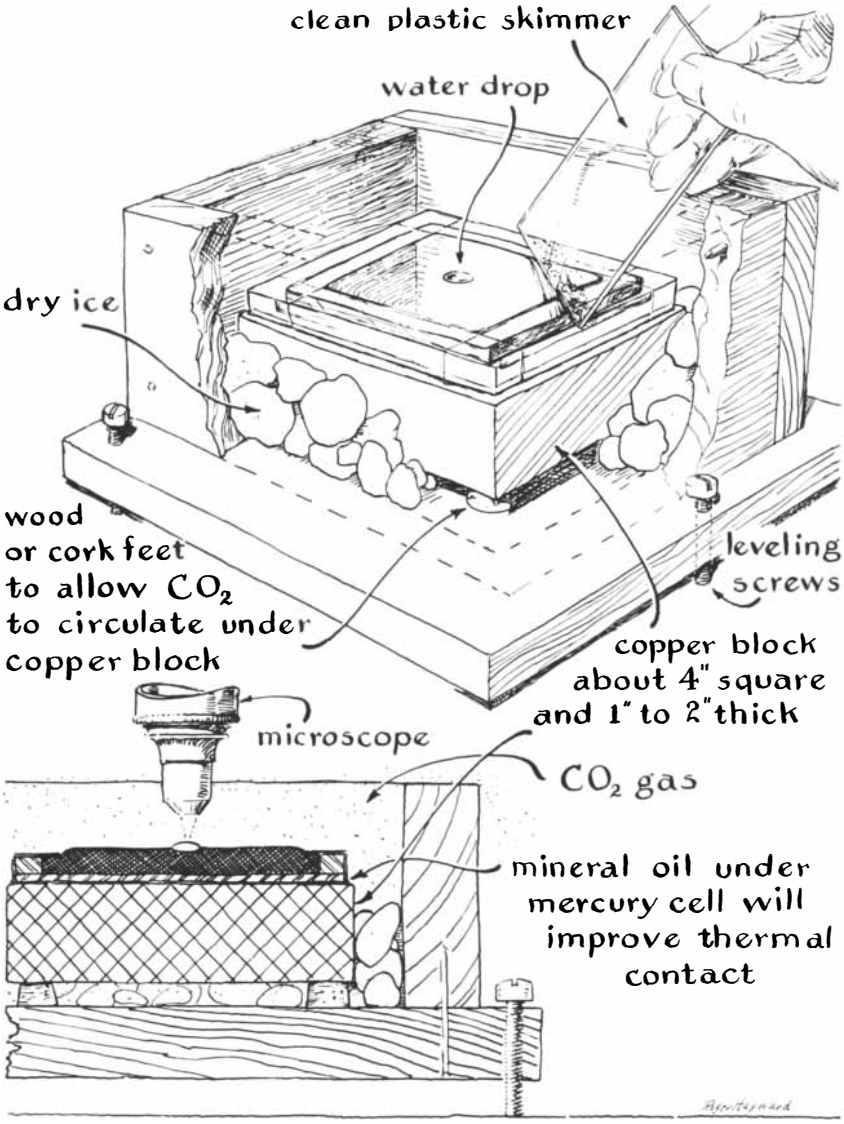
"My system consists essentially of a small freezer in which is placed a shallow trough of mercury, supported on a large block of metal that acts as a heat sink to stabilize the temperature of the mercury. The refrigerator is flooded with carbon dioxide to keep atmospheric oxygen from reacting with the mercury and modifying its surface properties.

"Although my experiments were made with a small chest refrigerator designed for cooling soft drinks, a thick wooden box or one assembled from sheets of foam plastic should work as well. Refrigeration and carbon dioxide could be provided simultaneously by a layer of roughly crushed dry ice in the bottom of the box, as shown in the accompanying illustration [*next page*]. I used a four-inch cylinder of copper approximately six inches long for the heat sink. Copper rod of this size and shape is not readily available in all communities, but rectangular copper stock of the type used for bus bars—four inches wide and up to two inches thick—will do; it can be obtained from dealers in heavy electrical power apparatus. The copper block rests on wood or cork feet on the bottom of the refrigerator and supports the trough of mercury. A microscope for observing small crystal formations can also be set on the bottom of the refrigerator, with the substage of the instrument removed so that the legs straddle the heat sink.

"The trough for the mercury can be made of any material to which mercury is relatively inert, such as sheet iron, sheet plastic or glass. It need be only a quarter of an inch deep, with enough of a rim to catch spills and films skimmed off the mercury surface. The bottom of the trough should be thin so that heat will be conducted readily between the mercury and heat sink. A film of mineral oil between the bottom of the trough and the metal block will improve heat conduction. The trough is filled to the brim with mercury. A small depression caused by the negative meniscus of the mercury extends around the inner edge at the top of the trough between the walls and the metal. To prevent scum from collecting in this depression when the surface of the mercury is skimmed with a glass or plastic wiper, the meniscus is covered by strips of Scotch tape applied to the edges of the trough so that one side of each strip extends across the space and rests on the surface of the mercury, as shown in the accompanying drawing [*page 164*]. The trough should also be equipped with a thermometer, preferably of the glass rod type, in direct contact with the mercury. The entire assembly must stand on a solid base free of vibration, such as the concrete floor of a basement, because even small ripples set up in the mercury will interfere with the natural growth of crystals.

"To prepare the assembled apparatus for an experiment, fill the trough with enough mercury so that the metal touches the inner edge of the tape on all sides, charge the box with dry ice broken into lumps roughly the size of pea coal and close the box with a loose-fitting cover. Observe the thermometer every five minutes until the temperature of the mercury drops to -10 degrees centigrade. Finally, skim the layer of surface contamination from the mercury by resting the flat edge of a thin strip of glass or plastic on one end of the trough and drawing it across the surface to the other side. Usually it is necessary to use a pair of wipers; use the first wiper to sweep off the bulk of the surface contamination and follow up immediately with another wiper to complete the job. Avoid breathing directly into the container or making rapid movements that would set up air currents of enough violence to displace the carbon dioxide or warm the chamber.

"To make an initial experiment, take



Apparatus for observing the mechanism of freezing

up a small quantity of distilled water in a pipette and allow one drop to fall on the center of the mercury from a height of about an eighth of an inch. The drop will immediately spread as a circular film (unless the mercury is not really clean, in which case the water will not spread satisfactorily). The thin film begins to freeze at one or more points, the crystallized areas growing radially until the whole disk is frozen. If the disk is thick, a quantity of water will remain on top and freeze over a few seconds later. The layer of ice that forms initially will be clear and will show a distinct grain structure. The second layer will be translucent, with no crystalline features apparent to the unaided eye. Now, ice exposed to a dry gas gradually sublimes as occasional molecules acquire enough thermal energy to break away from the crystal lattice and escape as vapor. The amount of energy required for escape depends on the temperature of the gas, the geometry of the crystals, the structure of the grain boundaries and the presence of impurities in the ice. In effect such sublimation etches the ice selectively and makes the pattern of its polycrystalline structure stand out in sharp relief. The accompanying photomicrograph [*top left on page 166*] shows a specimen of ice made from distilled water after thermal etching has proceeded for about 10 minutes. Herringbone structures and other interesting patterns are sometimes observed along the grain boundaries [*see illustration at top right on page 166*].

"My experiments were made with solutions of a single mineral salt. According to theory, when such mixtures cool, crystals of either the salt or the ice will begin to form at some temperature. Their growth during subsequent cooling alters the concentration by removing either salt or water from solution. Ultimately a concentration is reached at which minute crystals of salt and ice form simultaneously and in intimate association, and complete freezing then occurs at one temperature. This is known as the eutectic concentration. If the initial concentration is made equal to the eutectic concentration, the solution should freeze completely as a single substance when the proper temperature is reached. Such mixtures are called cryohydrates. The proportions of the cryohydrates with which I experimented are listed in the accompanying table [*bottom of page 166*].

"If the surface of the mercury is exceptionally clean, the smallest droplet of a eutectic copper sulfate solution will often spread over the entire surface of mercury maintained in the temperature range from − 19 to − 26 degrees C. The film appears iridescent until it freezes. The initial freezing, which occurs promptly, exhibits patterns of crystal growth in the form of fine concentric rings that meet at discrete boundaries, small sections of which appear striated [*see illustration at upper left on page 168*]. Whether the specimen is a thin film or a thick droplet, white spots soon appear and begin to grow through the ice. When they are examined by reflected light, these expanding disks of secondary ice appear to consist of fine crystalline needles that persist in growing radially in spite of variations in the thickness of the primary ice or other irregularities. Their growth stops at the edge of the ice and along the line of intersection where two disks meet. Ice formed during the initial freezing of dilute copper sulfate solution is soft and mushy, but it becomes rigid after this secondary crystallization.

"All grain differentiation seems to take place during the initial freezing. Secondary crystallization appears as an opacity that fills the spaces between and within the crystal outlines but does not disrupt their order. During an occasional experiment secondary crystallization merely brightens the primary structure. Two growing disks of secondary freezing are shown in one of the accompanying photomicrographs, and a set of disks that resulted from complete freezing is shown in another [*see illustrations at upper right and lower left on page 168*]. Depending on the initial temperature, freezing may occur in as many as three steps. At − 19 degrees C., for example, the thin film of crystals formed

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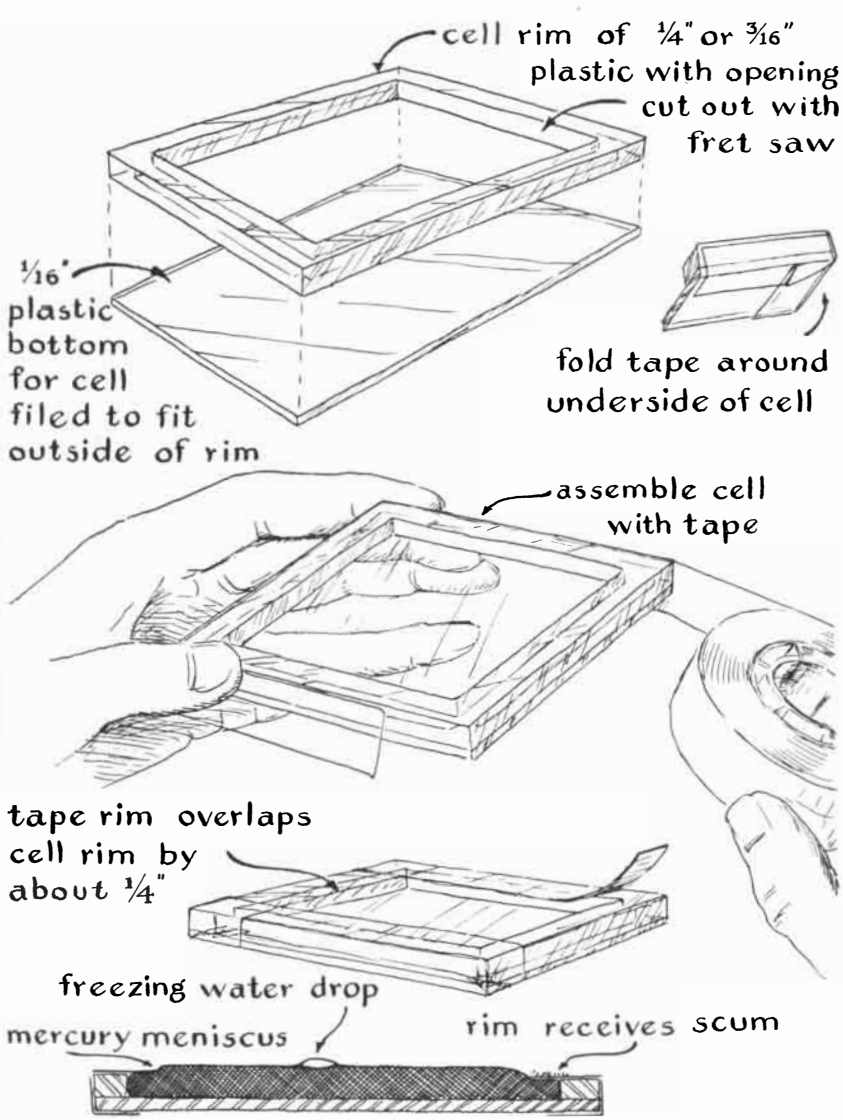
during rapid initial freezing is quickly overgrown by a few disks of secondary crystallization varying in width from two to five centimeters, which impart a bluish hue to the ice. Then small disks of white ice appear and grow slowly to the edges of the specimen. Specimens applied to mercury at − 26 degrees also spread as a thin film that freezes quickly. This ice exhibits faint crystalline patterns and a glossy surface, but no secondary or tertiary freezing occurs.

"Liquid can be forced from the initially frozen copper sulfate solution by dropping a small glass plate over the specimen and applying pressure. No liquid appears, however, when this experiment is made after secondary crystallization. This suggests that the secondary disks are composed of ice formed from the unfrozen portion of the mixture—although the solutions are cryohydrates and according to theory should freeze completely at one temperature.

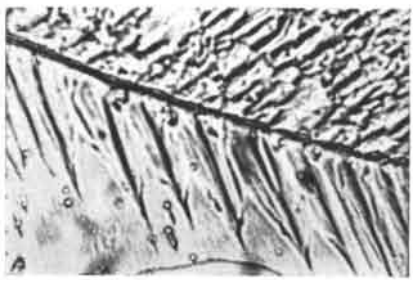
"Three-step freezing was also observed in solutions of double eutectic concentration through the temperature range of − 19 to − 26 degrees. Even the smallest drops usually spread and freeze over the entire mercury surface, but occasionally the film breaks apart and freezes as uniformly spaced islands of ice. During initial freezing, crystal growth often begins in the center and develops as slender radial fibers, which are occasionally scored by fine concentric circles. Usually a heavy white circle of frozen material forms at the center, the fibers looking like the petals of a flower made of lace. In almost every case such formations are separated from their neighbors either by a crack or a ridge of thickened ice.

"Second- and third-stage freezing in



Details of the mercury trough

Grain structure of ice



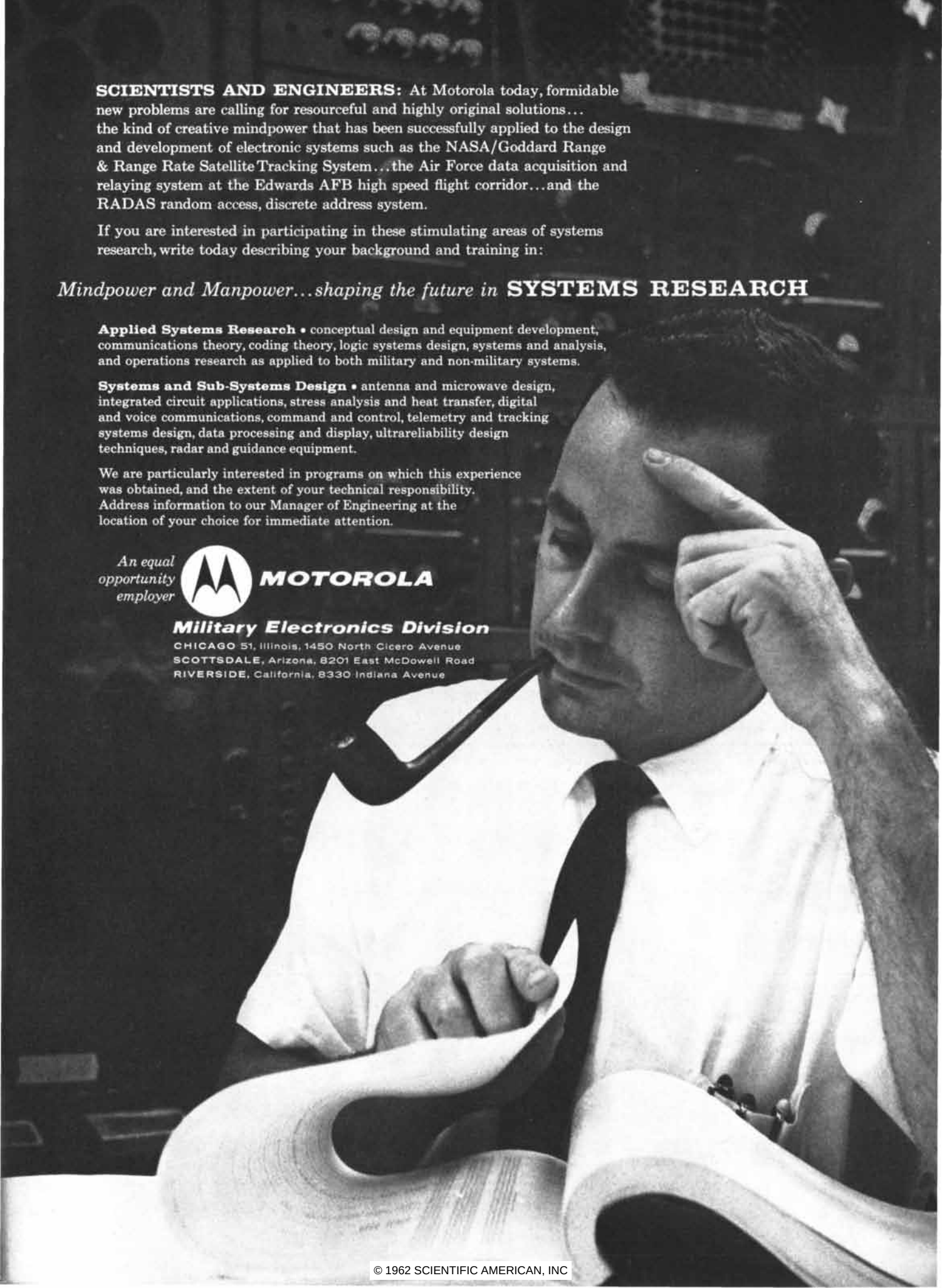
Crystal structure near a grain boundary

solutions of double eutectic concentration resemble those of the straight eutectic concentration but differ in detail. Secondary crystallization in a double eutectic concentration usually begins in a few places and spreads rapidly, altering the color to a distinctly bluish hue. Then white disks of tertiary freezing appear and grow through the blue areas at a much slower rate. Two types of tertiary disk were observed: perfectly circular disks marked by fine radial etchings, and coarser disks of irregular outline marked by dendritic, or branching, patterns. The coarser disks grow faster than the finer, circular ones and occasionally engulf some of the finer disks. Tertiary disks of the coarse type are composed of rough, bandlike collections of particles, whereas the finer disks often appear velvety smooth and marked by straight, slender crystals in radial array. Incidentally, the blue disks of secondary crystallization are not always observed. They may be present in all specimens and yet be easily overlooked because of their faintness and the speed with which they grow. The accompanying photomicrograph [*lower right on page 168*] shows a small area in which primary freezing is complete, the secondary disk formation is well under way and the tertiary stage is beginning with the appearance of an irregular white disk at the top of the micrograph.

"In one series of experiments that I found exceptionally interesting, plastic replicas were used to investigate the freezing mechanisms of double eutectic solutions of copper sulfate. A 2 per cent solution of polyvinyl formal dissolved in ethylene dichloride was stored in the refrigerated compartment and kept between − 4 and − 12 degrees. The mercury trough was lifted from the freezer for about a minute and exposed to the atmosphere so that a light oxide film formed on the surface. The mercury was then replaced without being skimmed. After the mercury had been cooled, a drop of specimen solution was placed on it. The oxide film prevented the drop from spreading. After the lens-shaped piece of ice had frozen, it was removed from the mercury with a pair of tweezers and allowed to etch thermally for about 10 minutes. The specimen was inverted and the plastic solution was spread on the lower, smooth surface. After the solvent had evaporated from the plastic, the ice could have been melted and the replica floated onto a microscope slide and dried. In this experiment, however, I allowed the ice to sublime, leaving the salt skeleton behind. The accompanying photomicrographs of a plastic replica so

SALT	EUTECTIC CONCENTRATION (PER CENT BY WEIGHT)	TEMPERATURE (DEGREES C.)
$BaCl_2$	22.5	−7.8
$CuCl_2$	36	−40
$Cu(NO_3)_2$	36	−24
$CuSO_4$	11.9	−1.6
$MgSO_4$	19	−3.9
NaOH	19	−28
NH_4Cl	18.6	−15.8
NH_4NO_3	41.2	−17.35
$(NH_4)_2SO_4$	38.3	−19.05

Eutectic concentrations and temperatures of cryohydrates



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prepared show a frozen film of double eutectic copper sulfate [*top of pages 170 and 171*]. Grains of approximately equal width and length occupy the center of the first photomicrograph [*top left on page 170*] and are surrounded by elongated grains. The disklike structures astride the grain boundaries, details of which are evident under higher magnification [*top right on page 170*], have an internal pattern of lineated crystals that appear to have grown from the grain boundaries, as seen in the third photomicrograph [*top of page 171*].

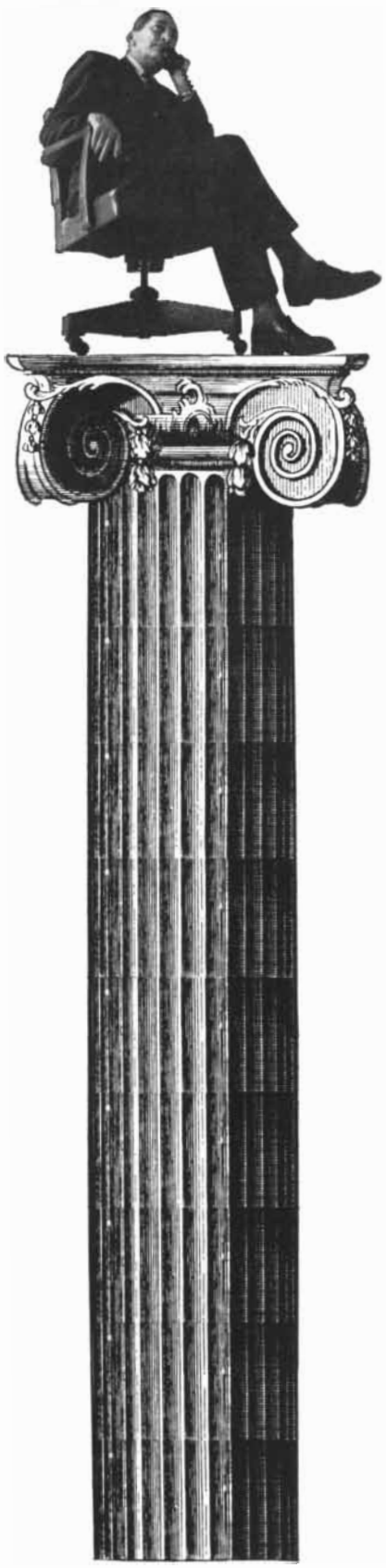
"A grain boundary is a transition lattice or assembly of dislocations between adjoining grains. If rapid cooling should cause the salt and ice phases to freeze simultaneously, severe local strain would develop because the highly organized structure of ice cannot easily accommodate other molecules. The strain would be greatest along the grain interfaces and should be relieved first at these interfaces, perhaps as a separation of the ice and salt phases. These disks may result from such recrystallization. The inner, darker portions of the disks may mark the initial precipitation of the salt, the solution being twice eutectic in concentration. If this is indeed so, the bordering lamellar structures could come from the successive precipitation of salt and

Initial crystal structure in copper sulfate

Beginning of secondary freezing

The secondary stage completed

Beginning of tertiary stage



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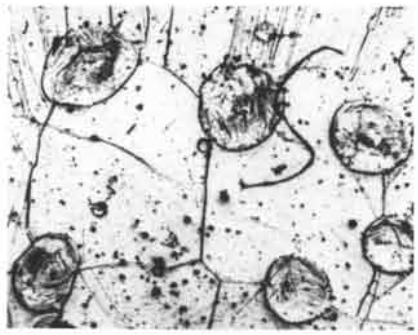


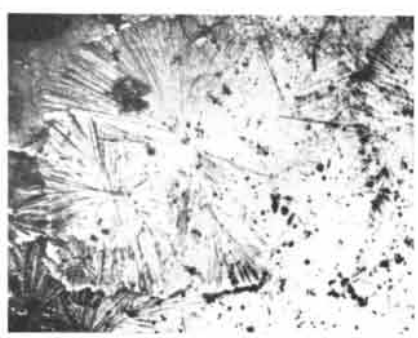
Plastic replica of frozen solution

Disk structure in plastic replica

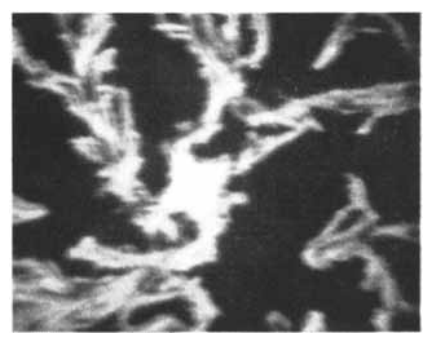
ice. The crystalline patterns of these areas resemble the disks of secondary and tertiary crystallization observed in thin films. Occasional fan-shaped patterns may indeed spread and develop into full radial patterns even in a lens. This appears to have occurred in a few drops that were frozen on oxidized mercury, as shown by the accompanying photomicrograph [*at left below*].

"Salt solutions other than copper sulfate produce different but equally fascinating structures. Freezing usually proceeds in two or more steps, depending on the nature of the salt. Eutectic ammonium chloride and ammonium nitrate solutions freeze much alike. A single drop of either solution spreads over the entire surface of the mercury and freezes almost instantly into thin areas of branching crystals that often surround an inner star embedded in a ridge of thicker material. A typical star of four points together with the dendritic formation is shown in the accompanying photomicrograph [*at right below*]. A 67.5 per cent solution of stannic chloride freezes at − 38 degrees. At slightly higher temperatures the firmly bound water molecules slowly crystallize out and float in a solution of hydrous tin chloride, either as angular branching growths or —more commonly—as long, thin needles. Four needles often branch from one point. The accompanying photomicrograph [*bottom of opposite page*] shows a typical ice formation floating in the salt solution after crystallization has been completed. Crystal formations large enough for study by the unaided eye are formed by some solutions. A representative example is barium chloride in eutectic concentration. This solution spreads slowly into a thin film that freezes into petal-like fibers extending from a small central mass surrounded by a heavy ridge. As growth proceeds, concentric bands of light and shade form across the radial structures to complete the symmetry, a development that is truly fascinating to watch.

"I intend to investigate these effects in detail as time allows and also look forward to trying a number of other experiments that came to mind in the course of working with the apparatus. The mercury surface should be ideal for studying the electrical effects that accompany freezing. Everly J. Workman and Stephen E. Reynolds, respectively president and project supervisor of the New Mexico Institute of Mining and Technology, have measured substantial differences in electric potential between a freezing solution and its metal container. Their experiments suggest that dilute salt solutions may reject ions at unequal rates as crystallization proceeds, so that a separation of charge occurs. They report that the effect is observed in solutions of sodium chloride, ammonia gas and carbon as dilute as .0001 normal.



Fully developed disk crystals



Crystals of eutectic ammonium chloride

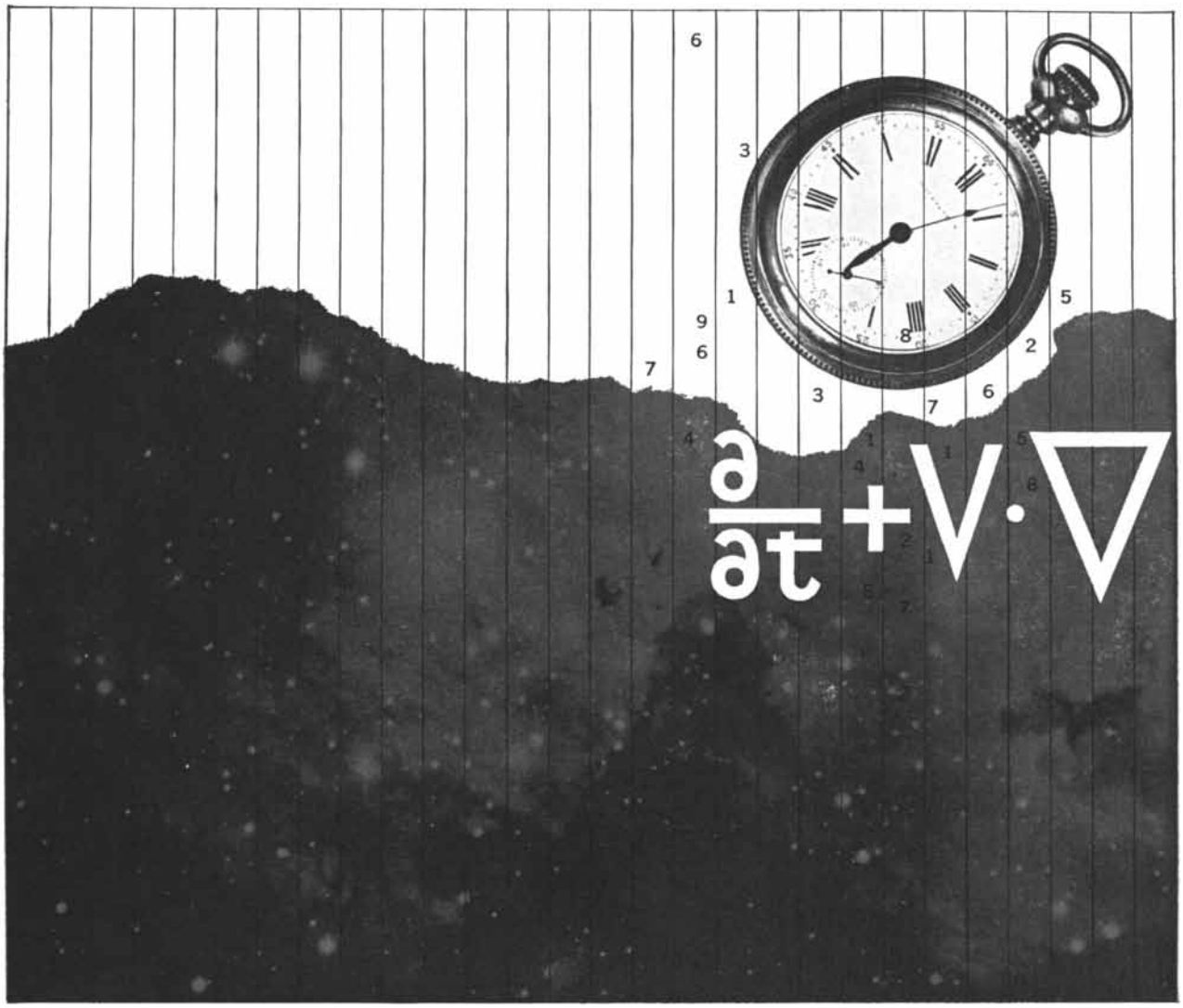
Details of salt skeleton in replica

Such concentrations are found in hailstones. Workman and Reynolds believe that the selective rejection of ions during the formation of hailstones may contribute significantly to the development of charge in thunderstorms and may be of geophysical significance in freezing at the earth's poles.

"The mechanical properties of frozen salt solutions could also be the subject of an interesting study. It is known that the strength of alloys may vary over a wide range, depending in part on the purity of the metal that acts as the solvent. Lead, for example, is hardened by adding a small amount of antimony to the melt. Perhaps some advantage could be imparted to ice as a structural material by dissolving in the water one or more salts that would deposit along the cleavage planes on freezing, much as crystals of antimony precipitate out of lead.

"The effect of dissolved gases on the crystallization of ice could also be the subject of an interesting series of experiments. Dissolved oxygen causes copper to freeze in grains of approximately equal width and length. Perhaps other gases similarly dissolved in water would modify the polycrystalline structure of ice. Such experiments would require freezing relatively thick layers of ice, but the mercury pool could still be used to provide a clean surface of low friction and remarkable smoothness."

Ice crystals in hydrous tin chloride



purposeful imagination....in time

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BOOKS

Rachel Carson's indictment of the wide use of pesticides

by LaMont C. Cole

SILENT SPRING, by Rachel Carson. Houghton Mifflin Company ($5).

As an ecologist I am glad this provocative book has been written. That is not to say I consider it a fair and impartial appraisal of all the evidence. On the contrary, it is a highly partisan selection of examples and interpretations that support the author's thesis. The fact remains that the extreme opposite has been impressed on the public by skilled professional molders of public opinion. It is surely time for laymen to take an objective interest in what man is doing to alter his environment, and *Silent Spring* provides many dreadful examples of how the environment has been damaged by the indiscriminate application of chemicals. Miss Carson gives little attention to poisoning from such chemicals as radioactive fallout, detergents, industrial poisons and food additives; she concentrates her attack on the pesticides, primarily insecticides and secondarily herbicides.

Miss Carson and her publisher are to be praised for devoting 55 pages of a nontechnical book to a list of sources so that the reader can look up the original accounts and judge the evidence on which the author bases her statements. Errors of fact are so infrequent, trivial and irrelevant to the main theme that it would be ungallant to dwell on them. I shall merely express the hope that chemists will not be shocked into abandoning the book when, on page 16, they find rotenone and pyrethrum listed among the "simpler inorganic insecticides of prewar days." Actually it might be interesting to reverse the argument and consider the proposition that the complex structure of pyrethrum, which has frustrated the analysis of the ablest organic chemists, is also responsible for frustrating the abilities of insects to develop resistance.

As Miss Carson describes it, all over the world, but particularly in the U.S., agricultural land, forests, gardens, lawns, roadsides and even urban centers are being dusted and sprayed with an assortment of violent poisons for the principal purpose of increasing agricultural production in a land already plagued by overproduction. The instigators of this abuse are chemical manufacturers seeking increased markets and a Department of Agriculture seeking increased appropriations.

The rain of poison seldom accomplishes its purpose of eradicating the target organism; indeed, the organism often becomes more destructive than before. If the undesirable species is temporarily controlled, it is likely to be replaced by an even more destructive form. People and game and domestic animals may suffer acute poisoning from contact with the drifting pesticide or objects coated with it. Those who escape this fate accumulate the toxin in their body fat, from which it may be released by dieting at a later date. Even without detectable poisoning our livers may be suffering impairment of the ability to detoxify other substances, and other tissues may be suffering damage that will subsequently appear as cancer or as defects in succeeding generations.

Meanwhile the poisoned insects are poisoning insectivorous birds or rendering them sterile. When the sprayed vegetation becomes litter on the soil, the poison is absorbed by earthworms. The worms then become poisonous to robins and other birds, or they may pass the toxins on to moles and shrews, which in turn become poisonous to predators such as hawks and owls. Residues get into water and kill stock drinking it; they also kill fish via the organisms on which they feed. Residues of different toxins react in the water to produce mixtures "that no responsible chemist would think of combining in his laboratory." This witches' brew enters the ground water, rendering the soil toxic for years and having little-understood effects on the organisms that are essential to soil fertility. It percolates into underground reservoirs, from which it may emerge years later. Eventually it reaches rivers and estuaries, where additional damage is possible. Young shrimp are very susceptible, but snails, the hosts of some dangerous parasites, thrive on their relative immunity and the food provided by the remains of their more vulnerable neighbors.

Anyone will recognize this as an argument that is bound to arouse the ire of powerful elements in our society. Indeed, the counterattack has already started, prompted by the prepublication of about a third of *Silent Spring* in *The New Yorker*. A reviewer for *Time* refers to Miss Carson's "emotional and inaccurate outburst" and, without citing evidence, proclaims the merits of pesticides in a statement with which, in my opinion, no responsible scientist would want to associate himself. Similarly, a magazine published by a major chemical manufacturer describes the "Desolate Year" that would overtake the U.S. if we should have to do without chemical pesticides. As one reads this skillful fantasy it is easy to become persuaded that years like those just before World War II could not possibly have occurred: no chlorinated hydrocarbons, no organic phosphates, payments to farmers to reduce production and still crop surpluses!

Where does the truth lie? It lies in part with Miss Carson, who presents enough solidly established facts to justify some alarm. It has been a long time since any of us has eaten a meal free of pesticides or has deposited any body fat uncontaminated by them. People have been fatally poisoned as well as wildlife and domestic animals. The long-term effects of these chemicals are quite unknown; some biologists, including my-

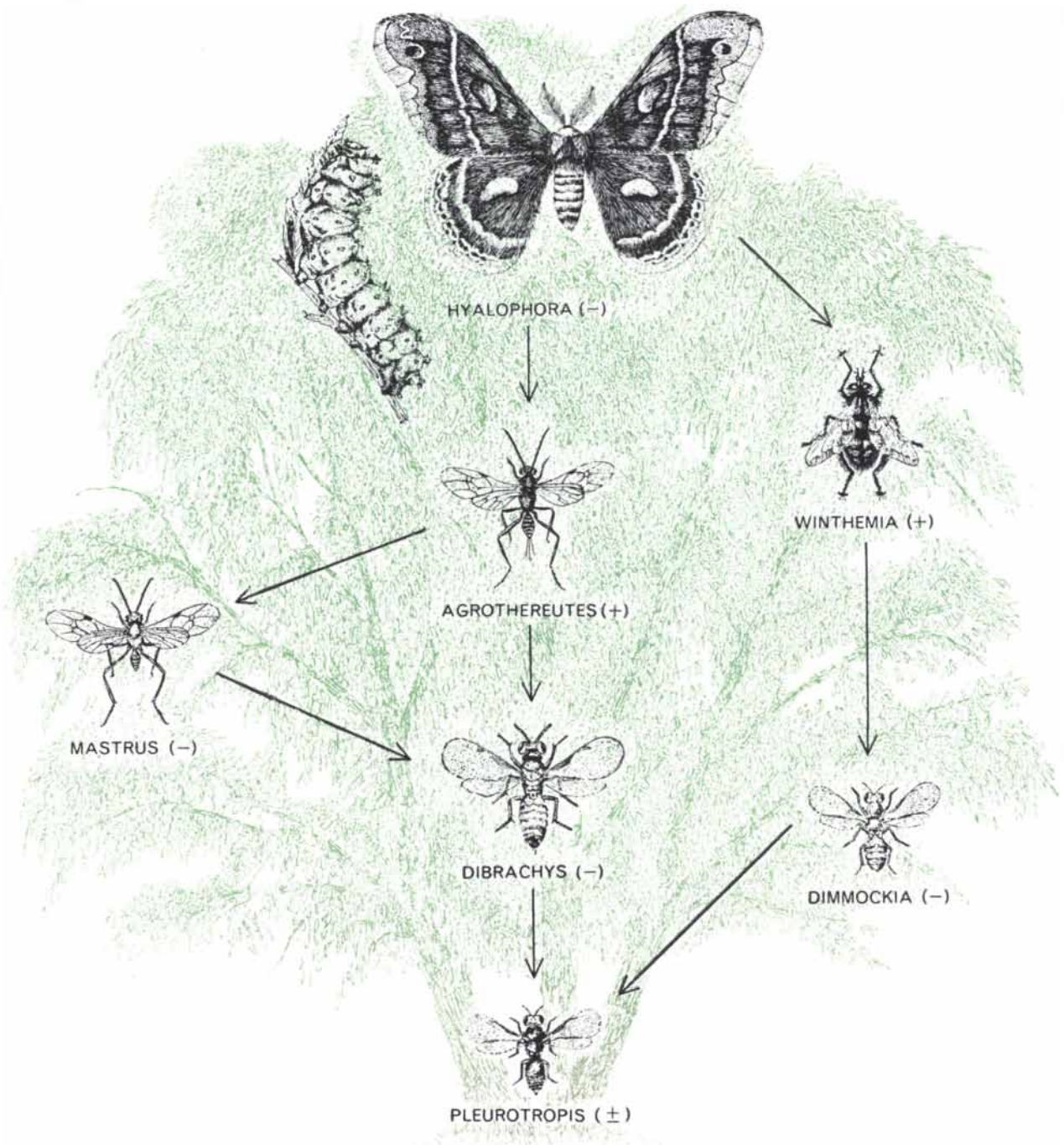
EDITOR'S NOTE

Each December since 1949 this department has reviewed a number of books about science for younger readers. The reviews begin on page 180.

self, have shied away from 2,4-D and its relatives for 15 years on the grounds that it is only discreet to regard a known mutagen as a potential carcinogen. The campaigns led by the Department of Agriculture against the gypsy moth in the East and the fire ant in the South are sadly reminiscent of the old Western conflict over the control of coyotes by poisoning.

On the other hand, insecticides that have a residual action have led man to some notable triumphs. Typhus is such a scourge that Hans Zinsser, in his fascinating book *Rats, Lice and History,* was able to develop a strong case for its governing role in human history. When, in 1944, DDT stopped an incipient typhus epidemic in Italy in its tracks, many of us then in Government service regarded it as the first authentic triumph of man over epidemic disease since smallpox vaccination. The road ahead looked bright, because we realized that the almost superhuman effort and exorbitant expense borne by the Rockefeller Foundation and the people of Brazil to exterminate the dangerous malarial mosquito *Anopheles gambiae* with pyrethrum could not often be duplicated. But soon insects began to develop resistance to the new insecticides. So began a race in which chemists sought to develop new insecticides faster than the insects could develop resistance.

In such circumstances it was out of



A simple ecological system in which it is difficult to distinguish friend (+) from enemy (−)

Statue of Benjamin Franklin by James Earle Fraser in The Franklin Institute, Philadelphia

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the question to test a chemical for long-term chronic effects before putting it into use. Many sincere and competent individuals used their best judgment in recommending precautions and, as Miss Carson admits, a large proportion of the unfortunate cases of poisoning have stemmed from improper use of and disregard for precautions. I suspect that the inevitable way to progress for man, as for nature, is to try new things in an almost haphazard manner, discarding the failures and building on the successes. In man's case there will always be some who deplore certain aspects of progress; to choose a chemical example at random, I myself deplore the curing of hams and bacon by a process more akin to embalming than to anything Grandfather did in his smokehouse. But in the long run, unless a new suggestion can be discarded on the basis of prior knowledge, the only way to evaluate it is to try it out. I am just old enough to recall campaigns against poisoning by iodized salt, ethyl gasoline and aluminum cooking utensils. On the other hand, I also recall the "testimonials" of persons cured by medicine-show nostrums.

Although Miss Carson is fully aware that the basis for control measures lies in the field of ecology, both she and her opponents have failed to place the controversy in a genuine ecological context. The "balance of nature," to which she refers several times, is an obsolete concept among ecologists. It is nonetheless true that the consequences of removing even a single species from a biotic community may be drastic. Moreover, as the development of resistance to insecticides has shown, alteration of the physical and chemical environment can alter the course of evolution. In the following paragraphs I shall try to suggest the complexity of the problem as it appears to an ecologist, hoping that this will convince the reader that nobody knows enough to adopt an extreme position in the matter. I shall use insects in my argument because I know most about them, but among ecologists there are weed fanciers who could make the same points with botanical examples.

Miss Carson's book appeals explicitly to cat lovers, bird watchers and sportsmen but contains little to comfort insect fanciers. She fails to mention that bees are probably less threatened by the modern insecticides than they were by the older arsenicals. If it were possible to exterminate insects without direct damage to man and other animals, I am not sure Miss Carson would not grieve chiefly for the starving birds and fishes that depend on insects for food. I too like woodpeckers, nuthatches and trout, but insects are more important to man. It is true that our modern economy could survive without silk, honey, beeswax and shellac, and I do not expect the layman to be impressed by the fact that biological science could not have achieved its present state so rapidly if our ancestors had succeeded in exterminating the fruit fly *Drosophila*.

But what would happen to the world of plant life without insects? The mere recognition that flowers on flowering plants evolved as adaptations for pollination, usually by insects, suggests the magnitude of the adjustment that would have to take place in an insect-free world. Agriculturists could still grow potatoes and corn, and it is possible, although expensive, to pollinate apples by hand. Cherries might conceivably become an expensive delicacy, as truffles are today, so that it would be economically feasible to pollinate the trees by hand. But it is unthinkable that man deprived of bees would attempt to pollinate alfalfa and clover. Substitutes for these crops would have to be found, and we would probably give up growing cotton and many fruits and vegetables.

When trees shed their leaves, and whenever vegetation dies, organic matter is added to the surface and below the surface of the soil. Much of it consists of decay-resistant materials such as cellulose and lignin. This plant debris must be broken down into simpler compounds that can be reused. Continued accumulation, such as occurs in peat bogs, would be highly detrimental to plant life. Therefore the rate of decomposition of organic matter must on the average equal the rate of accumulation, which in a dense forest may amount to several tons per acre per year. Insects, and their relatives the mites, play a large and perhaps indispensable role in this process. The despised termite is an essential part of tropical biotic communities. We are continuing to learn about these processes, but we do not yet know enough to predict with confidence the long-term effects of tampering with the insect populations of the soil. Here I am with Miss Carson. The chemical residues disturb me, and blind interference with such a complex system impresses me as being irresponsible.

I think, however, that Miss Carson misinterprets the evolutionary significance of the development of hereditary resistance to insecticides. Resistance comes about because members of the population differ in susceptibility to the

toxin and, unless treatment is intensive enough to cause extinction, it is the individuals with the highest intrinsic resistance that survive to become the progenitors of the next generation. It will normally be impossible to exterminate a population with insecticides except in a confined situation such as one would encounter on a boat or a small island. The edge of the treated area will usually provide a region of low dosage where conditions are right for selecting resistant strains.

As Miss Carson interprets the situation, "spraying kills off the weaklings ... it is the 'tough' insects that survive chemical attack." On this premise she reasons that we must forever seek more potent poisons. This line of reasoning is almost certainly incorrect. When members of a population are selected for one particular attribute, the resultant genetic constitution automatically changes other characteristics. The new form can be expected to be in some respects "tougher" and in others weaker, perhaps much weaker. Genes that cause damage can spread as long as incidental benefits outweigh the harm.

A striking example of this phenomenon is furnished by the very harmful gene causing "sickle cell" hemoglobin in man. Individuals receiving this gene from both parents are doomed to sterility and premature death. Those receiving it from only one parent are subnormal in their ability to tolerate reduced oxygen tension; they would not make good mountaineers, airplane pilots or divers, and it is possible that they are handicapped in their normal activities. Nevertheless, in West Africa native populations have been found in which 40 per cent or more of the people carry the sickle-cell gene. The reason for this high incidence is that the gene conveys resistance to the often fatal falciparum malaria. The resistance benefits the population enough to offset the damaging effect of premature death for a small proportion of the children.

Our domestic animals possess traits that have been selected to make them superior to their wild ancestors. But nobody can doubt that these animals are in other ways inferior; most of them probably could not survive in the wild. Similarly, houseflies that are DDT-resistant seem to grow more slowly and to be less prolific than susceptible flies. The resistant flies are adapted to an environment containing DDT (and often related compounds), but they appear to be inferior to susceptible flies in their adaptations to a DDT-free environment. Thus

a new chemical that is unrelated to DDT either structurally or in mode of action is likely to be more effective against DDT-resistant insects than against susceptible strains. I do not for a moment believe that the chemicals are producing superinsects.

Ecologists have more fundamental reservations about pest control than anything I have mentioned so far. These involve, first, the basic question of what regulates the size of any population in nature. The details are a matter of current controversy, but I think that if I choose my words carefully I can convey the essence of the problem without upsetting colleagues in any of the opposing camps.

The basic problem lies in this theorem: All sorts of environmental factors can affect fertility and mortality, but only certain types of factors can *regulate* population size in the sense of holding it within definite bounds. To do this a factor must exhibit what in electronics is called negative feedback. The average population member must be more liable to suffer death or sterility from the factor when he is a member of a large population than when he belongs to a small population.

An analogy may help to clarify this point. Imagine that you fill a bucket with water halfway to the top and set it outdoors with the expectation of having the water level become stabilized by a balance between precipitation and evaporation. For the population of molecules in the bucket these processes represent births and deaths respectively. Any student of probability theory can tell you that if these are the only processes acting on the population, it is 100 per cent certain that, no matter what the climate, at some later date the container will either overflow or be completely dry; no "regulation" is possible. If, however, the container leaks, and leaks faster the fuller it gets, a more or less stable water level may be attainable. The leaks represent a negative feedback mechanism that makes a molecule, on the average, more liable to loss by leakage as the number of molecules in the container increases.

Now, ecologists are universally agreed that shortages of essential environmental resources such as food, space and suitable nesting sites have this negative feedback property and set upper bounds to population size. Social interactions have this quality for some species in which the individuals cannot tolerate crowding beyond a certain point. It is also quite generally agreed that communicable diseases and parasites spread more readily when populations are dense and so have negative feedback qualities.

The situation for predators is much less clear. Often the predator is merely living on surplus individuals that have been forced by population pressures out of the most secure parts of the habitat. By and large the muskrats that are eaten by minks would die from exposure to the weather or something else if minks were not present. That is why ecologists hesitate to advocate spiders or "insect friends" such as the praying mantis or "our feathered friends" for pest control. No matter how friendly the control organisms are, it would take a great deal of careful study in any particular case to tell if their presence means much one way or the other to the populations on which they feed.

Predators are seldom able to increase in numbers as rapidly as their prey. If the cats in a farmer's barn had to depend on mice for food, they could never control the mouse population. They are effective only because of what has been called subsidized predation; the farmer subsidizes the cats to maintain a cat population large enough to turn to mice and exert control when the mouse population increases. In natural situations it is impossible to tell without careful quantitative study the extent to which something such as subsidized predation may be operating. When we subject an area to a nonselective insecticide, we run the risk of knocking out some predator currently subsisting on other foods but maintaining numbers adequate to suppress an incipient outbreak of a destructive form. No farmer would think of trying to control mice in his barn by indiscriminately slaughtering mice and cats, but we risk doing something analogous when the application of insecticide is routine and not based on a demonstrated immediate need.

Some ecologists contend that poisons lack the feedback qualities necessary to regulate population size, except when man creates the feedback by poisoning more intensively when populations increase. In this view poisoning should be carefully integrated with continuous study of population trends. I prefer not to commit myself as being for or against this generalization, but once again it illustrates the complexity of the problem of pest control. Most users and distributors of insecticides have probably never even heard this argument.

The situation becomes even more complex when we look into the network of interactions of a given species and parasites that really do have the ability to regulate population size. Numerous

cases have been observed of pest species made more abundant by spraying because their parasites were destroyed. Miss Carson gives examples, and the papers by Paul DeBach and W. E. Ripper that she cites explore the matter more thoroughly.

A simplified description of an actual multispecies system may help to clarify the problem. The example I present here was worked out by F. L. Marsh and published in *Ecology* in 1937. It is surely typical of relatively simple natural situations and is unusual only in having received careful study.

The larvae of the moth *Hyalophora cecropia* feed on the leaves of trees. It is not necessarily harmful to a tree to have insects feeding on it, any more than it is to have a gardener pruning it, but to simplify the argument we will assume that *Hyalophora* is an "enemy" of the trees.

It is also not necessarily harmful to a population to have parasites and predators thinning its numbers; this may sometimes be highly beneficial. But again let us regard any species that reduces the numbers of *Hyalophora* as a "friend" of the trees. Marsh found two species of woodpeckers, two species of mice and two insects—the tachinid fly *Winthemia* and the ichneumon wasp *Agrothereutes*—to be important in this respect. I shall say no more about the vertebrates but will describe the relations of the two "beneficial" insects and four additional species of insects. All six are "parasitoids" in which the females skillfully seek out immature stages of a host species and arrange to have their own young devour those of the host.

In the accompanying illustration [*page 174*] the arrows indicate the direction of flow of matter and energy: from tree to moth to consumers of the moth, and so on. Since we are putting ourselves in the position of partisans of the tree, we use plus signs to label influences that benefit the tree and minus signs to represent detrimental influences. Thus *Hyalophora* is a "harmful" insect and *Winthemia* and *Agrothereutes* are "beneficial."

Winthemia serves as a host for the eulophid wasp *Dimmockia*, which is here classed as harmful because it destroys a beneficial insect. *Agrothereutes* is host to no less than five parasitoids, but only two of these need concern us here: the pteromalid wasp *Dibrachys* and the ichneumon wasp *Mastrus*. These are by definition harmful because they destroy the beneficial *Agrothereutes*. But *Dibrachys* also attacks *Mastrus* and in this respect is beneficial. Evidently

Dibrachys can be either good or bad for the trees depending on which host is most heavily attacked, and this may depend on which is most abundant.

Even that is not the end. Another eulophid wasp, *Pleurotropis*, attacks both *Dimmockia* and *Dibrachys*. Its influence on *Dimmockia* must benefit the tree, but what can we say of its influence on *Dibrachys*? This is beneficial or not depending on what *Dibrachys* is.

The diagram illustrates on a small scale the sort of thing Miss Carson has in mind when she refers to the balance of nature. Most ecologists today object to using a static term like "balance" to describe such a dynamic system of whirling wheels within wheels. Monkey wrenches thrown at random into such an intricate machine can be expected to necessitate repairs far beyond any mere shifting of weight to restore a balance.

What should one expect from spraying a system such as this? To speculate a bit, flies tend to be more susceptible than wasps to some of the modern insecticides; as a result *Winthemia* might be the first to feel the effects. But we have decided that this is a beneficial form, so the spray damages the tree in this case. Marsh found that *Dibrachys*, unlike the others, has some individuals present throughout the year in the pupal stage, which is likely to be resistant to poisons. Therefore if the spray is applied at the wrong time, *Dibrachys*, which we have been unable to classify as good or bad, is likely to be the least affected. In the unlikely event that all the insects should be killed, the tree would be deprived of insect protectors and would be wide open to attack by the moths flying the next year.

This example, although simplified to the point of being unnatural, illustrates the difficulties of foreseeing the consequences of control measures. The suburbanite who goes to the store and buys something "to stop the bugs from eating up my trees" is likely to be in for a rude shock. Even if he does not poison his lawn, his cat, the songbirds or himself, he may unwittingly set in motion a train of events with no predictable destination. Perhaps it will be just as well if the insects are resistant.

To summarize, man is doing a great deal to alter the face of the earth and much of what he is doing is alarming to biologists. In recent years a number of able writers have brought some aspects of this threatening situation to public attention. Miss Carson is continuing the trend with an attack on chemical pesticides that is so vigorous it is easy to overlook a rare hedging sentence. (On page 12, for example, she disavows any contention that the chemicals should never be used.) She does not, however, convey an appreciation of the really great difficulty of the general problem. She underplays the importance of insects to man and probably overstates the importance of birds and other forms with many human admirers. But what I interpret as bias and oversimplification may be just what it takes to write a best seller, and Miss Carson has already proved that she knows how to do that. If the message of *Silent Spring* is widely enough read and discussed, it may help us toward a much needed reappraisal of current policies and practices.

Children's Books

THE LANGUAGE OF ANIMALS, by Millicent E. Selsam. William Morrow & Co., Inc. ($2.75). Can fish hear? What about snakes and turtles? When a croaker croaks and a catfish grunts, are they talking? How do fish use smell and taste signals? What is the meaning of the stickleback's dance? Why does a woodpecker drum on tree bark? How do penguins conduct their courtship? How do dogs, cats, rabbits, wolves, cows, deer, seals, monkeys and apes impart information? What are insect signal codes? What is the meaning of the wagging dance of bees? Mrs. Selsam provides answers to these questions in her usual relaxed way. Her children's science books have that something more which sets them apart from the average. Adequate drawings. For young teen-agers.

PREHISTORIC LIFE ON EARTH, by Kai Petersen. E. P. Dutton & Co., Inc. ($4.95). Originally published in Denmark, this book, now "edited, adapted and supplemented" by Georg Zappler of Columbia University, is an excellent introduction to the study of evolution. The first part traces the development of the idea itself, the contributions made to it by Niels Steensen, Georges Cuvier, Lamarck, Darwin, Mendel and others; the second part presents a panoramic view of the descent of man from the hypothetical molecular aggregates of the primeval seas. The geological, paleontological and biological records are skillfully woven into a scientifically accurate and highly readable primer. Illustrations (many in color) and an index. Recommended for anyone 14 or over.

ROBERT BOYLE, FOUNDER OF MODERN CHEMISTRY, by Harry Sootin. Franklin Watts, Inc. ($1.95). A straightforwardly written biography of the skepti-

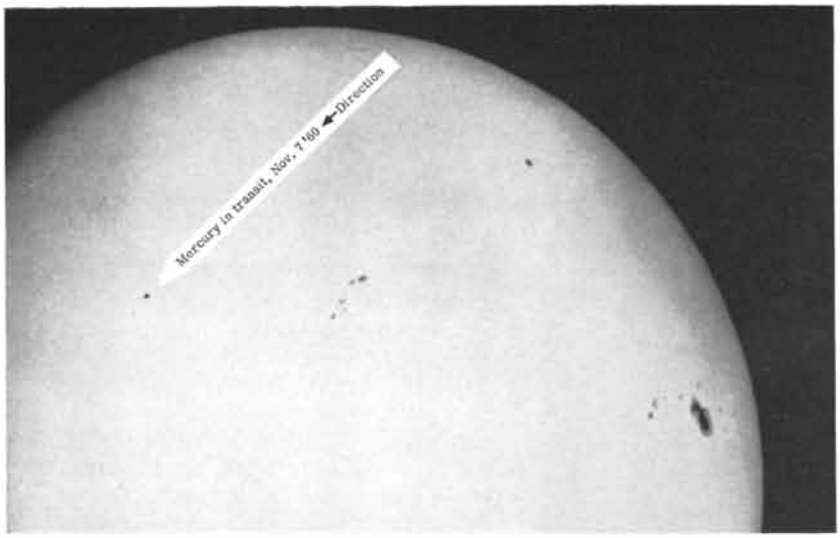
cal chemist, one of the monadnocks of science. The explanations of Boyle's researches are ably done. Good diagrams. For young teen-agers or precocious 10-to-12's.

THE WAYS OF THE AIR, by Roger Pilkington. Criterion Books, Inc. ($3.95). An account for teen-agers of the properties of the atmosphere, cloud formations, the ways of the wind, how rain and storms are born, how sound travels through air, and related matters. Pilkington has a sure grasp of his subject, writes pleasantly and introduces anecdotes and personal experiences (his hobby is exploring the waterways of the world in his private cruiser and he has written many books on the sea) that add to the story. Photographs and diagrams.

THE BOY'S BOOK OF BUSES OF THE WORLD, by Ernest F. Carter. Roy Publishers, Inc. ($3.75). The development of buses from the beginnings of public road transport in the 17th and 18th centuries to modern diesels. Along the way one learns, among other things, about six-horse omnibuses, mail coaches, land frigates (which were "elegantly sashed all round, and in order to preserve the Gentility and Respectability of the Vehicle" no outside passengers were carried), Cugnot's steam lorry, Walter Hancock's "Autopsy" steam bus of 1833 (the reason for the sinister name is not given), London excursion buses, early double-deckers, charabancs, electric and gasoline buses, trolley buses, four-wheelers, six-wheelers and even three-wheelers. This is a British book and mostly about British buses, but there is information about our own species, the illustrations are nice and the average boy should find it fun.

REPRODUCTION AND SEX IN ANIMAL LIFE, by Charles Gramet. Abelard-Schuman Limited ($3.75). A brief survey of the biological nature of reproduction in the animal kingdom, both in lower and higher forms. Chapters are included on the development of the young of each species from conception to birth and afterward, the role of genes in determining the characteristics of offspring, parental care. Many illustrations. A sensible book for 12-to-15's.

JAMES CLERK MAXWELL AND ELECTROMAGNETISM, by Charles Paul May. Franklin Watts, Inc. ($1.95). A biography of the great Scottish physicist and a description of the brilliant work he did in solving the problem of Saturn's rings, in the fields of heat, the kinetic theory of



gases, color vision and, of course, electromagnetism. Maxwell himself comes out cardboard but the explanations of his contributions to science are mostly clear. It is no easy matter to introduce any reader, young or adult, to Maxwell's theoretical models of the antics of electricity and magnetism (even to this day some seasoned scientists admit that they use Maxwell's equations but don't understand them) and the author, everything considered, has done well. The illustrations, except for those taken from Maxwell's own books, which have an appealing antique flavor, are altogether inadequate. For teen-agers.

LORDS OF THE BLUE PACIFIC, by Robert C. Suggs. New York Graphic Society Publishers, Ltd. ($3.95). A short history of the Polynesians for young teen-agers: where they came from, the islands on which they chose to settle, how they lived, how they sailed over thousands of miles of the Pacific, what modern anthropology, archaeology and other sciences have achieved in reconstructing the past of these remarkable people. Illustrations.

TAKE SHAPES, LINES AND LETTERS, by Jeanne Bendick and Marcia O. Levin. McGraw-Hill Book Co., Inc. ($2.75). A hurry-up journey through mathematics from elementary geometry to topology, including scraps of information on shapes in nature, mathematics in art, mathematics in music, algebra, statistics, secret codes. The book is mentioned because it is an example of how such primers should *not* be written. Part of the text is couched in language suited for nitwits, part is addressed to intelligent young teen-agers, and no topic is clearly explained.

THE HARMONIOUS WORLD OF JOHANN KEPLER, by Sidney Rosen. Little, Brown & Co. ($3.75). The story of Kepler's life and how he worked out his famous laws of planetary motion. The book is full of imaginary conversations and dramatizations, but it is not without a certain liveliness. The scientific explanations are sound and understandable. Illustrations. For young teen-agers.

RIVERS OF THE WORLD: VOLUME I, by Julian Popescu and others. Henry Z. Walck, Inc. ($3). Brief accounts of four major rivers: the Danube, Amazon, Niger and Ganges. A traveler down the navigable stretches of each river describes its course, the surrounding country and the people who live there, its exploration, its importance to the re-

gions through which it runs. Drawings and maps. For 8- to 12-year-olds.

THE UNIVERSE, by David Bergamini and the editors of *Life*. Time Inc. ($3.95). How men have probed the universe with telescopes, photographic plates, spectroscopes and radio receivers; what they have learned about planets, meteorites and comets; the biography of the sun; the nature of our galaxy; the birth and death of stars; the regions beyond the Milky Way; the enigmas of relativity and the various theories of creation. All this is handled in the familiar style of *Life:* professional, smooth, creamy, with an abundance of diagrams, black and white and color photographs, old prints, science-fiction conceptualizations. For teen-agers and grownups who want either to leaf through the book and look at the pictures or to take thought and actually read the text.

THE PICTURE HISTORY OF ASTRONOMY, by Patrick Moore. Grosset & Dunlap, Inc. ($5.95). A seasoned English writer on astronomy presents a reliable history of the subject, suitable for all ages from young adolescents up. This is not so slick as the *Life* volume, but there is more meat in it about the science itself, both the theoretical and the experimental side. There are 425 illustrations (161 in color), which serve the text very well.

THE SCIENCE OF OURSELVES, by W. N. McBain and R. C. Johnson. Harper & Row ($3.50). A sensible introduction to experimental psychology, this book discusses the functioning of the human senses, paradoxes and illusions of vision, the learning process, how animals can be taught certain responses and exercises, the nature of memory, teaching oneself how to strengthen one's memory, what is meant by intelligence and how it is measured, basic differences in human behavior, the uses of psychology in various fields. Included are a bibliography and many simple experiments that illustrate the principles of psychology. A satisfactory primer for thoughtful teen-agers.

STARS, MOSQUITOES AND CROCODILES: THE AMERICAN TRAVELS OF ALEXANDER VON HUMBOLDT, selected and edited by Millicent E. Selsam. Harper & Row ($3.50). Selections from the writings of Humboldt describing his experiences in South America, Cuba, Mexico and the U.S. from 1799 to 1804. Humboldt, whose books, particularly his *Personal Narrative Travels,* were enormously popular in the early part of

the 19th century, was not an impeccable reporter, and he was surely one of the windiest. The *Narrative*, for example, runs to 1,500 pages of fine print and takes the reader only to 1801. But Mrs. Selsam's few selections are palatable, and youngsters of 12 or over will enjoy them both as natural history and as adventure. Drawings and maps.

THE FABULOUS ISOTOPES, by Robin McKown. Holiday House ($4.50). What isotopes are, what they do, how they can be used. Plainly written, with better than average explanations of the rudiments of nuclear and atomic physics. Good drawings and photographs; a useful glossary. For ages 13 or 14 and up.

THE CONTINENT WE LIVE ON, by Ivan T. Sanderson. Random House, Inc. ($4.95). A special edition of this abundantly illustrated natural history of the North American continent, adapted for younger readers by Anne Terry White. Sanderson spent a year driving some 57,000 miles all over North America, taking in the landscape, animals, plants and flowers, lakes and rivers, game preserves, national parks, climate and weather and so on. He imparts many tidbits of information and a good picture of the extraordinary diversity of the continent, of the many places that men have desecrated and of those whose beauty remains intact. A book that most youngsters would be glad to have.

FRUITCAKE AND ARSENIC, by Josephine Hemphill. Little, Brown & Co. ($3.95). Miss Hemphill, who was formerly on the staff of the Food and Drug Administration, tells the story of the origins of the FDA, the different kinds of problems it has encountered, its successes and failures. Although the agency is of the first importance in enforcing standards and in guarding health by protecting people from poisonous, adulterated and mislabeled foods and from falsely and dangerously advertised drugs, its effectiveness has been impaired by defects in the organic law, by shortage of staff, by unconscionable procedural delays and by incompetence; moreover, it is scarcely equipped to deal with human credulity. The idea behind this book is a sound one, and a few of the more extreme FDA cases are well described, but in general Miss Hemphill is not a lively writer. Drawings. For young teen-agers.

THE PEOPLES OF AFRICA, by Colin H. Turnbull. The World Publishing Company ($3.50). A first-rate introduc-

tion to the continent and peoples of Africa. The author, who is assistant in charge of African ethnology at the American Museum of Natural History in New York, is an anthropologist who has made several extensive tours of Africa and lived with various tribes. He describes the land, man's beginnings in Africa, the hunters, the pastoralists, the cultivators, the customs and concepts so very different from our own, that arise from Stone Age beliefs and that are still shaping everyday life. There is no possibility, as he makes plain, of meeting the problems of Africa and of substituting the new for the old without understanding the force of ancient traditions. Turnbull writes agreeably, clearly, always sympathetically, and with an eye for the telling anecdote or detail. Highly recommended for teen-agers.

ALL ABOUT MOUNTAINS AND MOUNTAINEERING, by Anne Terry White. Random House, Inc. ($1.95). An interesting, well-written story of geology and adventure for young teen-agers. Mrs. White deals briefly with the great mountain chains of the world—the Alps, the Rockies, the Andes, the Himalayas; tells how the mountains were formed and what they look like; describes some famous glaciers, peaks and passes; and recounts certain classic climbs, including Paccard's 1786 ascent of Mont Blanc, Edward Whymper's tragic scaling of the Matterhorn, the strange conquest of Mount McKinley, Hillary and Tenzing's brilliant victory over Mount Everest. Excellent photographs and maps.

THE FIRST BOOK OF LIGHT, by George Russell Harrison. Franklin Watts, Inc. ($1.95). A complete introduction to all aspects of light by a Massachusetts Institute of Technology physicist. Included in the topics discussed are the main sources of light, its behavior, the waves of the electromagnetic spectrum, the basic laws of optics, the principles and uses of microscopes and telescopes. Many simple home experiments are given. Illustrations. For young teen-agers.

ALL ABOUT THE PLANET EARTH, by Patricia Lauber. Random House, Inc. ($1.95). A primer for young teen-agers that covers a wide variety of subjects, from the formation of continents, the structure of the earth, tall mountains, deep holes and contemporary theories about how the earth was formed to the oceans of air and water, solar phenomena, the earth's radiation belt and radio astronomy. Diagrams and photographs.

ANNUAL INDEX

The following index lists all the authors and articles that appeared in SCIENTIFIC AMERICAN *during 1962. Also indexed are "Mathematical Games," "The Amateur Scientist" and the principal book review in each issue.*

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