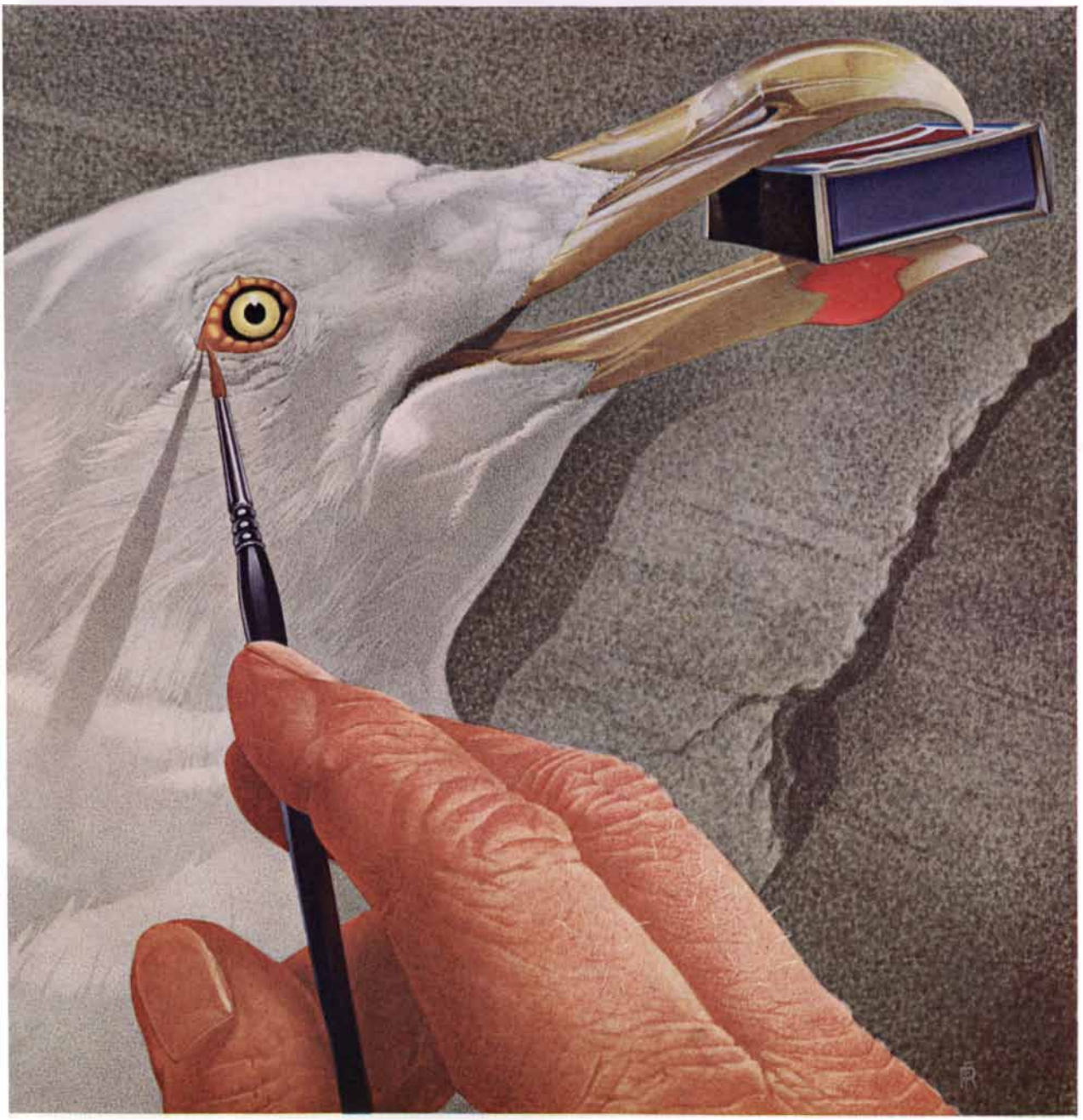
SCIENTIFIC AMERICAN



GULL EXPERIMENT

SEVENTY-FIVE CENTS

October 1967

Eastern opens The Space Corridor.

Along it lie 4 key centers of aerospace activity.

Boeing in Seattle. McDonnell in St. Louis. The George C. Marshall Space Flight Center in Huntsville. And Cape Kennedy.

Now Eastern links them all in one direct route. With daily round-trip jet service from Seattle to Orlando and Melbourne.

The Space Corridor means new convenience for the traveler. As well as a new kind of service.

The kind of service that has made Eastern the choice of one in six of the nation's air passengers.

A reservation confirmed in seconds.

A leisurely meal with your choice of gourmet entrées. Expertly prepared.

And a competence of flight and maintenance personnel second to none.

Because we offer more than a shortcut to space.

We make it more enjoyable getting there.

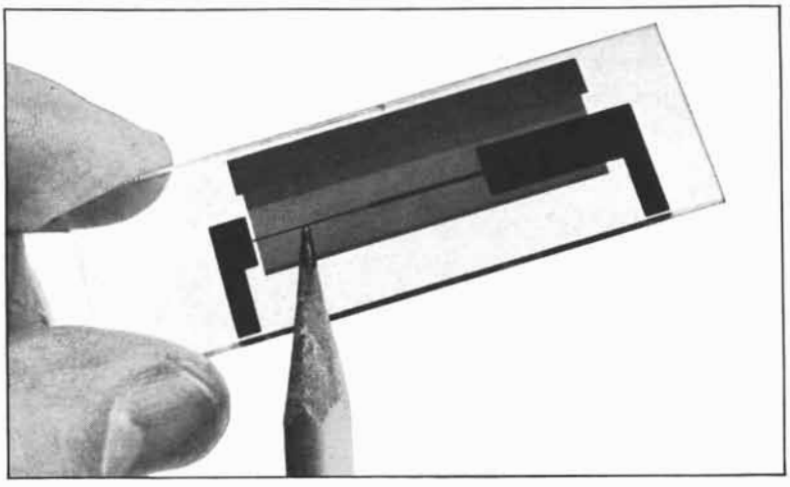
EASTERN

We want everyone to fly.

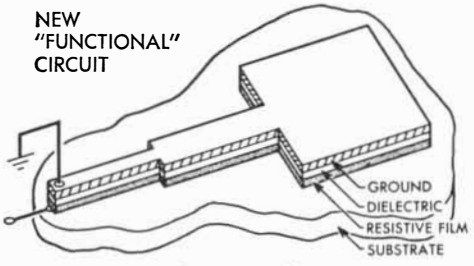
Report from

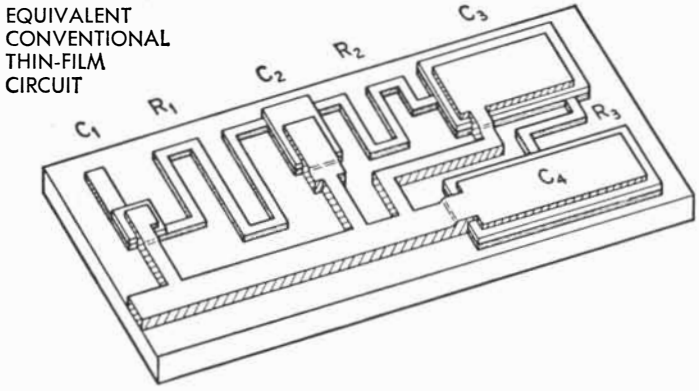
BELL LABORATORIES

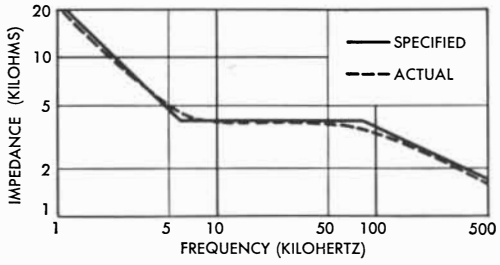
"Functional" Tantalum Integrated Circuits



The new "functional" thin-film circuit, shown in the above photo and in the drawing, right, is a two-terminal network consisting of thin films deposited on a glass substrate. For equivalent electrical performance, a conventional thin-film circuit would require at least three resistors and four capacitors (drawing, below).







Wyndrum formulated a class of equations which relate frequency response to the geometry of the thin-film pattern. The curves, left, show the specified and actual performance of such a circuit.

As electronic systems have grown in size and complexity, tantalum integrated circuits have reduced costs while increasing reliability and performance. To obtain even further integration of circuit functions, however, engineers at Bell Telephone Laboratories have used tantalum technology to build single thin-film components equivalent to networks of thin-film resistors and capacitors.

This new single, "functional" component (left) is basically a film capacitor with one electrode of resistive tantalum and a second electrode of conductive gold, separated by a dielectric layer of tantalum pentoxide. The component is made by depositing a thin film of tantalum onto a glass substrate, converting a portion of this layer to the insulating oxide, and then depositing the conductive gold electrode onto the oxide. In this arrangement, resistance and capacitance are distributed throughout the structure rather than among discrete electrical components. In addition to providing reliability and economy, this approach also offers the advantages of simpler fabrication and fewer electrical parasitics.

As an important contribution to the design of such structures, Bell Laboratories engineer Ralph W. Wyndrum, Jr., showed that it was possible to convert circuit performance specifications directly to tantalum thin-film patterns. Furthermore, he showed how appropriate geometries and film compositions could yield a wide range of impedance and transfer functions.

Wyndrum developed this synthesis technique while doing graduate work at New York University. He has advanced this technique further at Bell Laboratories, where tantalum integrated circuits were first created some ten years ago.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

RECENT FINDINGS

RESEARCH LABORATORIES

Ford

Evidence of chain folding of polymers in solution

Nuclear magnetic resonance spectroscopy (NMR) has been used to study normal paraffin molecules, CH_3-$(CH_2)_{n-2}$-CH_3, in solution. These molecules are low molecular homologues of polyethylene. In this investigation, a new understanding of polyethylene structures in solution was obtained by examination of these homologous molecules. A precis of the essential experimental evidence is given below.

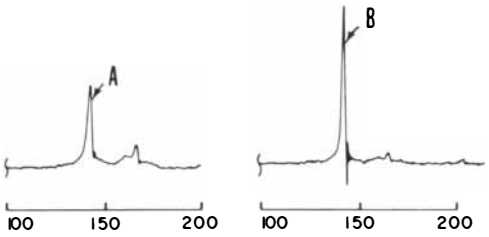


Figure 1

A. Methylene resonance of nonane (C_9H_{20}) in carbon tetrachloride solution at 35° C. B. Methylene resonance of eicosane ($C_{20}H_{42}$) in carbon tetrachloride solution at 35° C.

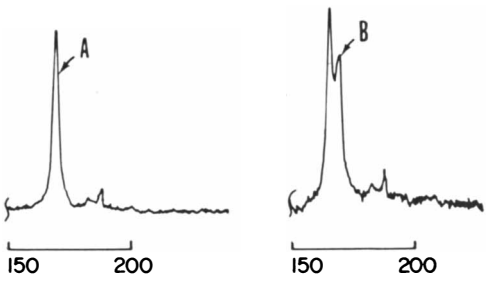


Figure 2

A. Methylene resonance of hexadecane ($C_{16}H_{34}$) in α-chloronaphthalene solution at 35° C. B. Methylene resonance of tetracosane ($C_{24}H_{30}$) in α-chloronaphthalene solution at 35° C. • Note: that the tetracosane resonance is split though the hexadecane has a single peak.

Except for penultimate groups, the CH_2 resonance of the normal paraffins is expected to be a singlet. Figure 1.

In certain aromatic solvents, this CH_2 resonance becomes more complex (provided that the chain length of the molecule is sufficiently long). Figure 2.

The complexity in the NMR spectrum tends to disappear as the temperature of the solution is raised. Figure 3.

The results enumerated above are insensitive to the solution concentration over a wide range (0.2% to 10%).

It follows from these experiments that under certain conditions, as in Figure 2b, the carbon atoms of the chain molecules are arranged in such a way that certain -CH_2-groups are in very different chemical environments from others on the same molecule. There is no simple direct evidence which tells what causes these different chemical environments.

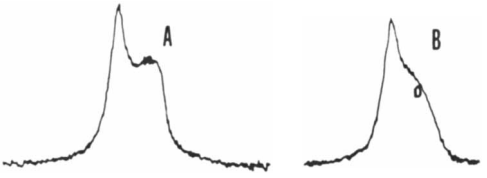


Figure 3

Methylene resonance of docosane ($C_{22}H_{48}$) in α-chloronaphthalene solution. A. At 51° C. B. At 94° C. At still higher temperature the peak becomes a simple singlet.

It is known that polyethylene and other polymeric molecules fold back and forth in the crystallic solid. The hypothesis that these folded chain arrangements persist in some solutions for polyethylene and the normal paraffins, which are low molecular weight polyethylene, is an attractive one. An analysis of the problem indicates that the dependence of chain folding on temperature and chain length is entirely consistent with the experiments shown in Figures 2 and 3.

The conclusion that chain folded arrangements are actually found in normal paraffin hydrocarbons is a probable one, though this may not be considered as firmly established. By implication, it would follow that similar structure may be found in other polymeric systems in solution. Further investigations are in progress to discover whether this is true, and if true, where the phenomenon is found.

Ford scientists and engineers have long known that improvements are most likely obtained when knowledge of the systems and materials under investigation is both sophisticated and profound. It is in this context that fundamental studies such as these become natural objectives of Ford research.

PROBING DEEPER FOR BETTER IDEAS

Ford

Established 1845 **SCIENTIFIC AMERICAN** October 1967 Volume 217 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows an experimenter painting the fleshy ring around the eye of a gull, a step in an investigation of how closely related species that live together discriminate between each other. In this case the species are four gulls of the genus *Larus* that closely resemble one another, nest together in various combinations in the Arctic and yet do not interbreed (see "Visual Isolation in Gulls," page 94). One possible explanation is that subtle variations in features are perceived by the gull, and one such feature is the color of the eye-ring. To test this hypothesis the eye-ring color of various gulls was changed by painting the eye-ring, and the effect of the alteration on the mating behavior of the gulls was observed. The gull in the painting is the glaucous gull (*Larus hyperboreus*). In this species the eye-ring is normally bright yellow. Here it has been painted orange to resemble the eye-ring of the herring gull (*L. argentatus*). While the gull is being painted it is anesthetized. The matchbox in the gull's bill was placed there by the experimenter to prevent his being nipped by the gull if it came out of anesthesia. The matchbox also prevented the gulls from possibly choking on regurgitated food while they were under anesthesia.

THE ILLUSTRATIONS

Cover painting by Rudolf Freund

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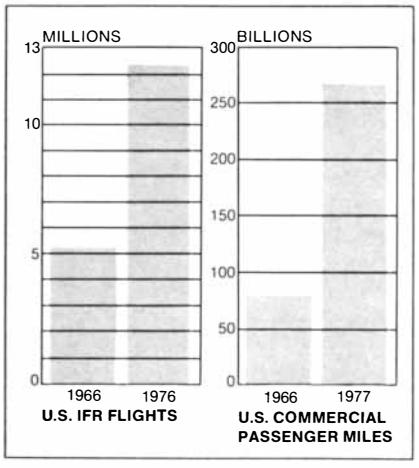
Helping the Federal Aviation Agency scuttle its "shrimp boats"

FAA air route traffic controllers continuously monitor all "IFR" aircraft in flight. Radar returns from surveillance radar antennas are displayed on a CRT to indicate the range and bearing of aircraft within a given area. Altitude, now, is determined by radio contact with each flight. Soon, a new display system, developed by Raytheon, will combine this information automatically, giving the controller a "3-dimensional" picture of aircraft under control.

What does it take to control an estimated 9,000 aircraft taxiing, taking off, flying, and landing within the U.S. at any given moment? For the FAA — overseer of all flights operating under instrument flight rules (IFR) in the U.S. — it takes 14,000 highly trained men, extremely sophisticated electronic equipment, and . . . a large supply of small plastic markers called "shrimp boats".

Today, skilled controllers at FAA enroute air traffic centers use these "shrimp boats"



to record the altitude and identity of each flight under control. In practice, the controller places a "shrimp boat", with its handwritten information, on his CRT display next to each radar target that represents an "IFR" aircraft. He then must update the information and constantly reposition each "shrimp boat" to match the progress of the flight it identifies.

The FAA, in anticipation of the air traffic control needs of the future (see chart), is rapidly developing its automated National Airspace System (NAS) which will scuttle the "shrimp boats" and free both pilots and controllers from tedious repetitive actions, permitting them to devote most of their attention and energy to their primary tasks — flying the planes and keeping flights safely separated.

CDC In — "Shrimp Boats" Out

A key element in the NAS is the Computer Display Channel (CDC), being developed and produced by Raytheon, which will provide the interface between the controller and an enormous amount of data being processed by a central computer complex.

The CDC will replace the old fashioned "shrimp boat" markers with electronically-generated alpha-numeric tags that will appear automatically on the controller's CRT display. Most of the vital flight information, formerly recorded manually, will be displayed and updated electronically as each tag follows its target across the scope. The electronic tags can supply the controller with current information about the identity and altitude of each flight, so he will have what amounts to an accurate "3-D" picture of air traffic in his area.

Greater Information Display Selectivity

The new CDC system gives the controller extraordinary selectivity in the type of information he can extract from the computer and how it is displayed. For example, when traffic is light, a few consoles can be used to display large control sectors. During peak periods, more displays can be brought into action to "zoom-in" on smaller areas for closer surveillance. Because input data is relayed simultaneously to all displays from a common refresh memory (see diagram), information appearing on separate consoles may be compared accurately, regardless of range scales used. In addition, the "electronic" center of each display can be positioned anywhere on the map, allowing the controller to monitor an entire air corridor or to select a particularly dense air traffic area for special attention.

The displays themselves represent a radical improvement over similar equipment in operation today. Because all information is digitally generated, the image is always sharp and flicker-free. Resolution is five times greater than that presently achieved by conventional displays. Each flight with its identifying tag is clearly defined at all times.

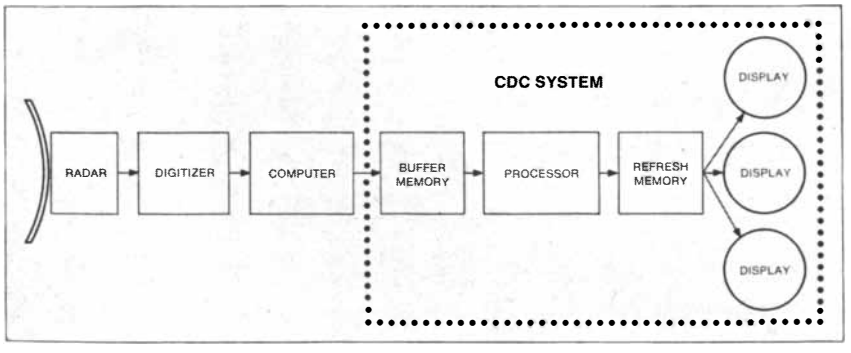
What About Flight "Hand-Offs"?

Today, when an aircraft leaves one FAA regional control sector to enter another, the controller "hands-off" the flight to the adjacent area by direct-wire telephone. The receiving controller must make positive identification of the approaching aircraft by radio before clearing the flight to enter. The CDC system, working in conjunction with other NAS equipment, allows this hand-off to be accomplished electronically, without telephone or radio contact, and without delay.

Applied Systems Management

The ultra-modern CDC equipment is being produced by Raytheon under the largest contract ($44 million) ever awarded by the FAA for air traffic control equipment. The system will utilize the very latest advances in electronic technology, including monolithic integrated circuits and high-speed core memories produced by Raytheon, to help insure greater accuracy and reliability. Result: a highly efficient and effective system requiring less space and less power at lower cost.

Solving complex problems by "systematic" thinking and utilization of the company's wide range of technical skills is typical of the way Raytheon works to assure complete customer satisfaction . . . in defense and other government systems and in such commercial markets as education, home appliances, natural resources development, electronic components, marine products and communications. Raytheon Company, Lexington, Mass.



RAYTHEON

LETTERS

Sirs:

In your June issue J. Herbert Hollomon wrote a rather extensive defense of the recently issued recommendations of the President's commission on the study of the U.S. patent system. As an inventor with some considerable number of patents, and not an inconsiderable amount of experience in innovating, I feel compelled to register a strong objection to many of the statements in the article.

It is simply impossible in this letter to discuss, even briefly, the commission's report or Dr. Hollomon's paper. I should like to touch on only a few points.

Both the report and the article stress the early publication of the invention as the main aim of our patent system. This is not correct. The main aim of the patent system is to get the invention into commercial and public use.

The whole drive for new laws, I believe, is based not so much on the difficulties experienced by our inventors and their employers as it is on the difficulties suffered by our Patent Office and by Dr. Hollomon's desire to promote the very worthwhile objective of getting an international patent system.

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Dr. Hollomon objects to secrecy, and so do I, but the proposed new laws will certainly increase secrecy rather than decrease it. We shall reward him who rushes to the Patent Office first, and since by Dr. Hollomon's own admission the keeping of records no longer will be needed, anyone who learns of another's invention can get full credit for it if he files first. He will not need any other proof of being the inventor.

The importance of the independent inventors and the inventors working for small companies is excellently brought out in Dr. Hollomon's article, yet many of us who have studied the commission's report have come to the conclusion that its proposals are directed against this group of inventors.

I also want to disagree with Dr. Hollomon's last statement: "It does seem evident, however, that agreement on the need to modernize the patent system is virtually unanimous." I know of no such unanimous feeling that our system has to be changed. If it does need changing, I do not believe that the proposed changes are "modernizations."

It seems to this observer that the whole drive for establishment of a new patent system is spurred by the difficulties our Patent Office is undoubtedly experiencing in trying to keep up with the growing modern technologies. I should like to echo the suggestions made many times before that the Patent Office needs more staff, more examiners trained in advanced technologies, higher salaries, better facilities and all the other things that money can provide.

I agree that an international patent system would be a highly desirable goal and that therefore the minimum number of changes should be made in order to help achieve such an international system. But let us not becloud this issue by adopting a great many changes—changes that in total will reduce the incentives to invent and innovate. In the biased opinion of people like myself these incentives today are at best marginal.

J. Rabinow

President
Rabinow Engineering Division
Control Data Corporation
Rockville, Md.

Sirs:

I am glad that Dr. Rabinow feels, as I do, that an international patent system would be a "very worthwhile objective." I disagree, however, that "the whole drive for new laws . . . is based . . . on . . . Dr. Hollomon's desire to promote the very worthwhile objective of getting an international patent system."

Many persons who have studied the problem over several years have concluded that the patent system needs modernization if it is to meet tomorrow's needs adequately. A good example is what Dr. Rabinow calls "the main aim of the patent system," namely "to get the invention into commercial and public use." The members of the President's Commission on the Patent System "unanimously agreed"—I quote from the commission's report—"that a patent system today is capable of continuing to provide an incentive to research, development and innovation. They have discovered no practical substitute for the unique service it renders." President Johnson, in submitting the Patent Reform Act of 1967 to the Congress on February 21, reiterated the necessity for modernization of the patent system so that it can better "serve the technological advances it was designed to foster." In my article I quoted the President's declaration in transmitting the act, that "its purposes are threefold: (1) to raise the quality and reliability of U.S. patents; (2) to reduce the time and expense of obtaining and protecting a patent; (3) to speed public disclosure of scientific and technological information." Only after listing those primary purposes did the President state "another important objective—they will bring the U.S. patent system more closely into harmony with those of other nations."

Dr. Rabinow and I agree on the importance of independent inventors and inventors working for small companies, and whether the Patent Reform Bill would be in their interests is a matter of opinion. Both the American Society of Inventors and the National Small Business Association have expressed support for a first-to-file system of priority—to take one key provision of the Patent Reform Bill.

The proposals of the commission and the Patent Reform Act include a number of changes that would tend to harmonize our system with those of the other countries of the world. One is the proposed first-to-file system. Seventy-four of the 77 countries that belong to the International Patent Convention (the Paris Union) have a first-to-file rule, and only three (the U.S., Canada and the Philippines) have the obverse, a first-to-invent rule. Businessmen, in-

SCIENCE/SCOPE

A new infrared missile for air-to-air combat with swift enemy fighters has blasted more than a score of jet target drones from the skies in test launches from Air Force F-4s. Latest addition to the Falcon family of air-to-air missiles, the AIM-4D was produced by "cross-breeding" two other Falcons, giving the Air Force a new, more effective missile of proven reliability at lower cost than developing a new model.

The F-4 will carry four AIM-4D missiles on wing pylons when they become operational. The AIM-4D can also be carried by the F-102 and F-101 interceptors.

Biggest communications satellite ever built will be the experimental tactical communications satellite now under construction at Hughes for the U.S. Air Force's Space & Missile Systems Organization. It will have an array of five UHF antennas extending from the top, each nearly eight feet long. Satellite will be spin-stabilized in its synchronous orbit.

A military magnetic drum system with a mean-time-between-failure in severe airborne or ground environments that is conservatively estimated at 10,000 hours, based on several drums now in operational use, has been developed by Hughes.

New memory system has a capacity of 5×10^6 bits, with rapid access. It is sealed for two years of operation, and is interchangeable in the field without adjustment or harmonization.

New commercial products from Hughes: a numerically-controlled wire-laying machine that reduces electronic assembly production time by a ratio of five to one...a six-color krypton laser for industrial and academic laboratories; it can be converted to an argon laser simply by changing tube and mirrors...a thermocompression bonder for bonding gold wire to cold substrates; its pulse-heated tip eliminates pre-heating of parts prior to bonding.

Hughes has immediate opportunities for engineers with at least two years of experience in weapon systems, radar system design and development, computer design, or communications systems. Requirements: accredited degree and U.S. citizenship. Please send your resume to Mr. J. C. Cox, Hughes Aircraft Company, Culver City, Calif. Hughes is an equal opportunity employer.

An improved infrared spectrometer for the Nimbus D satellite to be launched in 1969 is being built by Santa Barbara Research Center, a Hughes subsidiary. It will measure the temperature and humidity of the troposphere, providing useful data for weather forecasting.

An infrared radiometer to measure the surface temperature of Mars is also being developed by SBRC. The two-channel, five-pound instrument will be carried by the two Mariner flyby spacecraft to be launched in 1969.

Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY

ventors, patent practitioners and scientists and engineers in the first-to-file countries testify that this feature works satisfactorily in the public interest and in the private interests of all, with no significant problems, that is, no problems of secrecy, rush to the Patent Office and so on.

It seems to Dr. Rabinow "that the whole drive for establishment of a new patent system is spurred by the difficulties our Patent Office is undoubtedly experiencing in trying to keep up with the growing modern technologies." That is not correct. The proposed statutory changes are not aimed at relieving the pressures on the Patent Office, except for deferred examination, for which the Patent Reform Act asks only for standby authorization. The commission recommended first-class housing, staffing and equipping, regardless of whether the basic patent laws remain the same or are changed.

The last paragraph of my article summarizes my thoughts on the matter of patent reform. "The Patent Reform Act has drawn some opposition, as might be expected with any proposal to make fundamental changes in a long-established system that has built up an elaborate structure of traditional practices. I would not argue that the act is the last word on patent reform. It does seem evident, however, that agreement on the need to modernize the patent system is virtually unanimous."

J. Herbert Hollomon

Acting Under Secretary
Department of Commerce
Washington, D.C.

Sirs:

I am writing in reference to the article "Pre-Columbian Ridged Fields," by James J. Parsons and William M. Denevan [Scientific American, July].

Their findings of ridged fields in widely separated areas of South America support the notion they have expressed as "the idea that similar environmental adaptions are independently invented again and again."

There is further supporting evidence in the ridged tillage fields of East Africa in south central Tanzania between Iringa and Njombe. These fields are similar in appearance to the Columbian illustration at the head of the Parsons-Denevan article. The African fields [*see photograph at right*] are found in tropical highland country of over 5,000-foot elevation and in a climatic regime of pronounced wet and dry season. They are constructed in seasonal swamps and are planted to root crops and grains. The swamp cultivation is found in association with ridged fields on the upper slopes or valley sides.

I conjecture that the ridged fields in the swamps serve to broaden the subsistence base of local cultivators because the swamps have a more reliable supply of soil moisture over a longer period of the year than is the case with the dry ridged fields of the hillsides. This is the country where tillage cultivation on the hillslopes is precarious because soil moisture is available for relatively short and fluctuating periods of the year. The latter assertion is supported by examination of any of the available water-balance diagrams for this and other areas of the wet and dry Tropics.

It is likely that when high-resolution orbital-altitude photography becomes available we will locate additional widely dispersed examples of this and other technically simple man-altered land surfaces.

Walter Deshler

Department of Geography
University of Maryland
College Park, Md.

Ridged fields in East Africa

Tape it with a Sony Solid-State Stereo 560

There's a world of beautiful music waiting for you and it's yours for the taping. Let Sony-superb 4-track stereo capture every note faithfully while you relax in your easy chair. Simply connect your stereo tuner to the Sony Solid-State 560, "Stereo Compact Portable," and tape your favorites off the air. Here is the nucleus of a complete stereo sound system with an ESP automatic reversing stereo tape recorder as its main component. The Sony-unique Stereo Control Center permits four separate stereo components to be connected to its stereo preamplifier and 20-watt music power amplifier. Push buttons select your component source for listening or recording. Individual input level controls balance output whenever you switch between components. Sony's revolutionary ESP Reverse electronic brain constantly scans and automatically senses the voice of music modulations on your recorded tapes. When these modulations stop, the ESP (Electronic Sensory Perceptor) automatically reverses the tape direction in 10 seconds. The Sony Solid-State 560 incorporates the most advanced electronic developments for sound-quality control. The Sony-exclusive Servo-Control Motor provides, among other things, the flexibility of AC/DC operation and variable musical pitch tuning. Non-Magnetizing Heads eliminate the most common cause of tape hiss. The exclusive Scrape Flutter Filter eliminates tape modulation distortion providing the purest recordings ever. An exclusive Noise Suppressor Switch eliminates any undesirable hiss that may exist on older recorded tape without affecting the sound quality. All of this is yours, with two Sony F-98 cardioid dynamic microphones for less than $499.50! Check these Sony-exclusive features for luxury listening: ■ ESP Automatic Tape Reverse ■ Stereo Control Center ■ Scrap Flutter Filter ■ ServoControl Motor ■ Noise Suppressor Switch ■ Non-magnetizing Heads.

SONY'S PROOF OF QUALITY — A FULL ONE YEAR WARRANTY

SONY SUPERSCOPE The Tapeway to Stereo

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Sony Solid-State 560D ESP Automatic Reverse Stereo Tape Deck Recorder. If you already have components or a package stereo system, simply connect the Sony Solid-State 560D Stereo Tape Deck Recorder and add the incomparable advantage of stereo tape to your present stereo sound system. Here is the same superb ESP Reverse stereo tape deck that is the main component of the Sony 560. You will find every feature and the same advanced electronic developments for sound-quality control less the Stereo Control Center and speakers. Yet, mounted in its own handsome, low-profile walnut cabinet with recording amplifiers and playback preamplifiers, the Sony 560D sells for less than $349.50!

Stronger than Steel, Lighter than Aluminum: A report from General Dynamics

That elephant is standing on a plank made of boron-epoxy composite.

So far, this new structural material has been used only for aircraft and space vehicle parts on a research basis, but it will be going into commercial use in the near future. And it could lead to radical change in aircraft and vehicles of all types as we know them now.

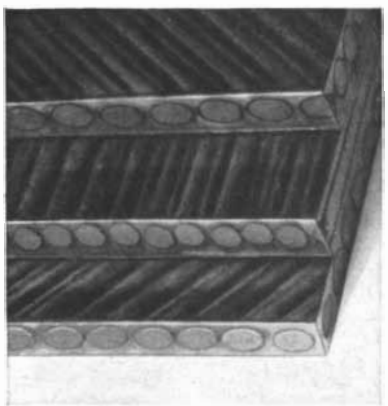
Take two identical aircraft, one built of conventional aluminum, the other with the same parts of boron composite. The boron airplane theoretically could carry twice the payload for the same distance, or go twice as far on the same amount of fuel.

An auto with body and frame of boron composite could be as big and comfortable as a Cadillac yet lighter than a Volkswagen. The combination of lightness and size would mean the car could be driven by a battery-powered aluminum engine and protected against impact with polyurethane foam bumpers.

For boron composites are a new *kind* of material. This form, with boron filaments embedded in epoxy plastic, is as strong and stiff as high-strength aircraft-quality steel, but 75 percent lighter. It is three times as strong as aluminum but more than 25 percent lighter.

What is boron?

Boron is a semi-metallic element—the fifth element in the atomic table. Widely available, it is usually found in combination with other minerals. Best known uses until now—and called for in limited amounts—have been the familiar household boric acid, or the borax used in glassmaking. In some chemical combinations it is almost as hard as diamond (but with even greater heat resistance), and is used to cut and shape such extremely hard materials as carborundum.



Each layer of the boron-epoxy filament tape is oriented at a different angle. This enables the laminated composite to withstand stress from any direction.

But boron was rarely, until recently, seriously considered as a structural material. The demands of space vehicles and high-performance military aircraft called for a deeper look. New kinds of materials, with hitherto-unrequired standards of strength, light weight, and heat resistance, have become crucially important.

For the past few years, General Dynamics has been working with boron composites—filaments of boron in "matrices" of plastics or metals—largely under contract to the United States Air Force. Sections of boron-epoxy have already been successfully tested in supersonic flight.

Brittle—and tough:

In many of the most common ways of shaping metals (casting, for one) boron is extremely brittle. But just as glass, brittle in many ways, has high strength in filament or fiber form, so has boron filament—extraordinarily high usable strength. And boron is also uniquely stiff—six times stiffer than glass.

These boron filaments mixed with, say, an epoxy plastic or molten aluminum, result in a composite which possesses the best qualities of both materials. The form closest to commercial use is the boron fiber in an epoxy matrix, although aluminum and even titanium matrices are being tested for more exotic uses.

For some military aircraft and space vehicles, these remarkable new materials offer an invaluable combination of great strength, stiffness, light weight and heat resistance.

But right now, boron is still expensive. Steel averages out at 6 cents a pound; glass fiber, at 60 cents a pound. And aluminum, which once cost $6,000 a pound, now ranges from 22 to 75 cents a pound, depending on the grade.

The boron-epoxy composite not long ago was priced at about $1,000 per pound. However, over the last few months, its cost has been reduced by more than two-thirds. As more applications are worked out and more demand arises, its price is already dropping still further to more economic levels, just as aluminum did.

It will be a while, however, before boron composite becomes competitive, on a pound for pound basis, with more conventional materials. But other factors might compensate.

In construction, buildings with structural members and other major parts made of boron composite could be built much taller—and in a wider variety of architectural shapes than is now practical.

Single span bridges twice as long as the longest now existing should be possible. Boron vehicles generally—cars, trucks, or planes—could go farther on less fuel. New commuter trains built of boron to aerodynamic principles could carry passengers to their jobs swiftly and comfortably.

The boron filament is made by drawing an extraordinarily fine wire of tungsten, heated to a bright-red temperature, through a chamber into which boron trichloride and hydrogen gases have been pumped.

Thin as a human hair:

In the vicinity of the hot tungsten wire, chemical reaction yields pure boron and hydrochloric acid. The particles of pure boron are deposited on the moving wire and the hydrochloric acid is removed from the chamber.

The final boron filament is four one-thousandths of an inch in diameter, about as thin as a human hair. It is 95 percent pure boron and 5 percent wire core.

To build anything out of these filaments, they are first made into a composite in the form of a tape. About 212 boron filaments to the linear inch are coated with and embedded in epoxy on a glass-cloth backing to make a continuous tape in any desirable width. The tape is then rolled up on a spool for easy handling.

To build something out of the composite tape, a basic "sculpture," which

might be a simple form for a flat panel or have more complex curves than the human body, serves as a mold.

Layer after layer of the tape is laid down on the form in much the same manner that any adhesive tape might be applied. Each layer is placed at a different angle (for instance, zero degrees, 45 degrees, 135 degrees) to enable the laminate to withstand stress from various directions. Composite products may be made in varying numbers of layers depending on the combination of weight, strength, and directional stress they must meet.

Any size or shape:

Boron-epoxy panels have been hand-laid experimentally in from three to 50 or more layers. Fully automated machines are being built that will lay-up boron composite sections in almost any size and shape that can be dreamed up.

When sufficient layers of tape have been placed, the entire form or part is "cured" in an autoclave—essentially a large pressure cooker.

The weight-saving will vary depending on how directional the load requirement is. The least reduction in weight compared to the same application in aluminum would be 45 percent. The reduction can be as much as 75 percent.

A three-layer piece would be only 1/60 of an inch thick. A 32-layer piece would be only 1/6 of an inch thick. But this 1/6 of an inch could be equal in strength to commercial building steel five times thicker, or aircraft-grade aluminum, three times thicker.

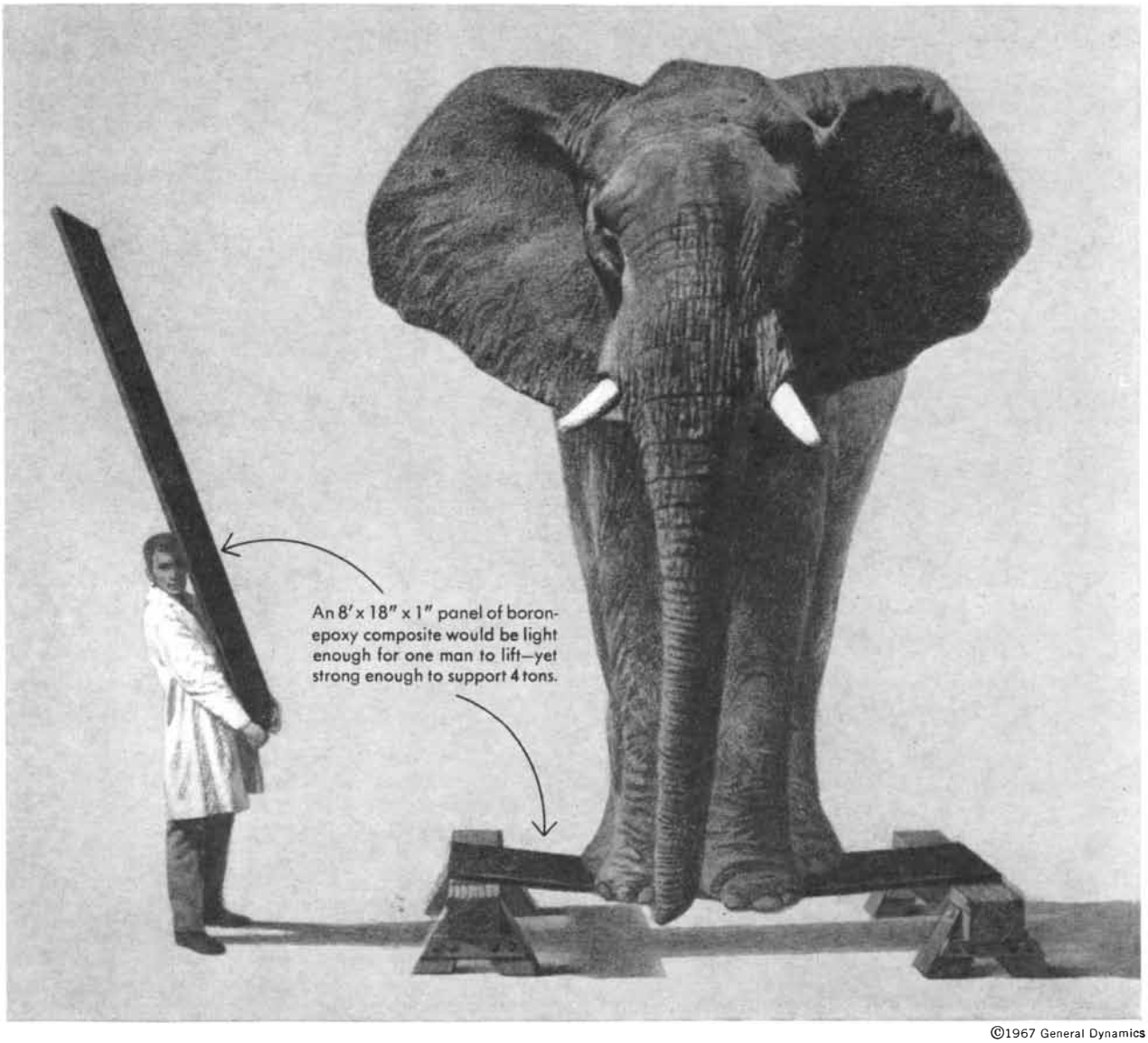
To meet some special conditions of space flight, General Dynamics is experimenting with variations far more exotic than the relatively simple boron-epoxy. These include boron-silicone-carbide filaments embedded in a whole range of metals such as nickel, copper, titanium, and aluminum.

General Dynamics is a company of scientists, engineers and skilled workers whose interests cover every major field of technology, and who produce: aircraft; marine, space and missile systems; tactical support equipment, nuclear, electronic, and communications systems; machinery; building supplies; coal and gases.

Reprints of this series are available.

GENERAL DYNAMICS

One Rockefeller Plaza, New York, New York 10020



50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1917: "Conditions in the present war are changing so rapidly that naval policy has to be alert and very elastic. Secretary Daniels has shown that he is keeping in close touch with developments; and the latest evidence of this is his adoption and earnest support of the proposal to build a large destroyer fleet, additional to the one we already possess. He recommends the expenditure of $350,000,000 for the construction of destroyers and the erection of new yards or the enlargement of existing yards to provide additional facilities for building these most useful craft. Plans have been prepared for a standardized type, and it should be possible to lay down from 250 to 300 destroyers within the year."

"In a notice of the epoch-making sanitary work of Gorgas on the Isthmus of Panama, published in SCIENTIFIC AMERICAN five years ago, the remark was made that 'when malaria can be practically extinguished in such a region, the same thing can be done pretty much anywhere else.' Strange to say, within the United States proper, where malaria is an economic factor of first-rate importance, effective measures to combat it have been desultory or lacking. A National Committee on Malaria has now been formed, and its personnel is highly impressive. General Gorgas is honorary chairman and Dr. Robert Blue, surgeon-general of the Public Health Service, is active chairman. The annual economic loss occasioned by malaria in the United States has been estimated at not less than $100,000,000, and the annual number of cases is supposed to be something like 1,500,000. It is evident that the national committee has embarked on a practical undertaking of the utmost importance."

"The War Department chose wisely in locating the majority of the training camps for our drafted National Army in the South; for they have decided not to send these troops to France until they have been toughened up by several months of training under simulated war conditions. The southern camps will benefit by the warmer temperatures and absence of snow, as compared with the winter conditions in the northern states. The War Department is justified in its determination not to send our drafted army into the trenches until it is in absolutely first-class shape."

"The 100-inch mirror of the new Mount Wilson reflector, the largest telescope in the world, has been taken from the shops in Pasadena, where it was ground and figured, to the top of the mountain. It was carefully packed in a large octagonal box, lined with paraffin to make it dustproof and placed on a specially constructed truck geared to a maximum speed of two miles an hour. A pilot truck preceded the one carrying the mirror, and men also went ahead to repair any weak spots in the road."

"It is very gratifying to learn that the attempt of the German government to wreck the fine merchant ships of the German lines that were interned in American ports, by destroying their machinery, has been foiled. Thanks to the resourcefulness and energy of our shipyards, both naval and private, these ships will be available as transports for our troops to Europe as soon as the troops with their artillery and supplies are ready to sail. For some weeks the American flag has been flying on the *Vaterland*—the world's largest ship—and those two fliers, the 23-knot *Kaiser Wilhelm II* and *Cecilie,* will shortly be in service."

SCIENTIFIC AMERICAN

OCTOBER, 1867: "With great regret we have to announce the death of Elias Howe, Jr., the inventor of the sewing machine. He succeeded in 1845 in producing a working machine, which would cost at least $300, even if manufactured in large quantities. So much opposition was made in this country to his invention that he was compelled to try to find a market in England. He succeeded in disposing of his right for 250 pounds, reserving a royalty of three pounds on every machine sold. On his return to this country he found that machines were being made that infringed on his patent and he immediately took means to defend his rights and was driven into litigation to secure his patent from piracy. This occupied years and demanded large sums of money. In the meantime this invention had begun to pay, and from a

few hundred dollars a year it rose to at least $175,000 annually."

"Among the many remedial agents which organic chemistry has afforded us, quinine occupies the first place, chloroform the second. Without quinine large tracts, indeed whole countries, would simply be uninhabitable for Europeans. If the search for artificial quinine has been as unsuccessful as that for the Philosopher's Stone, it has at least resulted in some great discoveries. It does not appear to be generally known that the first of the aniline colors was discovered during a search for artificial quinine! The cinchona plantations in India, where the plant was recently introduced, are now so flourishing that there need be no apprehension of the supply of quinine's ever failing, and if artificial quinine should now be made, it would have to depend upon its cheapness for its value."

"The boiler explosion which occurred on September 9 in New York was so remarkable that it has attracted the attention of engineers and practical men throughout the country. This boiler, which was eight feet diameter at the bottom, six feet at the top and 14 feet six inches high, and weighing five tuns, exploded about 4 P.M., ascending in the air nearly vertically, with a slight westerly inclination, and falling into the rear part of a house at a distance of 450 feet. Two persons were killed where the explosion occurred—the engineer and the fireman; and two children of Mr. Houseman, by its descent through his dwelling."

"Whenever a boiler explosion occurs, the attention of the coroner's jury is directed to the discovery of imperfection in the material or workmanship. Frequently the engineer and fireman, or the individual who combines both these offices in himself, is removed by the explosion from all opportunity to give his testimony, and the proprietors are unable, if not unwilling, to give light on the subject. Sometimes the engineer or fireman is censured, but seldom is the employer reprimanded. A correspondent says that it is surprising there are not more explosions. He says that in Connecticut the engineer is often required to be his own fireman, to do every 'chore' in and around the whole establishment for $1,50 to $2 per day. He asks, 'Who is going to study and fit himself for an engineer with such remuneration and such duties before him? Why doesn't our State Legislature make a law prohibiting any one from running an engine who is not a competent engineer?' "

The hot dog is said to have been born at the St. Louis Exposition in 1904. There a smart sausage peddler put his frankfurters in a bun to protect his customers' hands.

It turned out to be the most prolific mating in history. Descendants of that first hot dog, in wildly concocted varieties, can now be found wherever people eat. Some 10 billion puppies a year.

The hot dog used to have a skin as tough as rawhide. It split when you cooked it, yelped when you bit it. But not since we skinned it.

We did it with a strippable, cellulose skin you could stuff, cook and remove before packaging. Thus was born the skinless frank.

Similar cellulose casings are used to wrap sausages, turkeys, chickens and hams, preserving their just-butchered freshness right to your table.

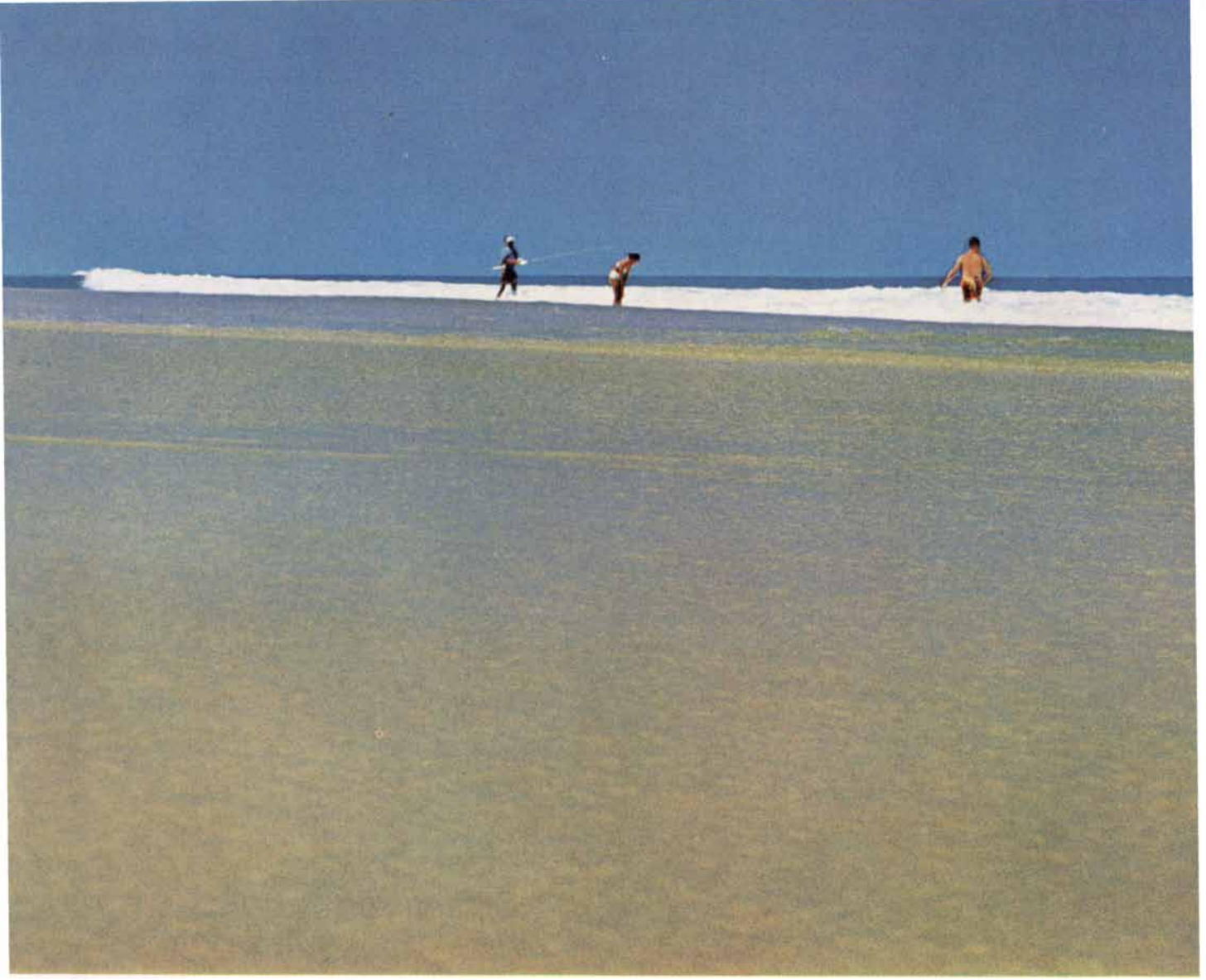
Other cellulose films are used as integral parts of instruments that duplicate the functions of the human organs.

That's what's always happening at Union Carbide. One discovery leads to another . . . and another . . . and another.

UNION CARBIDE

THE DISCOVERY COMPANY

Most ships used to pump oil overboard every time they cleaned their tanks. Then Jersey Standard put in a system to keep this oil out of the sea. Other tanker fleets followed suit. Now a major source of water pollution is almost gone. And a lot of oil is being saved in the bargain.



The last thing you want to strike when you go to the beach is oil.

But too often that's just where you find it. It might have come from a sunken wreck. Or an underwater oil formation. Or most likely from a ship at sea.

In 1964, the chances of its coming from a tanker went way down. And Jersey Standard had a lot to do with it.

Previously, when a tanker cleaned its cargo tanks (or any ship cleaned its fuel tanks), it took in seawater, sloshed it around, and ended up dumping a mixture of oil and water overboard.

This was standard practice. International regulations permitted it so long as it was done far from shore. The amount of oil carried by sea was a lot less than it is now. So the problem wasn't too serious.

But in the last fifteen years the volume of tanker-borne oil has more than tripled. That's why Jersey, with other oil companies, developed a new system to handle mixtures of oil and water.

It's called the load-on-top method. After the tanks are cleaned, the oil and water are separated by adding a chemical developed by Jersey Standard. Only the clean water is pumped overboard. The oil stays behind. In the tanks.

The next load of oil goes right on top of the oil in the tanks. Then, the whole cargo is pumped off at the next port of call.

Jersey tankers—all 126 of them—use the load-on-top method. So do most other major oil and tanker companies around the world—with the result that oil pumped overboard is down 95 percent. And a lot of oil is saved in the bargain.

All of which pleases Jersey. Not to speak of the beach lovers. The birds. And the fish.

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THE AUTHORS

WILLIAM MANGIN ("Squatter Settlements") is professor of anthropology and chairman of the department of anthropology at Syracuse University. He was graduated from that university in 1948, obtained a Ph.D. from Yale University in 1954 and has been on the Syracuse faculty most of the time since then. During the same period he has worked extensively in Peru; his activities have included a study of fiestas and the use of alcohol from 1951 to 1953 and an investigation of squatters from 1957 to 1959. From 1962 to 1964 he was deputy director of the Peace Corps in Peru. He spends a few days each month working as a research associate at the Center for Studies in Education and Development in the Graduate School of Education at Harvard University. Mangin writes: "I have been particularly interested in migration to cities and in problems of education in urban areas. I was the coordinator of a school for dropouts and boys having troubles in school in Syracuse. I was a losing candidate for the Syracuse Board of Education in 1965 and am running again this fall. (I came close.)"

NOEL DE NEVERS ("Liquid Natural Gas") is associate professor of chemical engineering at the University of Utah. He writes that he first became interested in liquid natural gas while studying for his doctorate at the University of Michigan, where "the transportation of liquid natural gas was one of the classic problems used to bedevil graduate students." The problem arises because natural gas is a liquid only at temperatures below −259 degrees Fahrenheit. Later De Nevers worked for the Chevron Research Company, a subsidiary of the Standard Oil Company of California, where he participated in a design study for the transportation of liquid natural gas. After five years with Chevron he went to the University of Utah. His interests include petroleum technology; fluid mechanics, about which he is writing a textbook, and thermodynamics, on which he is preparing educational films.

DAVID E. YOUNT ("The Streamer Chamber") is research associate in experimental physics at the Linear Accelerator Center of Stanford University. His degrees are in physics: bachelor's from the California Institute of Technology in 1957, master's and doctor's from Stanford in 1959 and 1963 respectively. He became an instructor in physics at Princeton University early in 1962 and was made assistant professor in 1964, shortly before leaving Princeton to work on positron scattering at the Linear Accelerator Laboratory in Orsay, France. Yount joined the professional staff at the Stanford accelerator in 1965 and has been participating in photoproduction experiments involving the two-meter streamer chamber.

DESMOND KING-HELE ("The Shape of the Earth") is senior principal scientific officer in the space department of the Royal Aircraft Establishment in Farnborough, England. He was graduated from the University of Cambridge in 1948 with first-class honors in mathematics and has been at Farnborough since then; last year he became the first person to be elected a Fellow of the Royal Society for contributions to space science. King-Hele writes: "I am married, with two daughters aged 10 and 7, and we live on the outskirts of Farnham, looking out over unbroken countryside to the west. Apart from my scientific work on space research I am interested in poetry and literature and in the history of science, particularly the period from 1750 to 1820, as evidenced by my books on the poet Shelley and the poet-scientist Erasmus Darwin. My recreations include playing tennis, writing verse, walking in the countryside and observing satellites in comfort from my back garden, with binoculars and a deck chair."

R. R. PORTER ("The Structure of Antibodies") was recently appointed Whitley Professor of Biochemistry at the University of Oxford and director of a Medical Research Council Unit for research into immunochemistry that is being set up at the university. Previously he had been for seven years Pfeizer Professor of Immunology at St. Mary's Hospital Medical School of the University of London. Porter, who was elected a Fellow of the Royal Society in 1964, studied at the University of Liverpool and the University of Cambridge. From 1949 to 1960 he was a member of the scientific staff at the National Institute for Medical Research in London. He lists his recreations as walking and fishing.

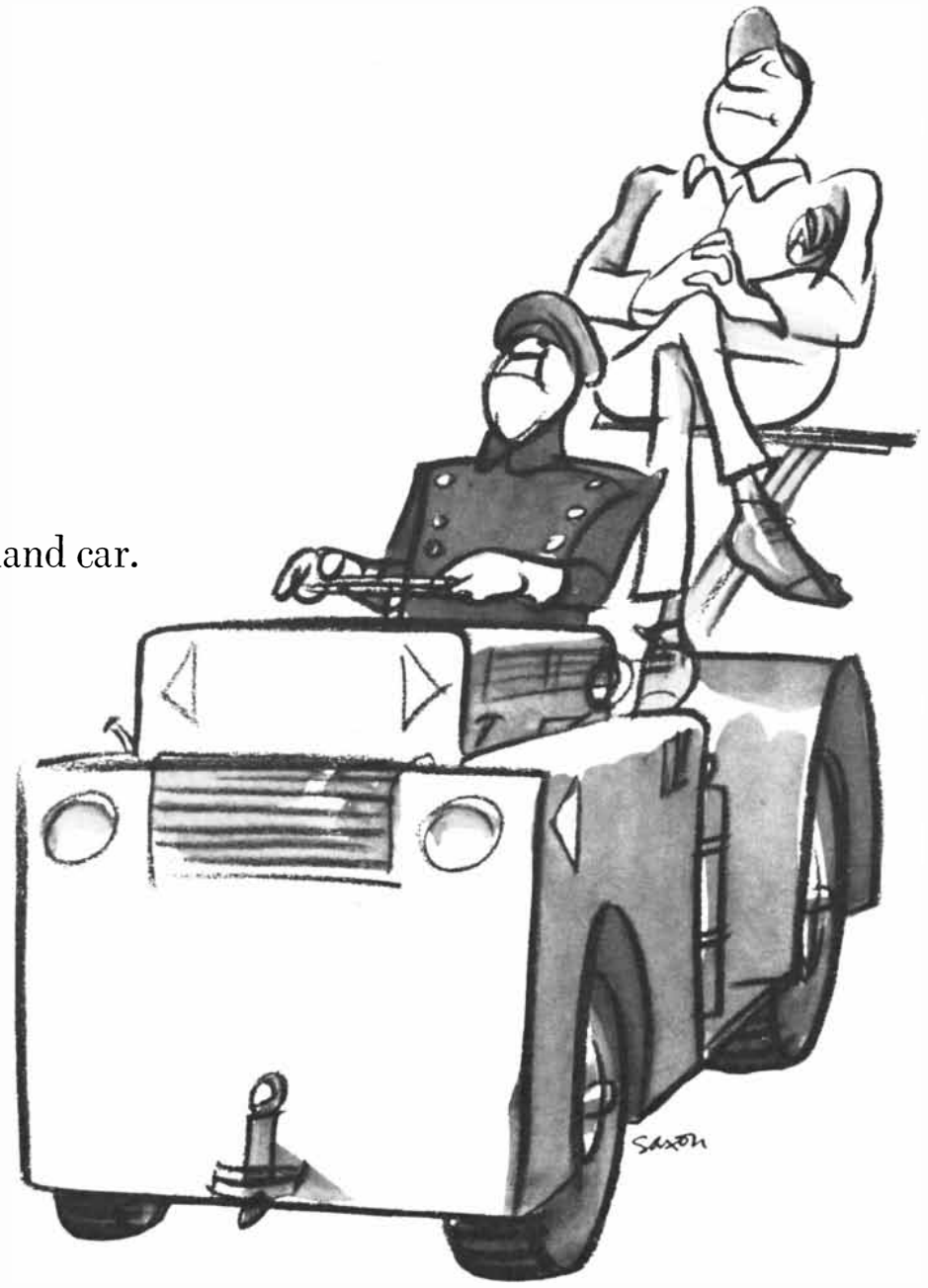
NEAL GRIFFITH SMITH ("Visual Isolation in Gulls") is a zoologist with the Smithsonian Tropical Research Institute, operated in the Panama Canal Zone by the Smithsonian Institution. He went to the Smithsonian in 1964, after receiving a Ph.D. from Cornell University. His undergraduate work was done at St. John's University in New York. Smith writes: "My research interests center on experimental investigations in the field of evolution of specific adaptations in animals, particularly birds. Put less ponderously, I like to manipulate birds to discover how certain 'tricks' they have evolved work and why they have evolved. I am currently investigating some tricks evolved by avian brood parasites such as tropical cowbirds and cuckoos and the evolution of the counter-adaptations by their hosts. The strategies involved are complex and fascinating; among them are egg mimicry and behavior polymorphism."

J. MAYO GREENBERG ("Interstellar Grains") is professor of physics and astronomy at Rensselaer Polytechnic Institute. He has been at Rensselaer since 1952, when he joined the department of physics as assistant professor. Before that he had been a physicist with the National Advisory Committee for Aeronautics from 1944 to 1946, obtained a Ph.D. from Johns Hopkins University in 1948, spent three years teaching at the University of Delaware and worked for a year as research associate at the Institute of Fluid Dynamics and Applied Mathematics of the University of Maryland.

JOHN CERASO ("The Interference Theory of Forgetting") is at the Newark campus of Rutgers University, where he is a member of the department of psychology and of the Institute for Cognitive Studies. He went to Rutgers in September, after eight years at Yeshiva University; for the past two years he was chairman of the department of psychology there. Ceraso writes: "I am a New York City boy and have had all my education there: public grade school in Brooklyn, Stuyvesant High School, Brooklyn College (B.A.) and the New School for Social Research (M.A., Ph.D.). I was a research assistant for three years, working with Solomon Asch and Wolfgang Köhler at Swarthmore College and the Institute for Advanced Study in Princeton. With the Ph.D. I went to Yeshiva. At Rutgers I plan to continue studying the processes involved in recall, especially as they may be involved in thinking."

L. PEARCE WILLIAMS, who in this issue reviews *Humphry Davy,* by Sir Harold Hartley, is professor of the history of science at Cornell University.

Our command car.



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Established 1845 SCIENTIFIC AMERICAN October 1967 Volume 217 Number 4

Squatter Settlements

The shantytowns that have sprung up in developing areas are widely regarded as being sinks of social disorganization. A study of such communities in Peru shows that here, at least, the opposite is true

by William Mangin

Since the end of World War II squatter settlements around large cities have become a worldwide phenomenon. In the rapidly urbanizing but not yet industrialized countries millions of families from the impoverished countryside and from the city slums have invaded the outskirts of major cities and there set up enormous shantytowns. These illegal usurpations of living space have everywhere aroused great alarm, particularly among the more affluent city dwellers and government authorities. Police forces have made determined and violent efforts to repel the invasions, but the tide has been too much for them. The squatter settlements give every sign of becoming permanent.

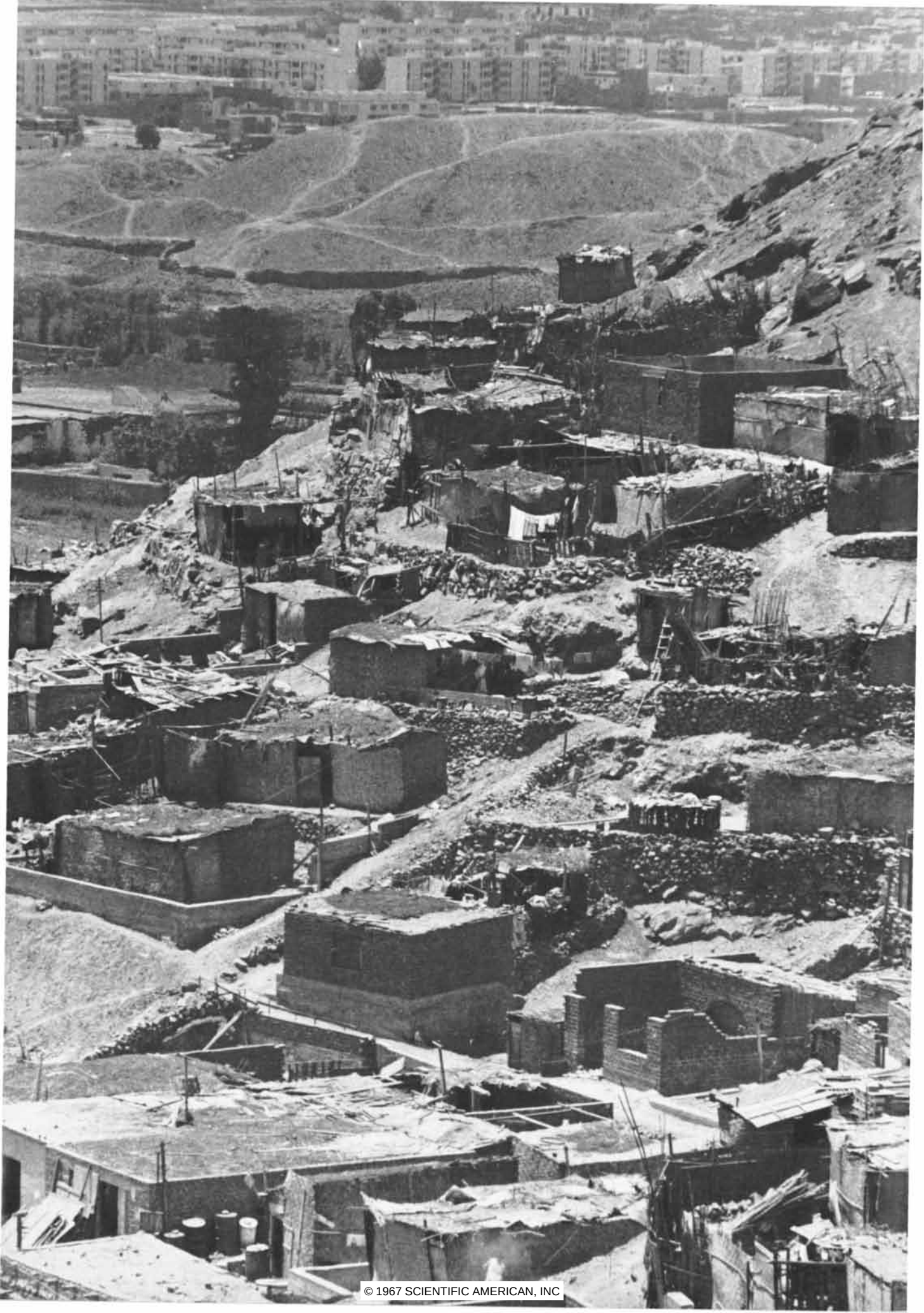
The new shantytowns are without public services, unsanitary and in many respects almost intolerably insecure. Most middle-class and upper-class observers are inclined to regard them as a virulent social disease. Politicians and the police see them as dangerous defiance of law and order. Conservatives are certain that they are seedbeds of revolution and communism. City planners and architects view them as inefficient users of urban real estate and as sores on the landscape. Newspapers treat them as centers of crime and delinquency. Social workers are appalled by the poverty of many of the squatters, by the high incidence of underemployment and low pay, by the lack of medical treatment and sewage facilities and by what they see as a lack of proper, decent, urban, middle-class training for the squatters' children.

The truth is that the shantytowns are not quite as they seem to outside observers. I first became acquainted with some of these settlements in Peru in 1952. Conducting studies in anthropology among villagers in the Peruvian mountains at that time, I occasionally visited some of their friends and relatives living in squatter settlements (they are called *barriadas* in Peru) on the fringes of the city of Lima. I was surprised to find that the squatter communities and the way the people lived differed rather widely from the outside impression of them. Since then I have spent 10 years in more or less continuous study of the *barriadas* of Peru, and it has become quite clear to me that many of the prevalent ideas about the squatter settlements are myths.

The common view is that the squatters populating the Peruvian shantytowns are Indians from the rural mountains who still speak only the Quechuan language, that they are uneducated, unambitious, disorganized, an economic drag on the nation—and also (consistency being no requirement in mythology) that they are a highly organized group of radicals who mean to take over and communize Peru's cities. I found that in reality the people of the *barriadas* around Lima do not fit this description at all.

Most of them had been city dwellers for some time (on the average for nine years) before they moved out and organized the *barriadas*. They speak Spanish (although many are bilingual) and are far removed from the rural Indian culture; indeed, their educational level is higher than that of the general population in Peru. The *barriada* families are relatively stable compared with those in the city slums or the rural provinces. Delinquency and prostitution, which are common in the city slums, are rare in the *barriadas*. The family incomes are low, but most of them are substantially higher than the poorest slum level. My studies, based on direct observation, as well as questionnaires, psychological tests and other measurements, also indicate that the *barriada* dwellers are well organized, politically sophisticated, strongly patriotic and comparatively conservative in their sociopolitical views. Although poor, they do not live the life of squalor and hopelessness characteristic of the "culture of poverty" depicted by Oscar Lewis; although bold and defiant in their seizure of land, they are not a revolutionary "lumpenproletariat."

The squatters around the cities of Peru now number about 700,000, of whom 450,000 live in the *barriadas* of Lima itself. This is a substantial portion of the nation's entire population, which totals about 12 million. Like the squatter settlements in other countries, the *barriadas* of Peru represent the worldwide migration of people from the

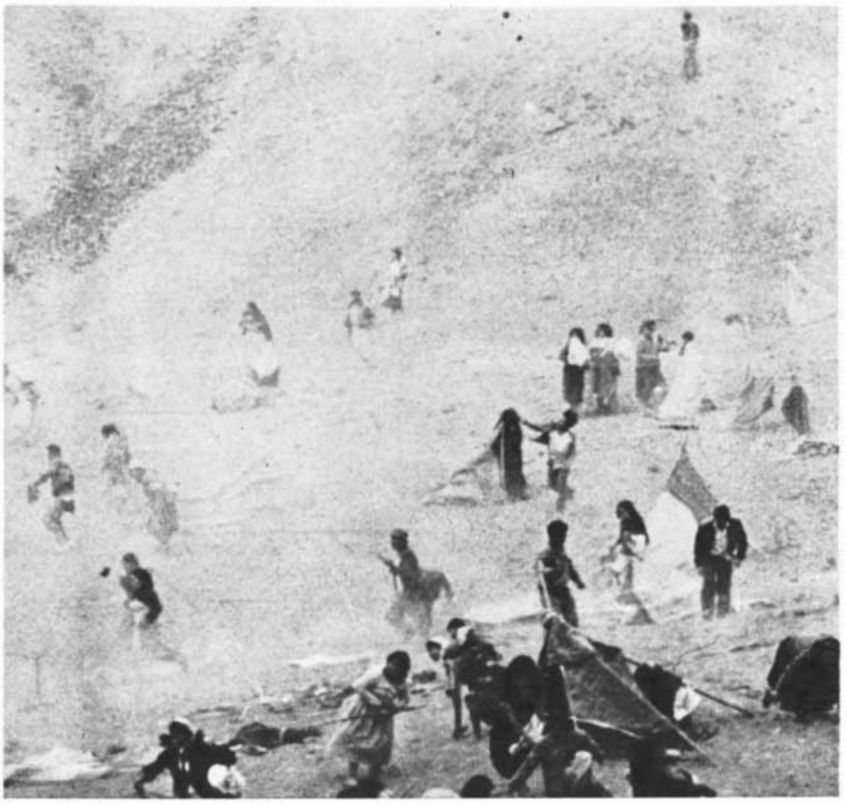


country to the city and a revolt of the poor against the miserable, disorganized and expensive life in the city slums. In the shantytowns they find rent-free havens where they feel they can call their homes and the land their own.

The *barriadas* of Lima began some 20 years ago as clusters of families that had spontaneously fled from the city and set up communities of straw shacks on the rocky, barren land outside. The first, small settlements were short-lived, as the police forcibly drove the settlers off, sometimes with fatal beatings of men, women and children, and burned their shacks and household goods. Nevertheless, the squatters kept returning, as many as four times to the same place. They soon learned that there was greater safety in numbers, and the invasions of land and formation of *barriadas* became elaborately planned, secretly organized projects involving large groups.

The enterprise generally took the form of a quasi-military campaign. Its leaders were usually highly intelligent, articulate, courageous and tough, and often a woman was named the "secretary of defense" (a title borrowed from Peruvian labor organizations and provincial clubs). For the projected *barriada* community the leaders recruited married couples under 30 with children; single adults were usually excluded (and still are from most *barriadas*). Lawyers or near-lawyers among the recruited group searched land titles to find a site that was owned, or at least could be said to be owned, by some public agency, preferably the national government. The organizers then visited the place at night and marked out the lots assigned to the members for homes and locations for streets, schools, churches, clinics and other facilities.

After all the plans had been made in the utmost secrecy to avoid alerting the police, the organizers appealed confidentially to some prominent political or religious figure to support the invasion when it took place; they also alerted a friendly newspaper, so that any violent police reaction would be fully reported. On the appointed day the people recruited for the invasion, usually numbering in the hundreds and sometimes more than 1,000, rushed to the *barriada* site in taxis, trucks, buses and even on delivery cycles. On arriving, the families immediately began to put up shelters made of matting on their assigned lots.



SQUATTERS BATTLE POLICE the morning after an "invasion" of unoccupied land near the Engineering School, north of Lima's city limits. The clash occurred in 1963; although police managed to clear the site temporarily, the squatters soon returned to build there.

More than 100 such invasions to set up *barriadas* have taken place in the Lima area in the past 20 years. The settlers have consistently behaved in a disciplined, courageous, yet nonprovocative manner, even in the face of armed attack by the police. In the end popular sympathy and the fear of the political consequences of too much police violence have compelled the government authorities to allow the squatters to stay. The present liberal regime of President Belaunde tries to prevent squatter invasions, but it does not attack them violently when they occur.

Once a *barriada* has established a foothold, it grows until it has used up its available land. The original settlers are joined by relatives and friends from the provinces and the city. From the relatively flat land where the first houses are built, new shacks gradually creep up the steep, rocky hillsides that overlook the city.

The surface appearance of the *barriadas* is deceptive. At first glance from a distance they appear to be formless collections of primitive straw shacks. Actually the settlements are laid out according to plans, often in consultation with architectural or engineering students. As time goes on most of the shanties are replaced by more permanent structures. As soon as the residents can afford to, they convert their original straw shacks into houses of brick and cement. Indeed, the history of each *barriada* is plainly written in the mosaic of its structures. The new houses clinging to the high hillside are straw shacks; at the foot of the hill the older ones are built of masonry. One of the oldest *barriadas*, known as San Martin, has a paved main street, painted houses and elegant fronts on stores, banks and movie houses.

The squatters improve their houses as they accumulate a little extra money from employment and find spare time. At present the *barriada* communities are far too poor to afford the capital costs of utilities such as water systems and sewers. Water and fuel (mainly kerosene) are transported in bottles or drums by truck, bicycle or on foot. Some houses have electricity supplied by enterprising individuals who have invested in generators and run lines to their clients; a few of these entrepreneurs

HILLSIDE SHANTYTOWN in the Rimac district of Lima is seen in the photograph on the opposite page. Many squatter houses, originally straw shacks, are being rebuilt in brick and masonry whenever the earnings of the owners permit. Visible behind an unexcavated pre-Columbian mound (*top*) is one of the few public housing projects in Peru.

have gone so far as to acquire a television set (on time) and charge admission to the show. In some well-established *barriadas* the electric company of Lima has installed lines and service.

The major concern of the *barriada* people, and the greatest source of anxiety, is the problem of finding steady employment. The largest *barriadas* do provide considerable local employment, particularly in construction work. Many families obtain some income by operating stores, bars or shops in their homes; in the *barriada* I have studied most closely about a third of the households offer some kind of goods for sale. By and large, however, the people of the squatter settlements around Lima depend mainly on employment in the city. Most of the men and many of the women commute to jobs in Lima, working in personal services, factories, stores, offices and even in professional occupations. One *barriada* men's club includes among its members a physician, a bank branch manager, a police lieutenant, four lawyers, several businessmen and two Peace Corps volunteers.

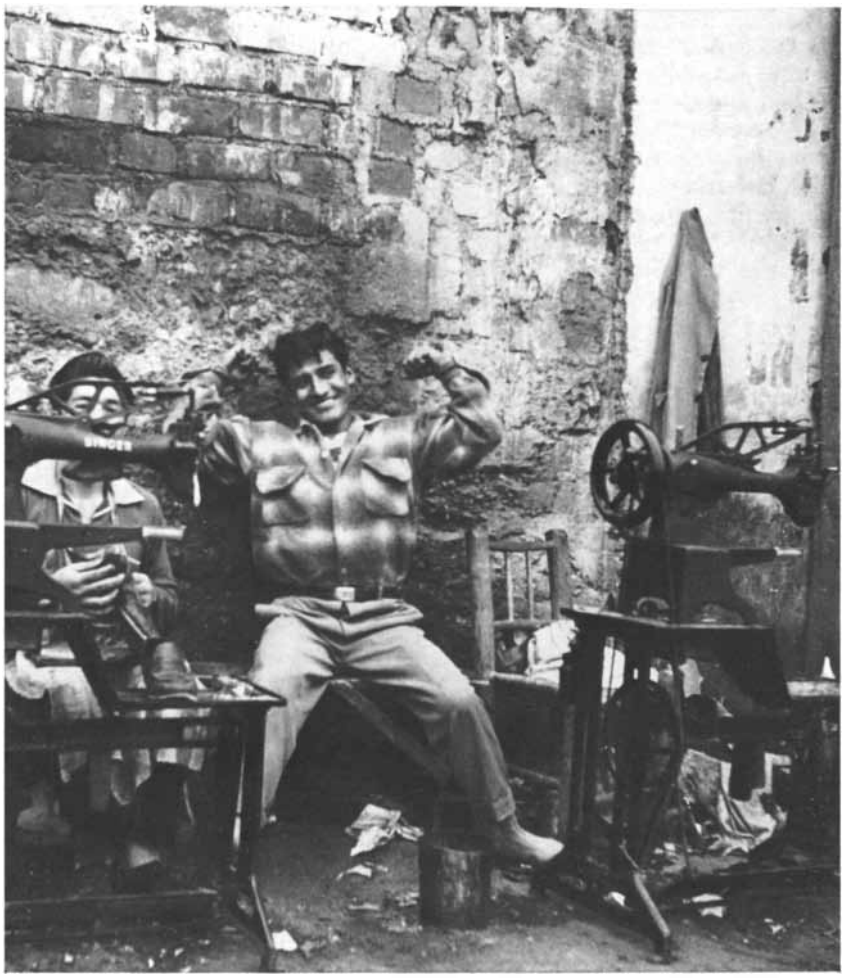
The families that colonize a *barriada* are regarded as "owners" of their lots. As time goes on, many rent, trade or sell their lots and houses to others, using beautifully made titles with seals, lawyers' signatures and elaborate property descriptions—but in most cases with no legal standing. (Actually it appears that in Peru even private property is usually clouded by at least two titles, and much of the land is in litigation.) In the *barri-*

BARRIADAS **of the city of Lima and its outskirts (*color*) shelter some 450,000 squatters who began to establish rent-free communities in 1945 on unoccupied hillsides north and south of the Rimac River. Now major *barriadas* also occupy both sides of the river downstream toward the port of Callao; a 20-kilometer stretch of the Pampa de Comas, including some agricultural land, along the road north to Canta, and hillsides bordering the road south to Atocongo, adjacent to the richest residential district in the Peruvian capital.**

adas, as elsewhere in the nation, disputes over lot "ownership" arise; the claimants appeal variously to the association that runs the *barriada* or to the National Housing Authority, the Lima city government, the police or the courts. The decisions of these agencies generally have only a provisional character. A law adopted by the Peruvian national legislature in 1957 authorized the granting of land titles to *barriada* dwellers, but for several years it was ignored. In 1962 a group of engineers and architects in the National Housing Authority, taking advantage of the preoccupation of the military junta with other matters, passed out land titles to a few hundred families in two of the oldest *barriadas.* Even these titles, however, were marked "Provisional."

In most matters of public concern the *barriadas* are governed by their own membership associations. They hold elections about once a year—a rarity in Peru, where, except in the *barriadas,* no democratic elections of local officials had been held for more than 60 years before the present national government took office. The *barriada* associations levy taxes (in the form of "dues") on the residents, and they usually manage to collect them from most members. They also screen new applicants, resolve land disputes, try to prevent land speculation and organize cooperative projects. For official papers, such as voting registration and certificates of marriage, birth and death, the *barriada* people must resort to the city hall, and their reception by the town clerks is often so uncordial and whimsical that the quest for an essential document may be a heroic ordeal. (I have seen *barriada* birth certificates stamped "Provisional"!) Lacking authoritative police forces of their own, the *barriada* residents usually take their complaints of crimes and misdemeanors to the city police, but the latter seldom do anything more than register the complaint. For schooling of the children the *barriadas* depend mainly on the city's public and church schools. A few have elementary schools of their own, but generally students must commute to the city in the elementary grades as well as to high school and the university. The *barriada* people also have close connections with the city through their jobs, unions, social clubs, churches and services such as medical care, social security and unemployment insurance.

Many of the *barriada* associations have established working relations with city and national agencies and even

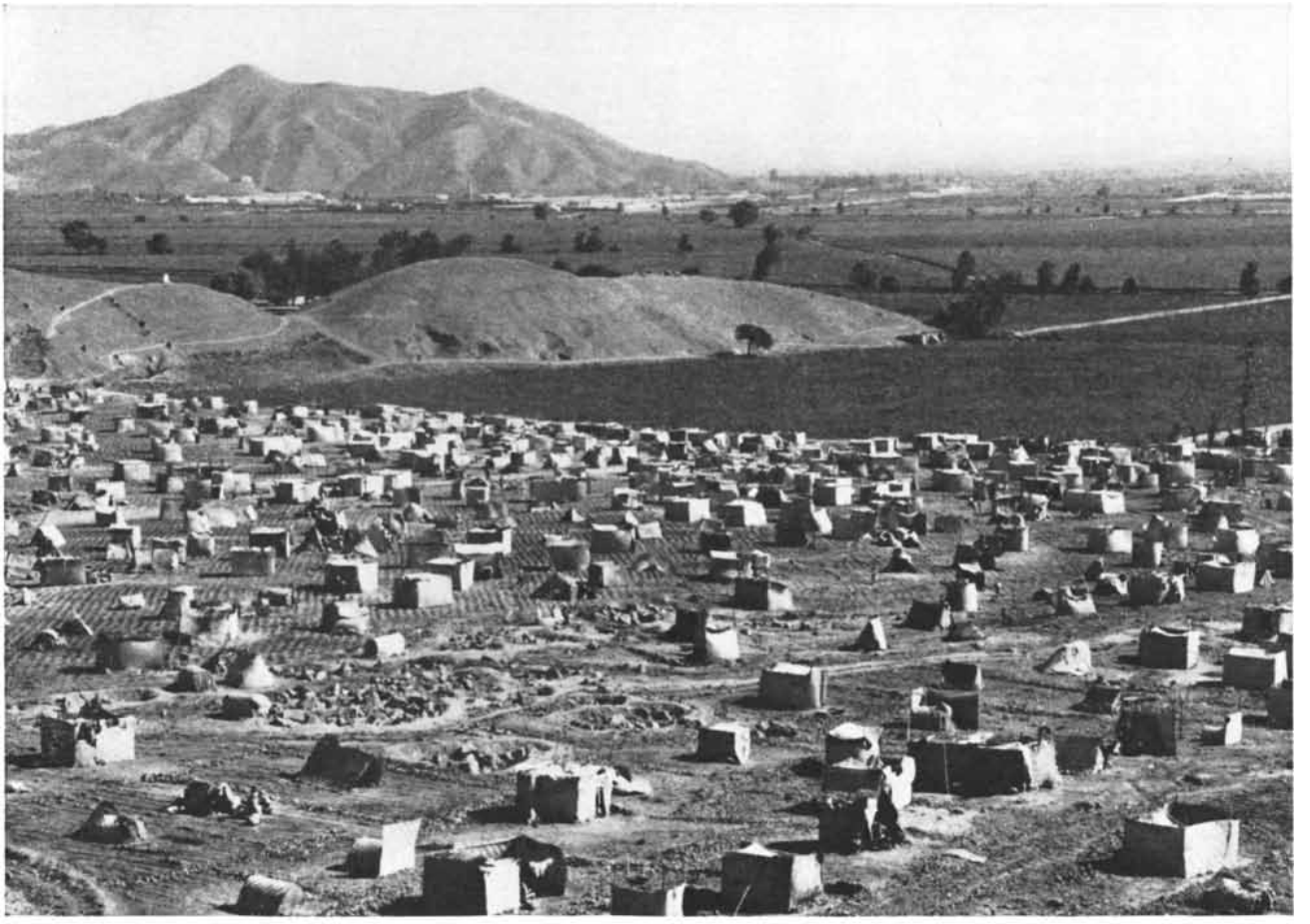


SQUATTER ENTREPRENEURS, residents of a Rimac *barriada,* run a sidewalk cobbler's shop complete with foot-powered stitching machines at the edge of the wholesale market.

AGED BUS is one of the many vehicles, some communally owned, that connect the outlying *barriadas* with downtown Lima. Many squatters commute to steady jobs in the city.

with international organizations such as the Peace Corps and the United Nations. Of the various agencies in a position to assist the *barriadas* perhaps the most important is Peru's National Housing Authority, known as the JNV. The JNV has been beset by power struggles between the national office and local city officials and by other confusions, so that its accomplishments are uneven. In some *barriadas* representatives of the JNV are cheered; in others they are stoned. (In one settlement the agency erected an impressive sign announcing that it was installing a water and sewage-disposal system; after six months had passed with no visible evidence of a start on the project, the residents began to pile fecal matter under the sign, whereupon JNV removed the sign.) Recently, however, the housing agency gave Lima officials authority to adopt and proceed with specific plans, and there is now considerable activity.

WAITING FOR INVASION, a squatter advance party at dawn inspects the previous night's work of blocking out the town plan for a new *barriada*. The rest of the invading squatters, as many as 1,000 in number, will soon arrive in trucks, buses and taxis.

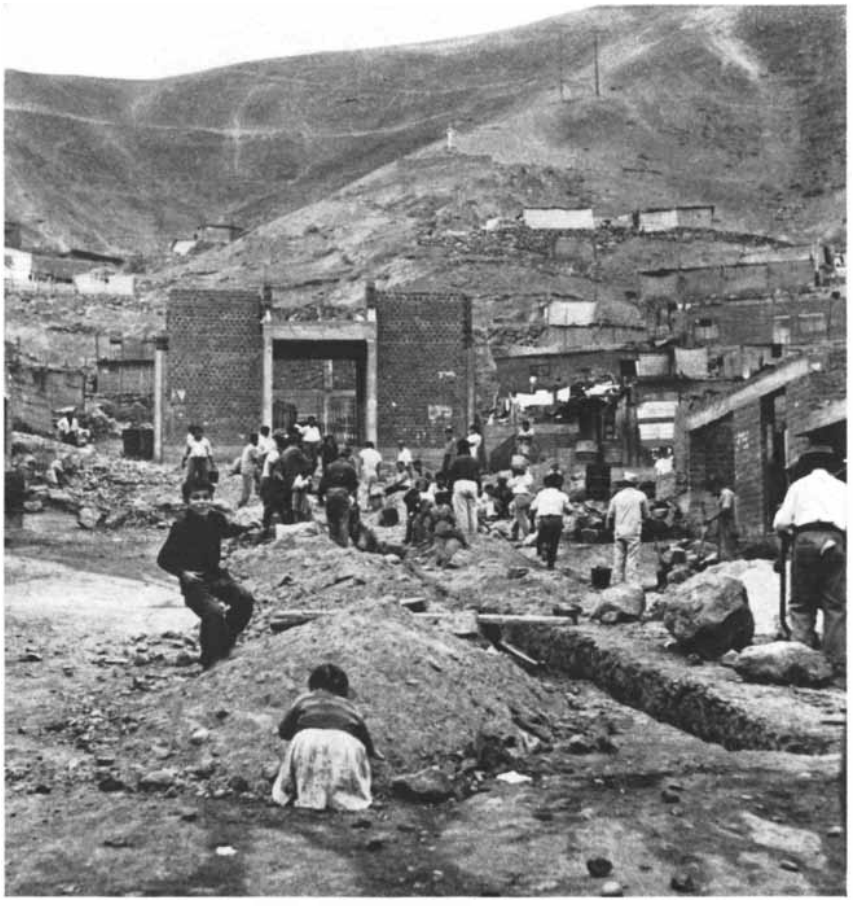


MAT-SHED SETTLEMENT springs up within a few hours after an invasion and a new *barriada* is established. This squatter settlement on the Pampa de Comas is an unusual intrusion on cultivated land; the majority of invasions occupy idle or desert areas.

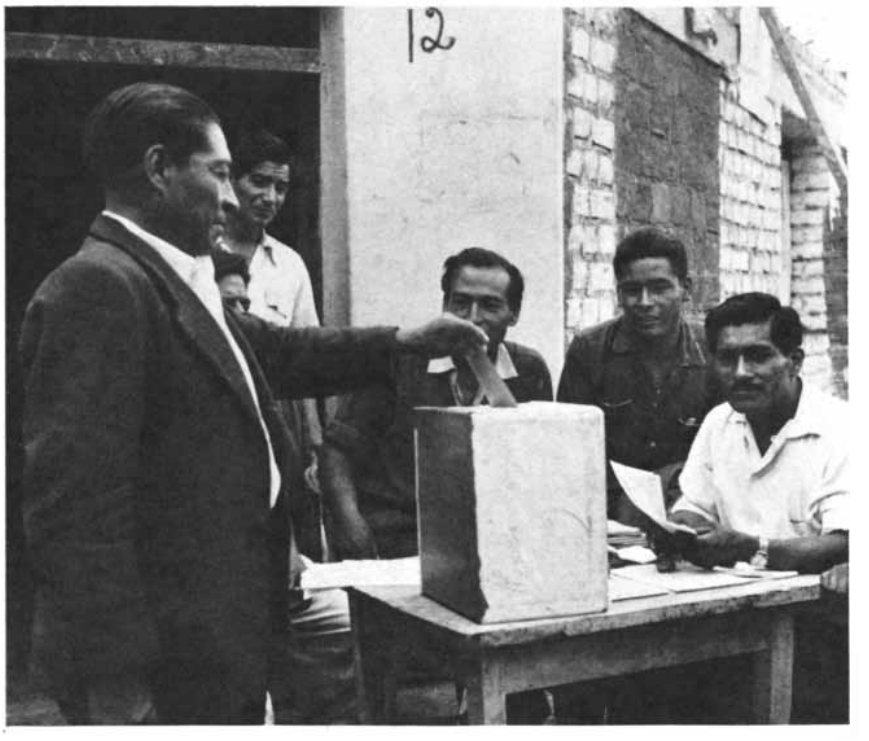
The *barriada* governments have not lacked the usual trouble of municipal administrations, including charges of corruption and factional splits. Moreover, their prestige and authority have declined as the need for community cohesion and defense against attack from outside has been reduced. There is a compensating trend, however, toward replacement of the original associations by full-fledged, official town governments. The two largest *barriadas* in the Lima area, San Martin and Pampa de Comas, now have elected mayors and town councils.

What, if anything, can be learned from the squatter settlements that will be of value in resolving the monumental problems of today's cities and their desperate people? I should like to present some conclusions from our own 10-year studies. They were carried out on a grant from the U.S. National Institute of Mental Health in cooperation with the Institute of Ethnology of the University of San Marcos and the Department of Mental Hygiene of the Ministry of Public Health in Peru, and with the assistance of a group of psychiatrists, anthropologists and social workers. We concentrated on an intensive study of a particular *barriada*, which I shall call Benavides. It consists of some 600 families. Over the 10-year period I have spent considerable time living in the community (in a rented room), interviewing a large sample of the population and examining their attitudes and feelings as indicated by various questionnaires and inventories, including the Rorschach and thematic apperception tests.

I am bound to say that I have been profoundly impressed by the constructive spirit and achievements of the *barriada* people. They have shown a really remarkable capacity for initiative, self-help and community organization. Visitors to the *barriadas*, many of them trained observers, remark on the accomplishments of the residents in home and community construction, on the small businesses they have created, on the degree of community organization, on how much the people have achieved without government help and on their friendliness. Most of the residents are neither resentful nor alienated; they are understandably cynical yet hopeful. They describe themselves as "humble people," abandoned by society but not without faith that "they" (the powers that be) will respond to people's needs for help to create a life of dignity for

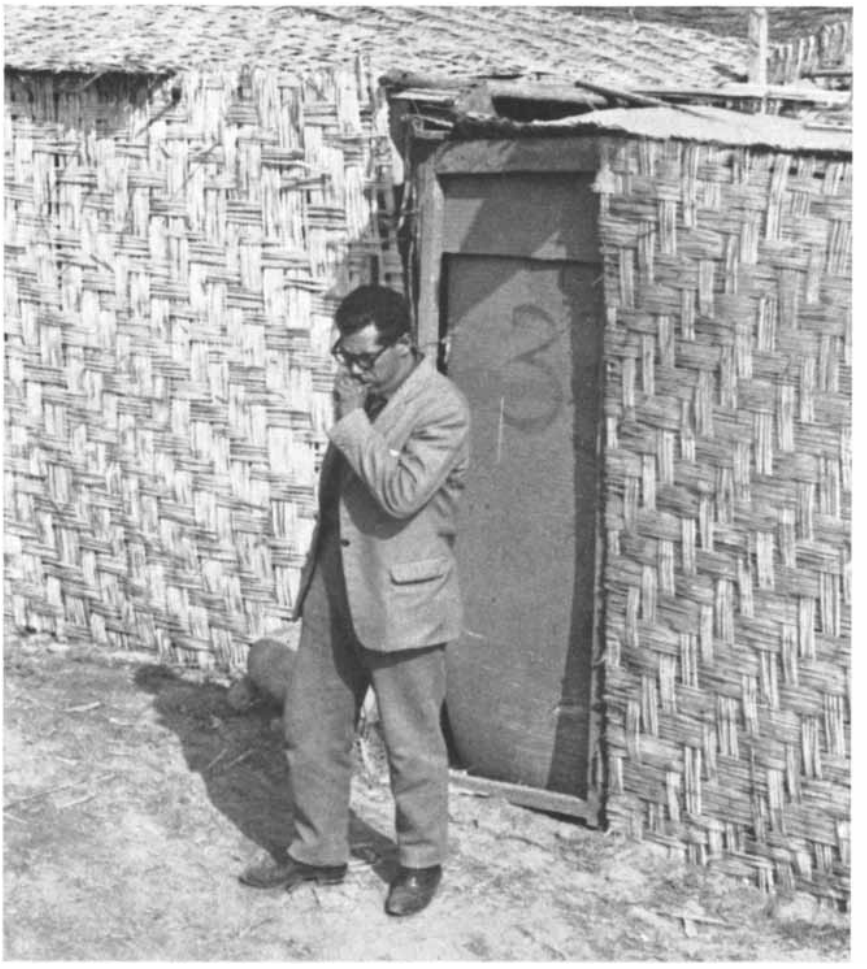


DIGGING A SEWER is typical of squatters' communal ventures in self-improvement. The large brick structure beyond is another communal project, a partly finished church.



YEARLY ELECTIONS are a feature of *barriada* life scarcely known to other citizens of Peru. Until the Belaunde regime took office in 1963, democratic local elections were rare.

SWIFTNESS of a squatter invasion is exemplified by the settled appearance of this quiet lane in a new *barriada* outside Lima. None of these buildings had existed 24 hours earlier.



STREET DOOR of a mat-shed shelter consists of wooden frame and cloth drop that carries the house number. The resident wears conventional city dress. Many in the *barriadas* come to Lima from the country, but most are townfolk fleeing slum rents and slum conditions.

themselves. Recognizing fully that they are living in "infrahuman conditions," the *barriada* dwellers yearn for something better. Given any recognition or encouragement by the government, such as the paving of a street or even the collection of taxes from them, the people respond with a burst of activity in improvement of their homes.

This is not to say that either their spirit or their behavior is in any sense idyllic. There are tensions within the *barriada* and people take economic advantage of one another. They are victims of the same racial prejudice and class inequality that characterize Peruvian society in general. As in the world outside, the *barriada* people identify themselves as city people, country people, coastal people, mountaineers, Indians, Cholos, mestizos, Negroes—and cliques arise. With the passage of time and weakening of the initial *esprit de corps,* bickering within the community becomes more and more common. Charlatans and incompetents sometimes take over leadership of the *barriada*. Moreover, because of the poverty of their resources for financing major projects in community services, the people have a low estimate of their own capabilities and continually look to the government or other outside agencies for solutions to their problems.

Nevertheless, to an outside observer what is most striking is the remarkable progress the *barriada* people have made on their own. They have exhibited a degree of popular initiative that is seldom possible in the tightly controlled community-action programs in the U.S. The *barriadas* of Peru now represent a multimillion-dollar investment in house construction, local small businesses and public services, not to speak of the social and political investment in community organization. Such achievements hold lessons from which more advanced countries may well profit.

Particularly in house construction and land development the *barriada* people have done better than the government, and at much less cost. The failures of governments and private developers everywhere to provide low-cost housing for the poor are notorious. Administrative costs, bureaucratic restrictions and the high cost of materials and construction when government agencies do the contracting generally put the housing rentals beyond the reach of the lowest-income group. Equally disappointing are the failures in the design of this official public housing, which usually disregards the desires and style of life

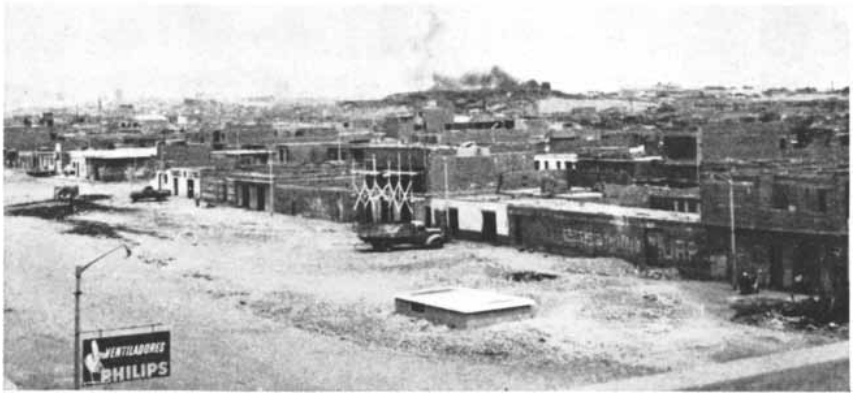
of the people for whom it is intended.

In the Peruvian *barriadas,* by avoiding government control and the requirements of lending institutions, the people have built houses to their own desires and on the basis of first things first. Because they needed shelter immediately, they built walls and a roof and left bathrooms and electricity to be added later. They want flat roofs and strong foundations so that they can add a second story. They want a yard for raising chickens and guinea pigs, and a front room that can serve as a store or a barroom. They have dispensed with the restrictive residential zoning and construction details that middle-class planners and architects consider essential for proper housing.

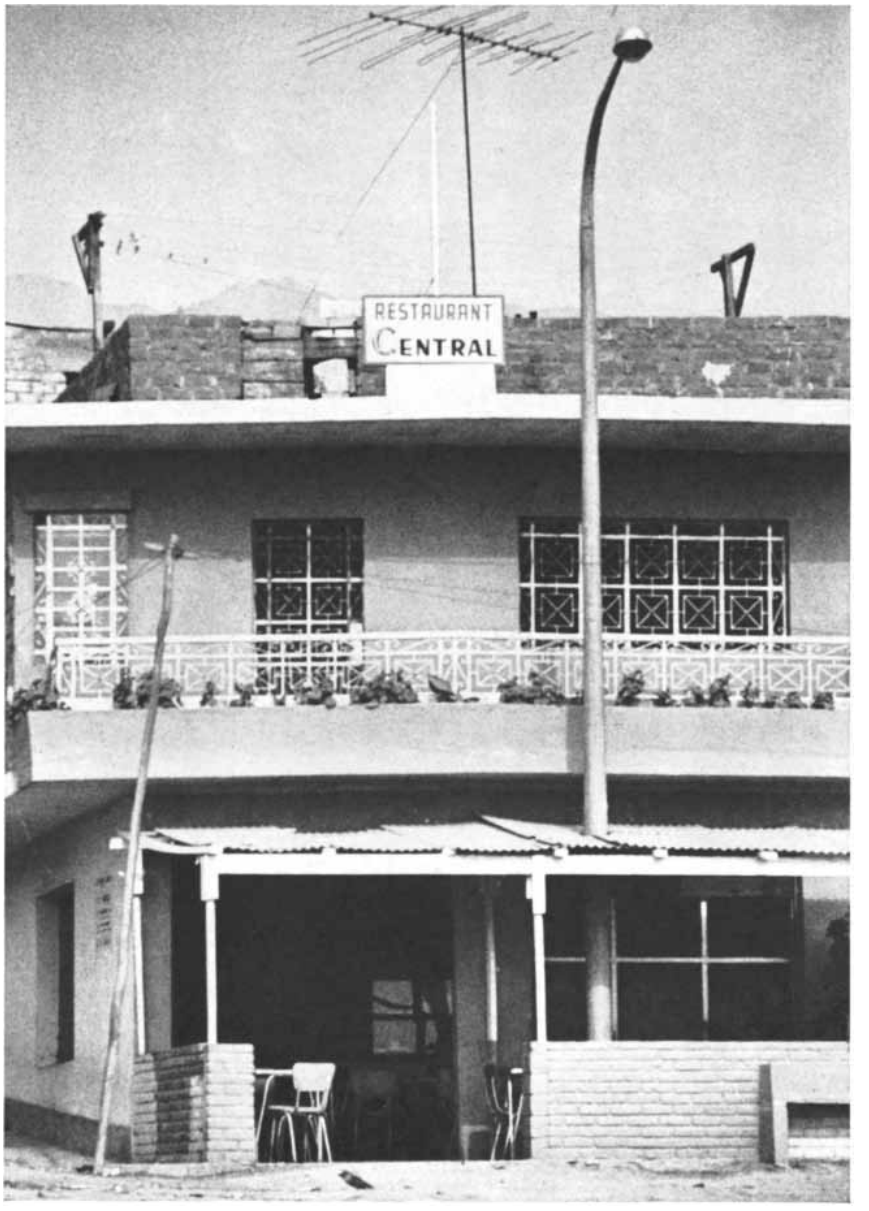
Like most rural people in Peru, the *barriada* settlers are suspicious of large-scale projects and wary of entering into loan or mortgage arrangements. Indeed, throughout South America there is a general dissatisfaction with large housing projects. Costly mistakes have been made in the construction of "satellite cities" and "superblocks." This has led the national governments and other interested agencies to give more attention to the possibilities in rehabilitating existing housing. In Peru the government is now initiating experiments in offering low-cost loans through credit cooperatives, providing optional technical assistance and other services and letting the prospective housebuilder do his own contracting. As John Turner, an architect with many years' experience in Peru, has pointed out, if people are sold land and allowed to do their own contracting and building with optional help, the costs go down for both the clients and the government.

Our studies of the *barriadas* of Peru show, in brief, that these settlements contain many constructive elements whose significance should not be ignored. The people believe that their present situation is far preferable to what they had in the provinces or the central city slums and that they have an investment in their future and that of their children. What we have learned in Peru is supported by investigations of squatter settlements around the world.

The squatters have produced their own answer to the difficult problems of housing and community organization that governments have been unable to solve. In Peru we may have a chance to study what can happen when a government works with popular initiative rather than fighting it.



TRANSFORMED *BARRIADA* was one of the first in Lima. Today most buildings are brick or stone and many have a second story. Although unsurfaced, its avenue is illuminated.



PROSPEROUS ENTERPRISE, the Restaurant Central, is located in the Pampa de Comas. In 1956 it was a one-story bar in a newly built *barriada* that had no electric power. Now there are streetlights and the restaurant has a second story, a coat of plaster and television.

LIQUID NATURAL GAS

Natural gas is now the fuel most commonly used in the U.S., but under certain circumstances it is uneconomical to transport and store. This drawback is being overcome by transporting and storing it as a liquid

by Noel de Nevers

Natural gas has many virtues as a fuel, including the cleanness with which it burns, the reasonableness of its price and the ease with which it can be distributed to consumers who can be reached by pipeline. These attributes have made natural gas the most widely used fuel in the U.S., supplying more energy than either coal or oil. Natural gas nonetheless has a severe drawback: it has large volume per unit of heating value. Until recent years this made the fuel uneconomical to transport to some areas (for example Europe) and difficult to store at the point of use. This drawback can be overcome by liquefaction. If natural gas is brought to a temperature of −259 degrees Fahrenheit, it becomes a liquid with only 1/600th the volume of the gas, and both storage and transport to areas not accessible by pipeline become economically feasible. In recent years the manufacture, transportation and regasification of liquid natural gas have been undertaken by a growing industry. The increasing use of the liquid gas promises to alter the world's fuel economy significantly.

Liquid natural gas, usually called LNG in the industry, consists mainly of methane; it may also contain traces of ethane and propane. It is clear and colorless; in most ways, except for its low boiling point, it is an ordinary liquid. Other liquids with low boiling points—oxygen, nitrogen, helium and hydrogen—have been articles of commerce for as long as 50 years. They are sold in small amounts, however, and can be delivered to consumers by tank truck. The industry making and delivering liquid natural gas is a giant by contrast; it manufactures its product in plants that dwarf those making other very cold liquids, and its means of transport include ocean-going tankers.

Although the Chinese used natural gas as a fuel centuries ago and it was used in the U.S. as early as the 1820's, it was not available in large quantities until the petroleum industry began to grow rapidly about 1890. In most oil fields it is impossible to produce oil without obtaining natural gas as a by-product; the gas is in the same reservoir as the oil and is normally dissolved in it at the high pressures deep underground. When the reservoir is tapped, the gas comes out with the oil.

Natural gas can be economically distributed over short distances by low-pressure pipelines, and it is so distributed within most American cities. Over long distances the large-scale transportation of natural gas by pipeline must be accomplished at high pressure to be economical, since pressure increases the density of the gas and so reduces the size of the pipe needed to transport a given amount. High-pressure pipelines did not exist when the large oil fields of the Gulf Coast and the Southwest were discovered; as a result the fields produced an abundance of natural gas for which there was little use, although a huge potential market existed in the East if a way could be found to get the gas there.

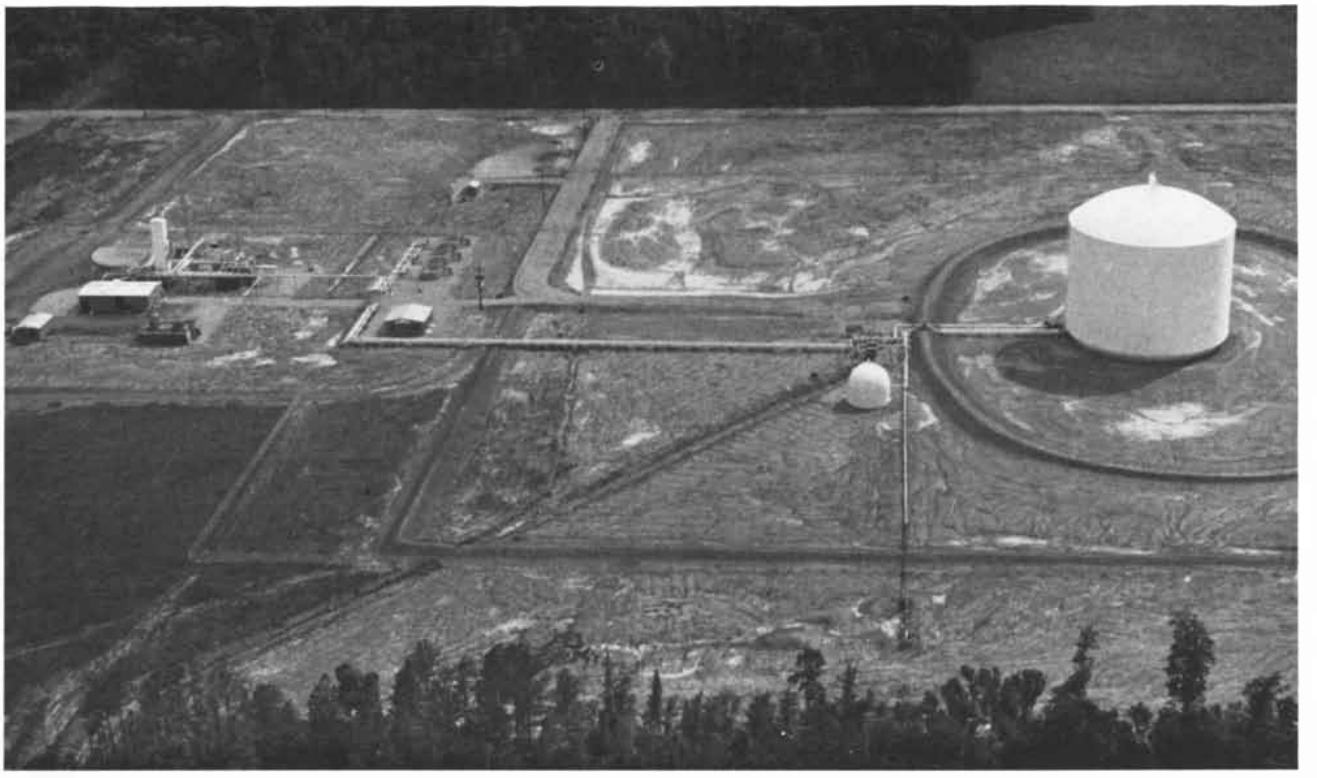
In the circumstances the gas was often just thrown away (by being vented to the air or burned), a practice still encountered in some oil-producing countries that have no markets for natural gas. The gas was virtually given away to the few industries that could be set up near the oil fields to use it. Such industries included plants that burned natural gas to produce carbon black, an aluminum-reduction plant based on electric power generated by gas-burning engines, and a plant that made gasoline from natural gas but failed because the process became uneconomical as the price of natural gas rose.

The situation changed late in the 1930's when techniques were developed for welding pipelines that could carry natural gas at high pressure. Welded high-pressure pipelines, made in sizes up to about 36 inches in diameter and operating at pressures of from 30 to 100 atmospheres, can transport large quantities of natural gas for long distances at a reasonable cost. A 36-inch line can usually supply the entire gas needs of a city with a population of two or three million. The development of high-pressure pipelines brought natural gas to the eastern U.S.

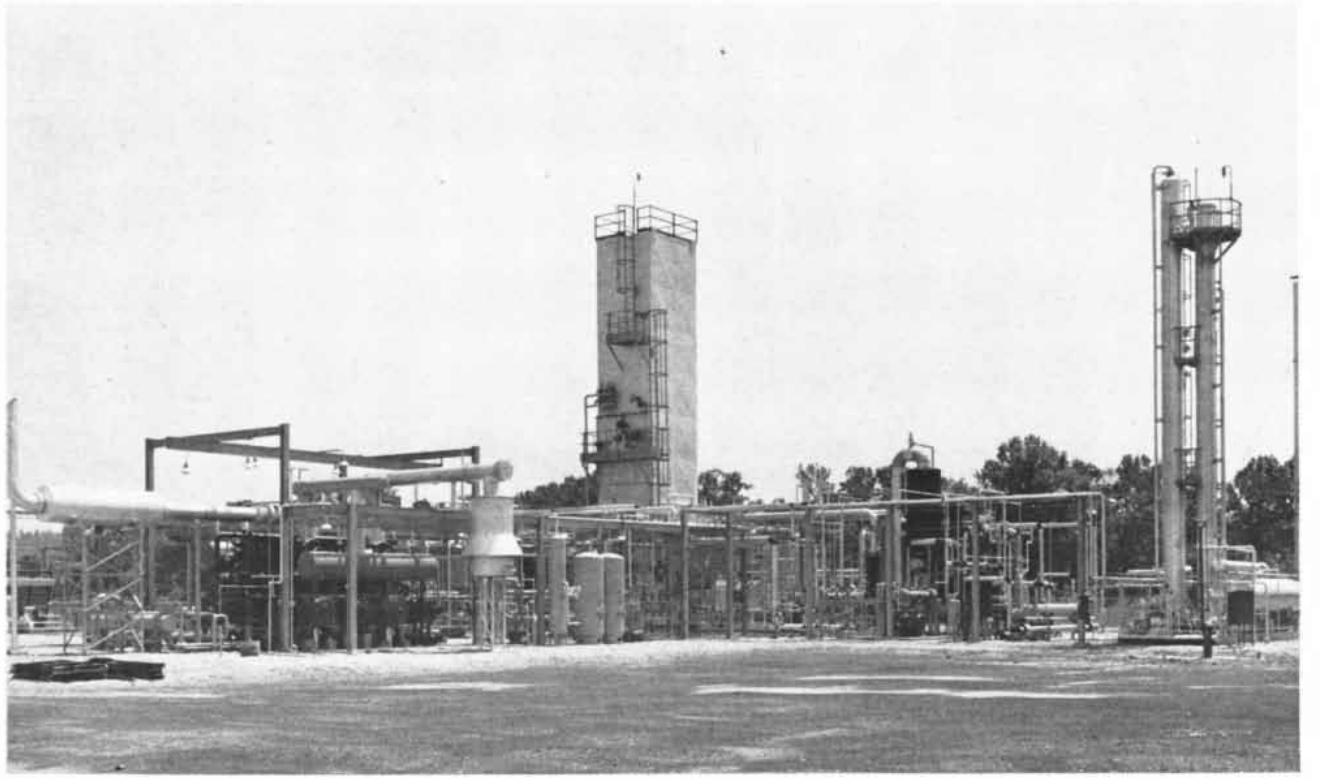
In the course of exploration for oil many fields that contained only natural gas were found on the Gulf Coast and in the Southwest. Until the early 1930's they were considered practically worthless. After the high-pressure gas lines were developed, however, the fields became the principal source of the gas sent to the eastern U.S. The gas fields have the virtue of supplying gas as it is needed; since gas from oil fields is a by-product, its rate of production is tied to the rate at which oil is produced.

The advent of pipelined natural gas for heating in the eastern U.S. gave rise to what is known in the gas industry as the peak-demand problem. The use of gas as industrial fuel is fairly steady all year, but the demand for it in domestic heating is small in summer, larger in winter and very large for from 10 to 20 peak-heating days in the coldest part of the winter. A gas company must obviously be prepared to supply the demand on the peak-heating days.

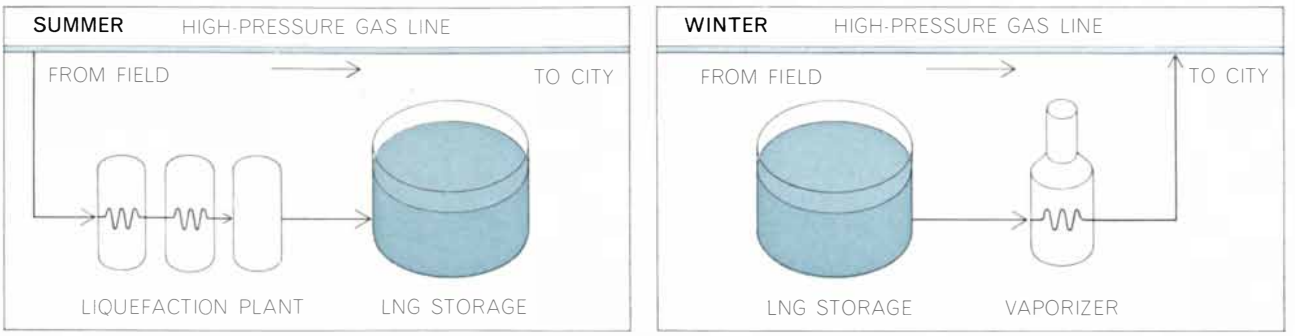
Before natural gas was available the gas companies produced gas from coal or oil and distributed it for use in cook-



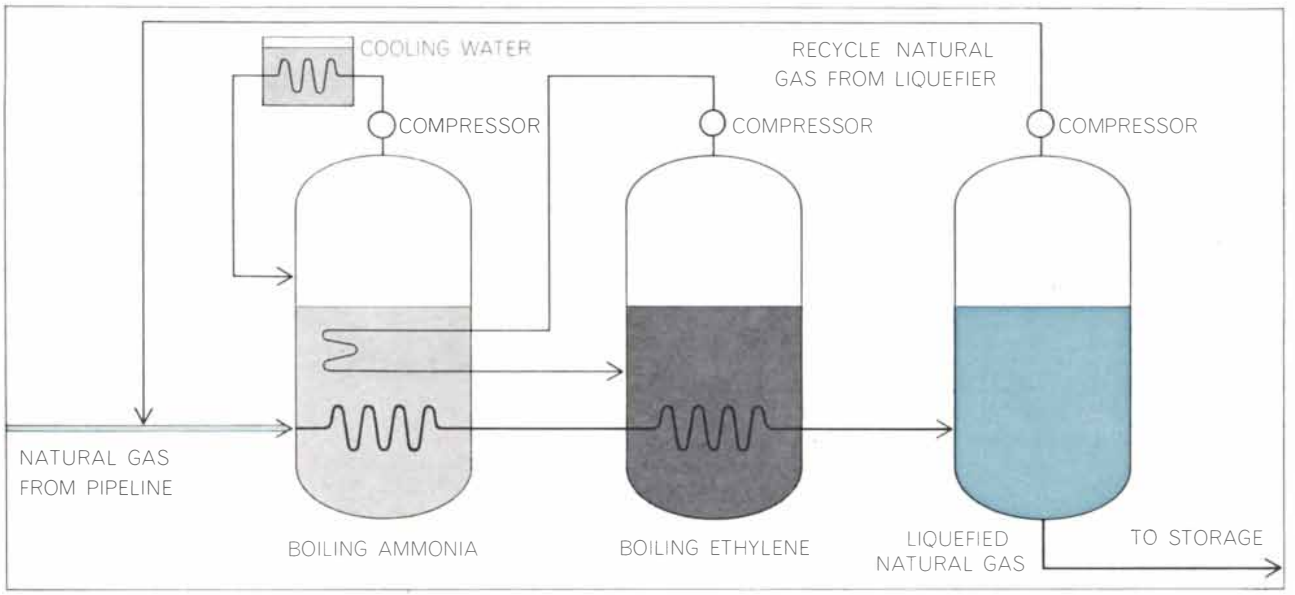
LIQUID NATURAL GAS PLANT near Birmingham, Ala., is operated by Air Products & Chemicals Inc. for the Alabama Gas Corporation to deal with peak demands for natural gas. Main features are the liquefaction apparatus, in and near the tower at left; the storage tank (*right*), surrounded by a circular dike to hold the liquid gas in the unlikely event that the tank should rupture, and three vaporizers near the bend in the road at left center. The vaporizers heat the liquid for distribution in gaseous form as fuel.



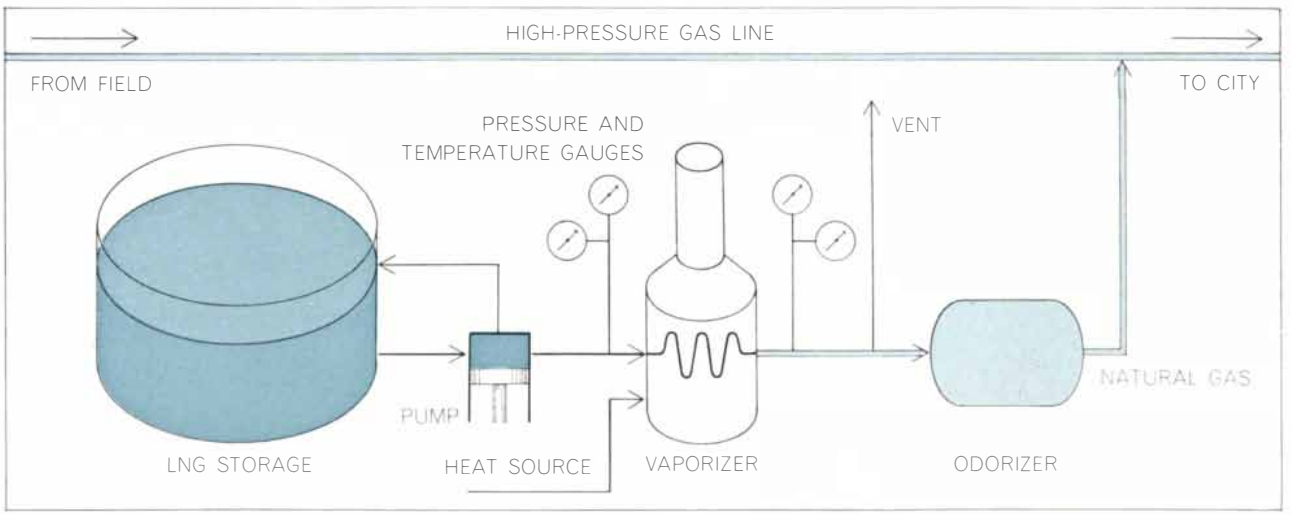
LIQUEFACTION AREA of the Birmingham plant includes the "cold box," which is the tall structure at center; liquefaction of natural gas takes place there. At left is a unit that compresses the propane, ethylene and methane refrigerants, which have progressively lower boiling points and are used stepwise. Column at right removes carbon dioxide, which would freeze and plug the liquefier.



SEQUENCE OF OPERATIONS by which natural gas is liquefied, stored and regasified for use in a city on days of peak demand is depicted schematically. During the warmer months of the year some natural gas is withdrawn from the high-pressure pipeline serving the city. The gas is liquefied and stored. In cold months the liquefaction plant stands idle; liquid is withdrawn from storage as needed and put through a vaporizing process that returns it to the gaseous state; the gas goes into the pipeline for delivery to the city.



LIQUEFACTION of natural gas (*light color*) is most economically done by the "cascade" process, shown here schematically. Gas at high pressure is cooled in turn by two or more boiling liquids with successively lower boiling points; in this case the coolant liquids are ammonia and ethylene. The natural gas is then reduced to a low pressure, at which much of the gas becomes a liquid (*dark color*).



REGASIFICATION involves heating liquid natural gas (*LNG*), which is at a temperature of —259 degrees Fahrenheit, so that it vaporizes and is raised to a safe temperature of 40 degrees F. The odorless gas is then given an odor so that leaks can be detected.

ing and lighting. It cost too much to be used for heating homes, and so the companies did not face the large peak demands of winter. Their problem was a daily variation in demand, which was high at dinnertime and in the early evening and low at other times. The companies solved the problem by building large gasholders ("gas tanks"), which stored the gas produced in off-hours for use during peak hours. The cylindrical gasholder, which was a common sight in industrial areas of cities, accommodated the daily variation in gas consumption by storage at low pressure. To store gas for the seasonal peak demand on cold days would have required enormous gasholders, which would have been not only prohibitively expensive but also depressingly ugly.

One solution to the peak-heating problem would be to make the long-distance gas lines large enough to supply the peak load. The peak load may be twice the average load, however, so that the lines would be operating at an uneconomical half of capacity most of the time. A second solution is for the gas company to agree with some big industrial customers that in return for a lower gas price they will allow their gas to be shut off on the coldest days of winter. Such "interruptable service" agreements are widely used by gas companies. The arrangement reduces the size of the winter peak-demand problem but does not eliminate it.

A third approach is to store surplus gas underground. Near Chicago and in northern California there are some porous geologic formations that have been used to store extra gas brought in by long-distance pipeline in the summer and to return the gas on the peak-heating days in winter. Unfortunately there do not seem to be suitable geologic formations in many areas of the U.S., notably the Northeast.

A fourth approach is to manufacture the peak-heating gas from some storable fuel such as oil or coal. Some companies do so, but the technique appears to be more expensive than the fifth and most interesting approach, which is to store the extra gas for the winter as a liquid. Since liquefaction reduces the volume of the fuel six-hundredfold, quantities that would require vast storage tanks for the gas require much smaller containers for the liquid.

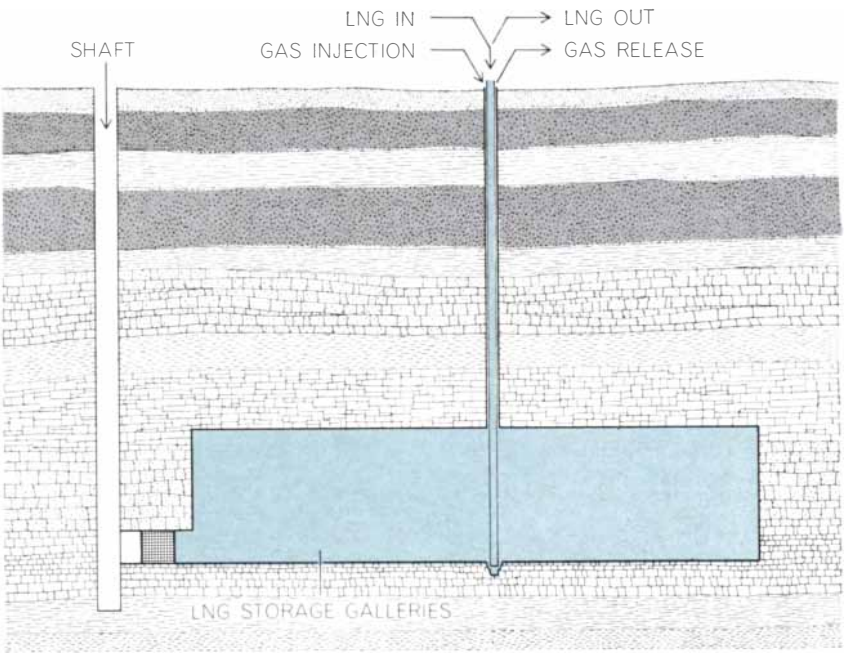
The gas is liquefied by cooling it to the required temperature of −259 degrees F. Although the refrigeration involves no principles basically different from those used in household refrigerators, it calls for several modifications to make it efficient. The main difference between the natural-gas liquefier and a household refrigerator is the wide range of temperatures involved. An ordinary refrigerator cools its interior to about 0 degrees F. at the lowest and dissipates its heat at a temperature of about 100 degrees. The range of roughly 100 degrees is the maximum efficient temperature spread for such a refrigerator. For a refrigerator liquefying natural gas, if heat is dissipated at 100 degrees, the spread is 359 degrees, so that no simple one-stage refrigerator will be practical. Of the numerous schemes that have been proposed, the most practical seems to be the "cascade," which can be regarded as a stepwise pumping of heat from a low temperature to the dissipation temperature using a series of different refrigerants with progressively lower boiling points [*see middle illustration on opposite page*].

To use liquefaction for peak-heating supply the gas company would withdraw surplus gas from the long-distance pipeline for about eight months of the year, liquefy it in the refrigeration plant and store it. During the four cold months of winter the liquefaction plant would stand idle; liquid natural gas would be withdrawn from the tank, vaporized and sent to customers as needed.

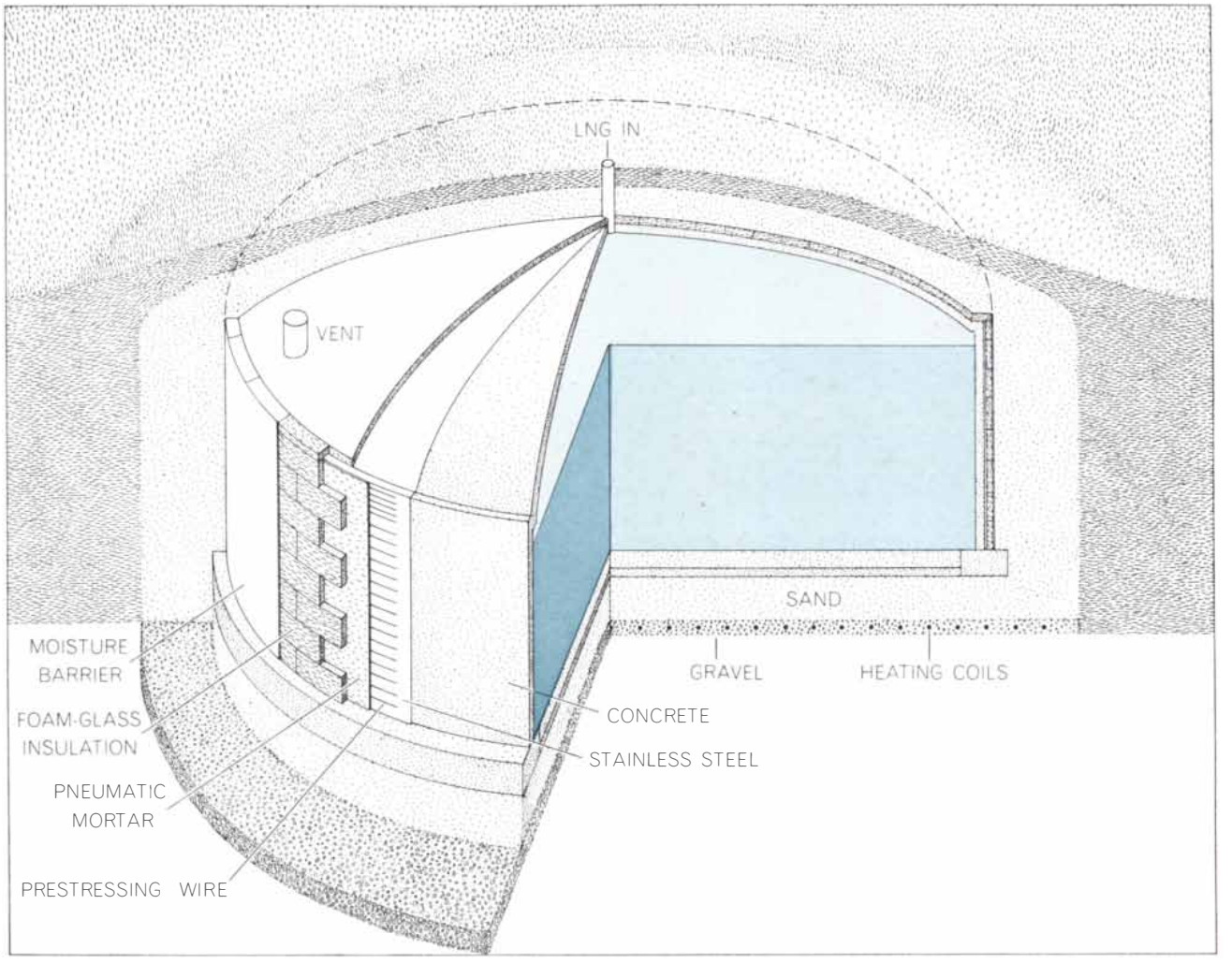
The use of liquid natural gas to meet peak demands was first tried on a commercial scale by the East Ohio Gas Company in Cleveland. The firm built a plant in 1940 and 1941 and used it successfully for several years. On October 20, 1944, however, one of the storage tanks ruptured, spilling about a million gallons of liquid gas that vaporized and ignited. The fire sent flames 2,800 feet in the air, killed 128 people and caused property damage of about $7 million.

The exact origin of the tank failure has never been determined. The most probable cause was the use as tank material of a steel alloyed with 3.5 percent nickel. Such an alloy becomes brittle at the temperature of liquid natural gas. Although the fact that the steel would become brittle was known in advance, the cost of materials that do not become brittle at such temperatures was too high. Moreover, the design of the tank was thought to be safe. Brittleness alone will not cause a tank to fail; some external shock is needed to make the tank rupture. The source of the external shock received by the Cleveland tank has never been conclusively identified.

The explosion at Cleveland set liquid natural gas back many years. In retrospect it is clear that the safety precautions taken with the Cleveland storage tanks were inadequate. For large gasoline-storage tanks it is normal practice to surround the tank with a dike of earth



CAVERN STORAGE of liquid natural gas was worked out experimentally by a French firm receiving liquid natural gas from Algeria. Shaft at left is used to excavate the storage cavern, which is in an impermeable stratum about 150 feet below the lowest water-bearing stratum (*dark gray*). Shaft at right is used for storing and withdrawing liquid natural gas.



UNDERGROUND TANK of prestressed concrete was built by a group of firms to test a method for large-scale storage of liquid natural gas. The heating coils at bottom were needed to keep the ground under the tank from freezing and heaving because of the cold liquid natural gas; heaving could crack the tank. Other elements are mainly concerned with insulating the liquid natural gas.

or concrete, so that if the tank ruptures, the fluid and the almost inevitable fire will be contained in a small area. No dikes were built around the tanks at Cleveland, because it was believed that the liquid gas would instantly vaporize if it spilled on the warm ground and so would not spread by liquid flow. Evidence found after the fire indicated that the liquid did flow down gutters and sewers. Therefore the fire was far more destructive than it would have been if dikes had been built.

As the commerce in interstate shipment of natural gas by pipelines increased, the need for a good solution to the peak-demand problem was also intensified. It was clear to engineers that the idea of storing liquid natural gas would be the most economical solution if the cost of storage could be reduced. Storage in low-alloy steel tanks like the one in Cleveland would have kept the cost low enough, but after the Cleveland fire that type of tank material was unacceptable. Stainless steel, copper and aluminum were acceptable but too expensive.

Three alternative ways of achieving lower storage costs have now been developed. The first is the straightforward metallurgical approach of designing better aluminum tanks or tanks with low-alloy steels (containing about 9 percent nickel) that are satisfactory for low temperatures. The second is the use of prestressed concrete tanks, which have satisfactory low-temperature strength and toughness. The third is the imaginative idea of storing liquid gas in a hole in the ground.

When an ordinary liquid is dumped into a pit, it leaks away through the porous ground or is contaminated by groundwater leaking in. When liquid natural gas at −259 degrees F. is put in a pit, it freezes the water in the surrounding ground, thereby making a leakproof container for itself. Extensive tests have shown that this is a practical approach to the storage of liquid natural gas. Such a storage system was recently built in Carlstadt, N.J., by the Transcontinental Gas Pipe Line Corporation.

The cost of storing liquid natural gas has been lowered appreciably by each of the three new approaches. As a result the idea of storing gas in liquid form appears to be the most economical solution to the peak-demand problem. Several companies in various parts of the U.S. have now built or are planning plants for liquefying, storing and regasifying natural gas to cope with peak demands.

The high-pressure welded pipeline solved the problem of what to do with

surplus gas from the U.S. Southwest, but the problem remains for such gas-producing areas as Venezuela, Alaska, North Africa and the Persian Gulf. Those areas have large surpluses of natural gas and no markets accessible by pipeline. In 1952 the Bechtel Corporation, an engineering firm based in San Francisco, showed that a gas pipeline from the Persian Gulf to Paris was economically promising. It would be 1,800 miles long and would cost about $425 million. Assuming a reasonable purchase price for the gas that was being thrown away in the Persian Gulf, the line could deliver gas to Paris at a price about half that of coal having equal heating value. The line presented no technical or economic difficulties, but it required binding contracts with a number of governments. The project was shelved as being too risky politically. A pipeline from Alaska to the western U.S. has no such drawback but is technically difficult because of the great distance and mountainous terrain.

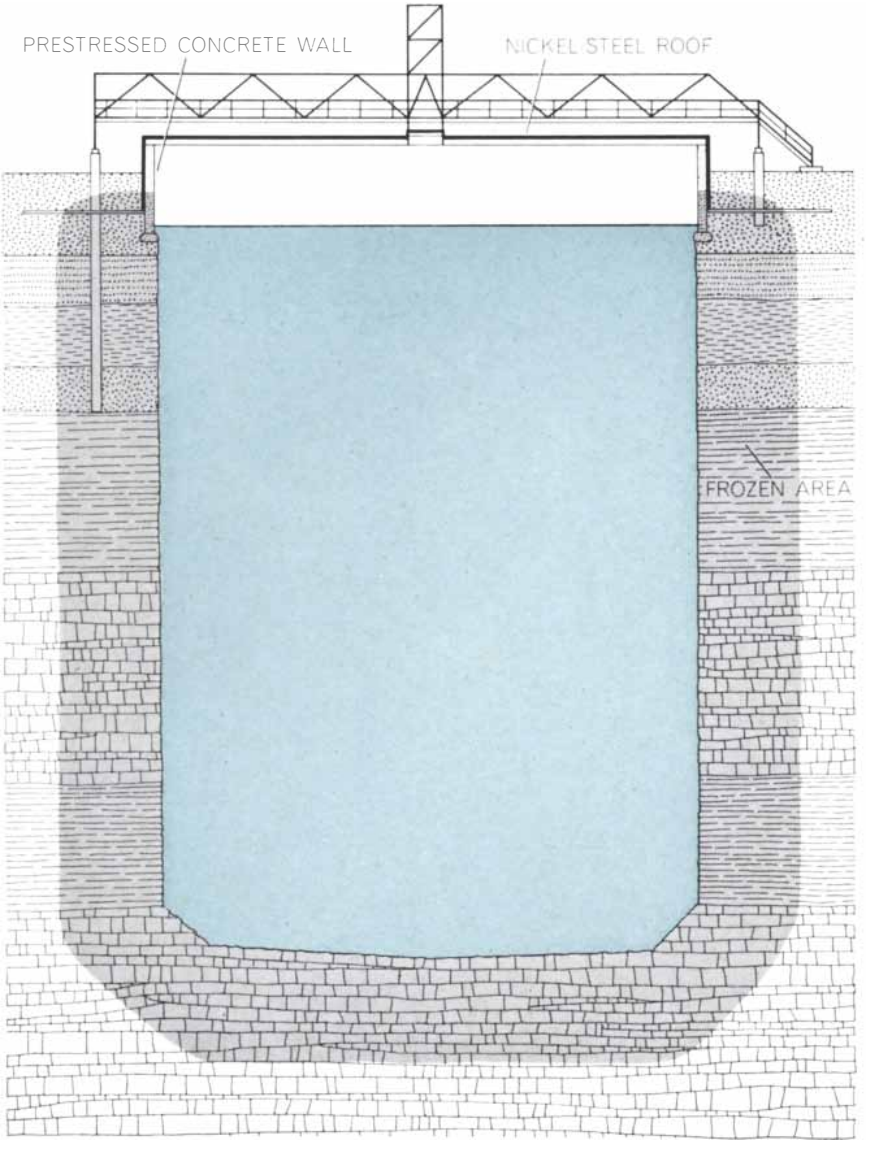
One solution to the gas-surplus problem in such areas is to liquefy the surplus natural gas, ship it by tanker to a consumer area and vaporize it there for delivery to consumers. The system differs from the peak-heating use of liquid gas, which supplies a seasonal demand, in that the liquid transported by tanker supplies the year-round gas demand of the consumer area. The technology of this type of shipment closely resembles that of the peak-demand operation; both have the same types of liquefaction plants, storage tanks and regasification apparatus.

At the consumer area the liquid gas must be vaporized for distribution. This gives liquid natural gas an enormous potential for refrigeration. The cold liquid gas can be used for refrigeration in the course of being evaporated to a gas at −259 degrees F. and then warmed as a gas to 40 degrees F. before going into the distribution system. If all the natural gas used by a typical American city were delivered in liquid form, the refrigeration potential would be roughly equal to one household refrigerator per family. The possibility of combining the transport of liquid natural gas with refrigeration led the Union Stock Yard and Transit Company of Chicago to consider shipping natural gas in liquid form by barges from the Gulf Coast to Chicago and using the gas to freeze meat at the Chicago stockyards. For this venture Union Stock Yard joined with the Continental Oil Company in a new company called Constock.

Although Constock worked out the technical details of the scheme successfully, its economics were not significantly better than the economics of long-distance transport of gas by high-pressure pipeline. It therefore did not appear commercially promising for use between the Gulf Coast and Chicago. In developing the concept, however, Constock had to work out the details of building barges for transporting liquid natural gas, a much colder substance than had ever been transported by water in any significant quantity.

The technology mainly involves insulation and structures. The cold tank must be insulated well enough so that the leakage of heat into it from the surroundings will not cause too large a fraction of the liquid gas to vaporize in transit. The insulation is achieved in land installations by using an inner and an outer tank with a thick layer of insulation between them [*see upper illustration on next page*].

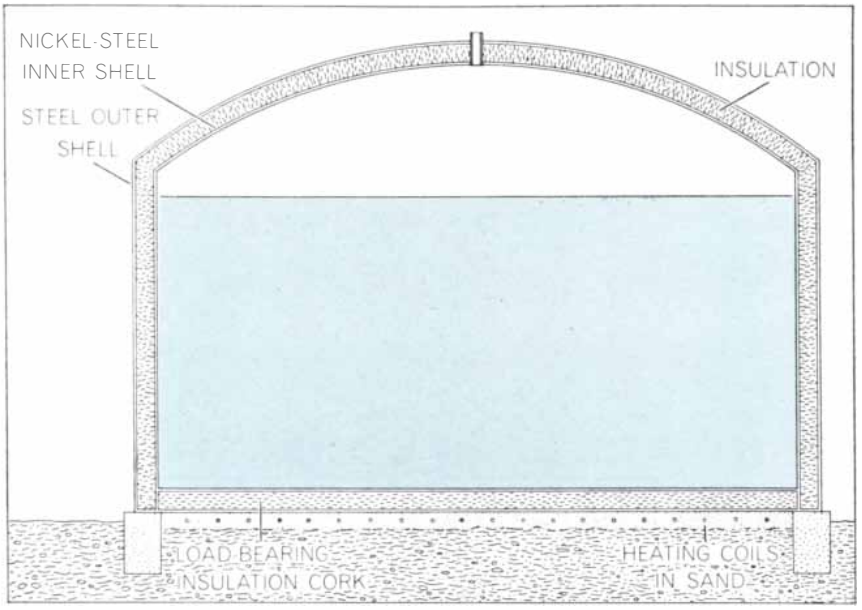
For a barge or tanker a thick layer of insulation is impractical because a large space between the inner and the outer tank would severely limit the amount of cargo space in a vessel of reasonable size. Moreover, a tank on dry land carries a load acted on only by gravity; the inner tank need only be supported from below. A barge or tanker, however, will roll and pitch, so that the inner tanks must be braced against lateral movement. The metal braces that would be used to support an ordinary cargo are



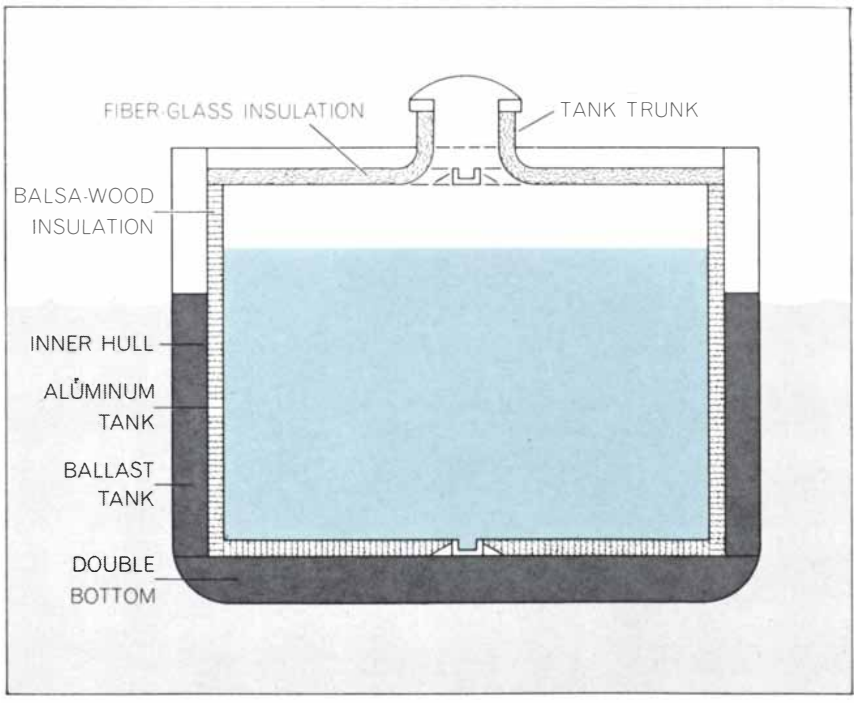
FROZEN STORAGE involves little more than a large hole in the ground. Cold liquid natural gas freezes the water in the adjacent soil, making the soil an impermeable wall. Such a storage tank has been built in New Jersey by the Transcontinental Gas Pipe Line Corporation.

unacceptable for use with liquid natural gas because they would conduct too much heat from the warm outer tank to the cold inner tank. Constock's solution to the problem was an aluminum inner tank separated from the hull of the tanker by balsa wood. The balsa wood is stiff enough to provide structural support for the inner tank and a sufficiently good insulator to prevent excessive heat leakage.

Having developed this technology, Constock applied it to the transport of liquid natural gas overseas. Such transport did not face competition from pipelines. The success of an experimental tanker that delivered liquid gas from Louisiana to England resulted in the formation of a new company named Conch International Methane Ltd., which has entered a joint venture with the governments of Great Britain, France and Algeria to liquefy natural gas in Algeria and transport it to France and England. The surplus natural gas of Algeria is liquefied at Arzew in one of the largest refrigeration plants in the world and shipped by tanker to Canvey (near London) and to Le Havre for storage, vaporization and distribution into the gas systems of England and France respectively.



ABOVEGROUND STORAGE of liquid natural gas usually requires a double-walled tank. The inner wall is made of aluminum or of steel alloyed with 9 percent nickel; the outer wall is steel. Between them is a loose insulation such as fiber glass. The insulation below the tank must be of a firm material, such as cork, in order to carry the weight of the tank.



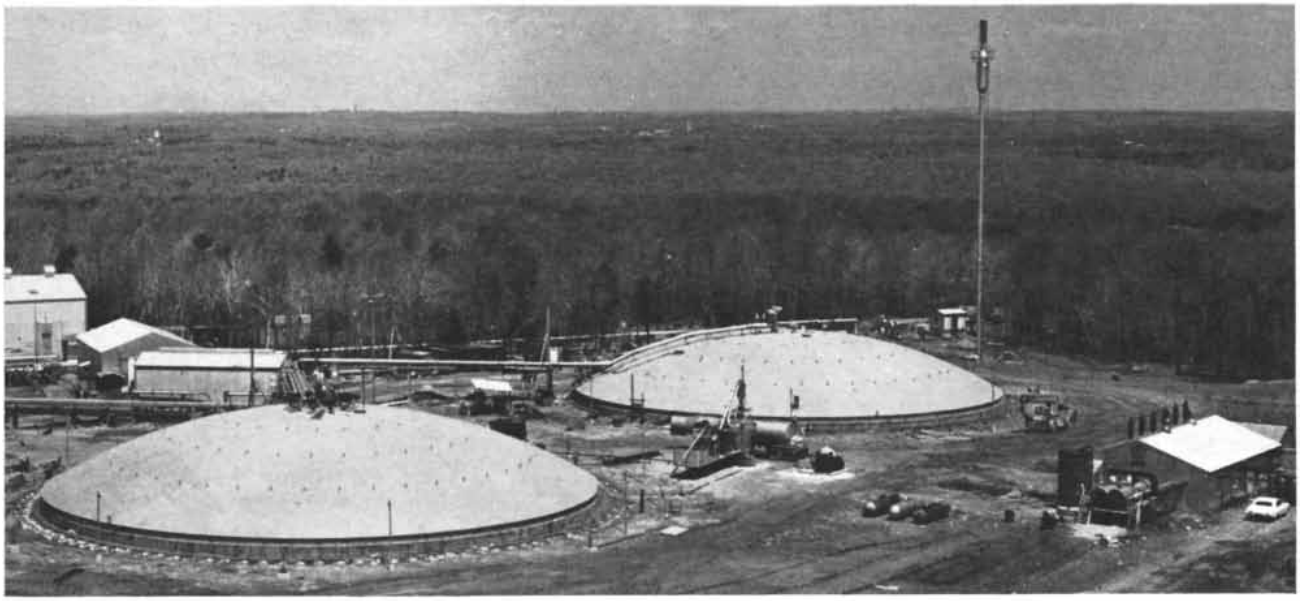
OCEAN TRANSPORT of liquid natural gas is carried out in tankers holding several tanks constructed according to the principles shown here. Balsa wood proved to be the best material for providing both insulation and support for the tank against pitching and rolling.

One aspect of the Canvey operation illustrates a problem that has not been satisfactorily solved, namely that none of the applications of liquid natural gas has included an economically feasible plan for regaining at least some of the energy expended to compress and refrigerate the gas. The Canvey installation was designed to use the low temperature of the liquid gas to generate electric power by a novel application of the theory of heat engines, but so far the economics of the scheme have not been attractive enough to bring it into use. The plan nonetheless indicates the possibilities.

A heat engine fundamentally extracts mechanical work from the difference in temperature between two heat sources or sinks. A typical example is a plant producing electric power by steam. In such an application the high-temperature heat source is the hot gas produced by burning a fuel. The heat boils water at high pressure to produce steam; the steam runs a turbine that generates power. At that point the steam, now at low pressure, goes to a condenser, where a low-temperature heat sink (usually water from a river or lake) converts the steam back into water, which is returned to the boiler to begin another cycle.

In the Canvey scheme water from the Thames would be the high-temperature heat source. It would boil propane, and the propane vapor would drive a turbine. The low-pressure propane would then be condensed by cold liquid natural gas and returned to the boiler. The cycle would produce power and also supply the heat needed to vaporize the liquid gas. Because the scheme has not proved economically attractive, however, the vaporization is accomplished by circulating water around coils containing liquid natural gas, and the refrigeration

STORAGE FACILITY at the liquid natural gas plant of the Tennessee Gas Pipeline Company in Hopkinton, Mass., involved excavating two cylindrical pits, each 172 feet deep and 135 feet wide. The pits were cut into granite at the bottom, lined with concrete at the top and roofed over; they then became storage reservoirs for liquid natural gas. Combined capacity of pits is 40 million gallons.

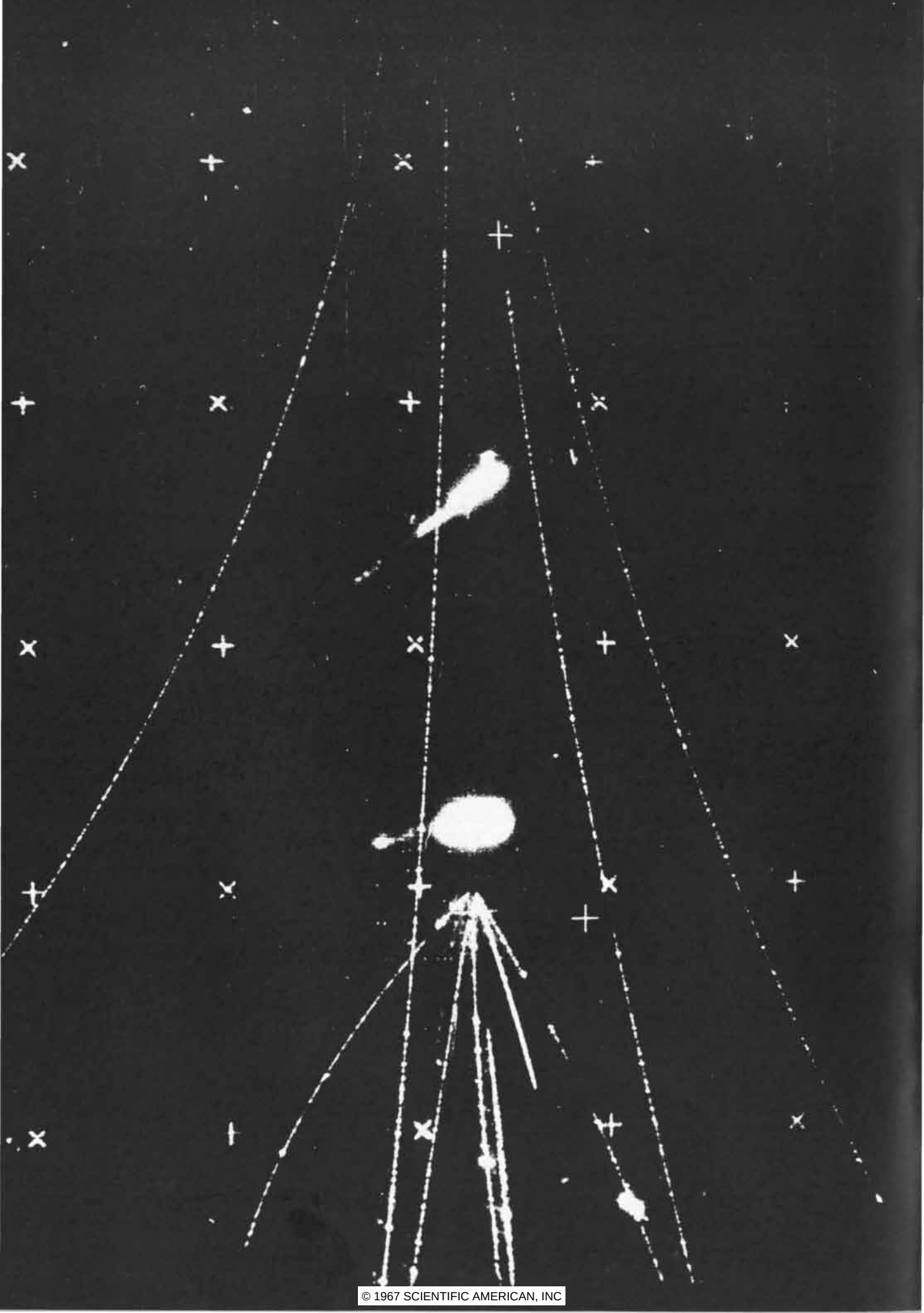


FINISHED TANKS at the Hopkinton plant looked like this when double-walled steel roofs were built over the pits shown in the photograph at the top of this page. The plant can liquefy as much as 12.5 million cubic feet of natural gas a day for storage in the two tanks.

potential of the liquid gas does nothing more than cool the water.

Apart from the power plan the shipment of liquid natural gas from Algeria to England and France has been a technical and economic success. As a result several similar schemes are under investigation or development. They include the shipment of liquid gas from Alaska to Japan and from Venezuela and Saudi Arabia to Europe, as well as a plant (three times the size of the one at Arzew) being built in Libya to supply Italy and Spain. For Japan and Spain, which have no substantial supply of natural gas, the availability of liquid natural gas could give rise to economic effects as far-reaching as those resulting from the introduction of cheap natural gas in the northeastern U.S. Northern Europe may obtain its cheap natural gas from the natural-gas fields recently discovered in the Netherlands and in France rather than from liquid gas.

Beyond the domestic and industrial uses of liquid natural gas in stoves and furnaces lies the possibility of employing it as a fuel for supersonic jet aircraft. The National Aeronautics and Space Administration has been looking into this possibility for a number of years. Recently some 80 representatives of the aviation, cryogenics and gas industries met at the Institute of Gas Technology in Chicago to discuss the prospects; they agreed that, although the technology of delivering liquid natural gas to aircraft and vaporizing it in flight has yet to be fully worked out, liquid gas offered two important advantages over the fuels of the kerosene type now used by jet aircraft. First, it has 13 percent more heating value per pound, which makes a significant difference in payload. Second, its refrigeration potential can be used to cool turbine blades, allowing a higher flame temperature and increased engine efficiency. These two advantages could lead to a reduction of up to 30 percent in the cost of operating a supersonic transport.



THE STREAMER CHAMBER

A new kind of particle detector is in use at the two-mile Stanford linear accelerator. In it the path of a particle is traced by small sparklike "streamers" in a gas between high-voltage electrodes

by David Yount

The effort of physicists to resolve matter into its ultimate constituents and analyze the nature of the elementary particles depends on two related tools, both equally important. On one hand there are the particle accelerators, which are probing matter with ever increasing vigor and producing more and more complex events. Coupled to this family of tools is a complementary and indispensable partner: the particle detectors, which are essential not only for identifying the particles but also for studying their interactions. Both instruments have advanced together. As new accelerators of higher energy and intensity have been built, they have been matched by new detectors endowed with an improved capacity for picturing events in the subatomic realm. The detectors have been so central in atomic studies that one can evoke a nostalgic review of the history of particle physics by listing the particle detectors: the cloud chamber, the Geiger counter, the nuclear photographic emulsion, the scintillation counter, the bubble chamber, the spark chamber. Now a new and very promising particle detector has been added to the family: the streamer chamber.

Before describing this new device it will be well to review the principles underlying the detection of the invisible elementary particles. The first step is to intercept the particles in some kind of matter—a gas, a liquid or a solid. When an energetic charged particle passes through matter, its collisions with atoms in its path ionize the atoms, thus leaving a residue of free electrons and positive ions. In the "counter" types of detector this "signal" is amplified and converted into an electric pulse that can indicate not only the presence of the particle but also its direction, its momentum (mass times velocity) and even its identity. Modern counters can record such events (that is, the arrival of single particles) at rates of up to 10 million or more per second.

In order to study the nature of the particles, one wants a great deal more information, particularly concerning their interactions in collisions and the possible disintegration or transformation of the colliding particles into new species. Such information is supplied by detectors of the "track" type, which show the actual track of the incoming particle and the birth and career of each newly created particle.

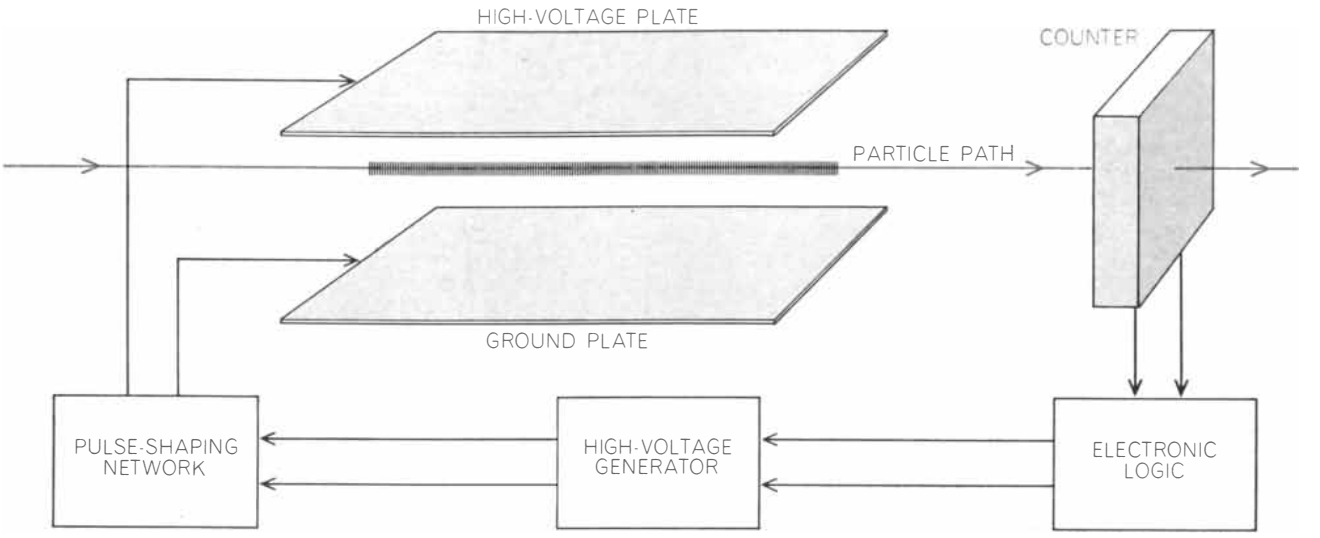
The first detector of this kind was the cloud chamber, invented by C. T. R. Wilson in 1911. The key to devising a track detector lies in finding a way to amplify the particle's ionization trail and make it visible. Amplification is essential because the number of ionizing collisions is relatively small (for example, a particle passing through hydrogen gas typically produces only about 10 ions per centimeter along its path) and the ions themselves, of course, are submicroscopic. Wilson amplified the trail to visibility by causing droplets of water to condense on the positively charged ions. The chamber is filled with a vapor and can be equipped with a Geiger counter that triggers an abrupt expansion and cooling of the chamber when a particle traverses it; the supersaturated vapor then condenses on the ions marking the track. A camera activated by the triggering mechanism photographs the track.

The triggering feature of the cloud chamber is one of its most valuable attributes. The drive system can be set to expand the chamber and to make a picture only when an interesting event occurs, which greatly simplifies the problem of scanning photographs to find significant events. In this respect the cloud chamber has a considerable advantage over a track detector such as the photographic emulsion, which records an accumulation of all kinds of particle tracks indiscriminately and therefore requires long, tedious examination with a microscope to disentangle the tracks and discover those that may be of interest.

The cloud chamber, however, has serious limitations. Since the medium through which the particles travel is a gas, interactions are so infrequent that many particles pass through without producing interesting events. The cycling time is very long: after each picture it typically takes 20 seconds to clear the chamber for another photograph; consequently the detector cannot record a rapid series of events from a high-energy particle accelerator. Furthermore, a track in a cloud chamber persists for a considerable fraction of a second—long enough to confuse the picture with unrelated tracks.

The bubble chamber, developed in

STREAMER-CHAMBER PICTURE resembles one made in a cloud chamber or a bubble chamber. Each of the tiny dots that trace the paths of the particles in the picture is a streamer seen from the end. The direction of the beam from the accelerator is from the top of the page. The paths of the particles are curved by a magnetic field, the lines of force in which are perpendicular to the page. The four long curved tracks from top to bottom are "background." The burst of particles at bottom is the event of interest. Among the interaction products is a neutral lambda particle, which decays into two oppositely charged particles after traveling a short distance from the main interaction.



BLOCK DIAGRAM OF STREAMER CHAMBER shows one of its principal advantages, which it shares with other kinds of spark chamber: it can be triggered by the kind of event it is supposed to detect. The passage of a charged particle (*colored line*) is detected by a counter (or a series of counters). The electronic logic distinguishes among different kinds of events and selects those of interest to the experimenter. A triggering pulse is then sent to a high-voltage generator, whose output is used to charge a pulse-shaping network. Finally, a high-voltage pulse is applied to the plates of the chamber, causing streamers (*short vertical lines*) to form on the ions that were left in the wake of the charged particle. The entire cycle takes less than a millionth of a second.

the early 1950's by Donald A. Glaser, became a popular replacement for the cloud chamber in high-energy particle physics. In this instrument the sensitive medium is a superheated liquid. A charged particle passing through the liquid produces ions and causes bubbles to form around them, thereby making a visible track. Although most bubble chambers operate at about one cycle per second, some yield as many as 10 photographs per second. As a denser medium, the bubble-chamber liquid contains many more target atoms and provides many more events than the cloud-chamber vapor. Like the cloud chamber, the bubble chamber can record an entire complex event, showing the tracks of all the charged particles that emanate from the original collision and its sequels, and it can be built large enough to follow the particles for a considerable distance. Bubble-chamber tracks are sharply defined, so that the location of points along the particle paths can be determined with precision. Moreover, various liquids can be used in the chamber to serve as specific targets. For example, if the bubble chamber is filled with pure liquid hydrogen, it will show exclusively and specifically the nuclear reactions involving the incident particles and the target protons.

The bubble chamber unfortunately has a serious shortcoming. It cannot be triggered to record selected events as they occur. The original ion trail generated by an incoming particle lasts much less than a millionth of a second—too short a time for activating the system. Hence the chamber must be turned on well before the events are expected to happen. A modern bubble-chamber experiment carried out with a beam of photons may involve as many as a million pictures, in which perhaps 10,000 events of a particular type are recorded. Obviously this calls for a considerable expenditure of time for analysis of the data, even with the modern semiautomatic methods available for accomplishing the task.

An entirely new approach to the problem of particle detection was introduced by the spark chamber. This instrument was not the inspiration of a single inventor, as were the cloud chamber and the bubble chamber. The idea evolved slowly over a period of perhaps 15 years and grew from the work of many physicists [see "The Spark Chamber," by Gerard K. O'Neill; SCIENTIFIC AMERICAN, August, 1962].

The spark chamber operates on an essentially simple principle. If a metal plate is charged to a high voltage and another plate is placed close to it, sparks will jump the gap between the plates. A similar effect can be produced, even with subthreshold voltages, if there is a "bridge" of ions across the gap. Such a bridge will be created from one plate to the other by the passage of an ionizing particle through the gas. The few electrons freed by the initial ionization process are accelerated by the applied voltage and produce additional ionization through collisions with the atoms of the gas. Thus an avalanche of ionization develops in the path across the gap. The multiplication of ions results in a bright spark that traces out the path.

The standard spark chamber consists of a series of closely spaced, parallel metal plates separated by an inert gas, usually a mixture of neon and helium. When a particle of interest traverses the chamber (passing through the plates and across the gaps between them), it trips a counter that triggers the charging of alternate plates with a short high-voltage pulse within a millionth of a second after the particle has arrived. Sparks flash across the gaps along the path of the particle, and the resulting track, forming a kind of broken line, is photographed. As in the cloud chamber and the bubble chamber, information about the charge and momentum of a particle can be obtained by placing the chamber in a magnetic field that curves the particle's path.

The spark chamber combines some of the best features of the cloud chamber and the bubble chamber. Like the cloud chamber, it can be triggered; like the bubble chamber, it produces tracks of short (indeed, much shorter) duration, so that the picture is not complicated by spurious events occurring before or after the interesting one. A continuous weak electric field applied to the spark

chamber sweeps each track away within microseconds, and some types of spark chamber can be cycled to record as many as 1,000 events per second.

In certain respects, however, the standard spark chamber is less efficient than the bubble chamber. Events that originate within the plates are not visible. The track is broken into segments, so that it does not define the particle's path as sharply as the fine track in the bubble chamber does. Moreover, whereas the bubble chamber is isotropic, that is, it faithfully pictures tracks made in all directions, spark chambers are usually ineffective in recording the tracks of particles that travel obliquely across the gaps within an angle of 45 degrees to the plates. Finally, the most serious shortcoming of the spark chamber is that it may not be sensitive to all the secondary particles emitted in a particle collision; typically it picks up no more than the first four to six tracks in a given event. This is a considerable disadvantage in the study of high-energy collisions, which often give rise to a large number of secondary products.

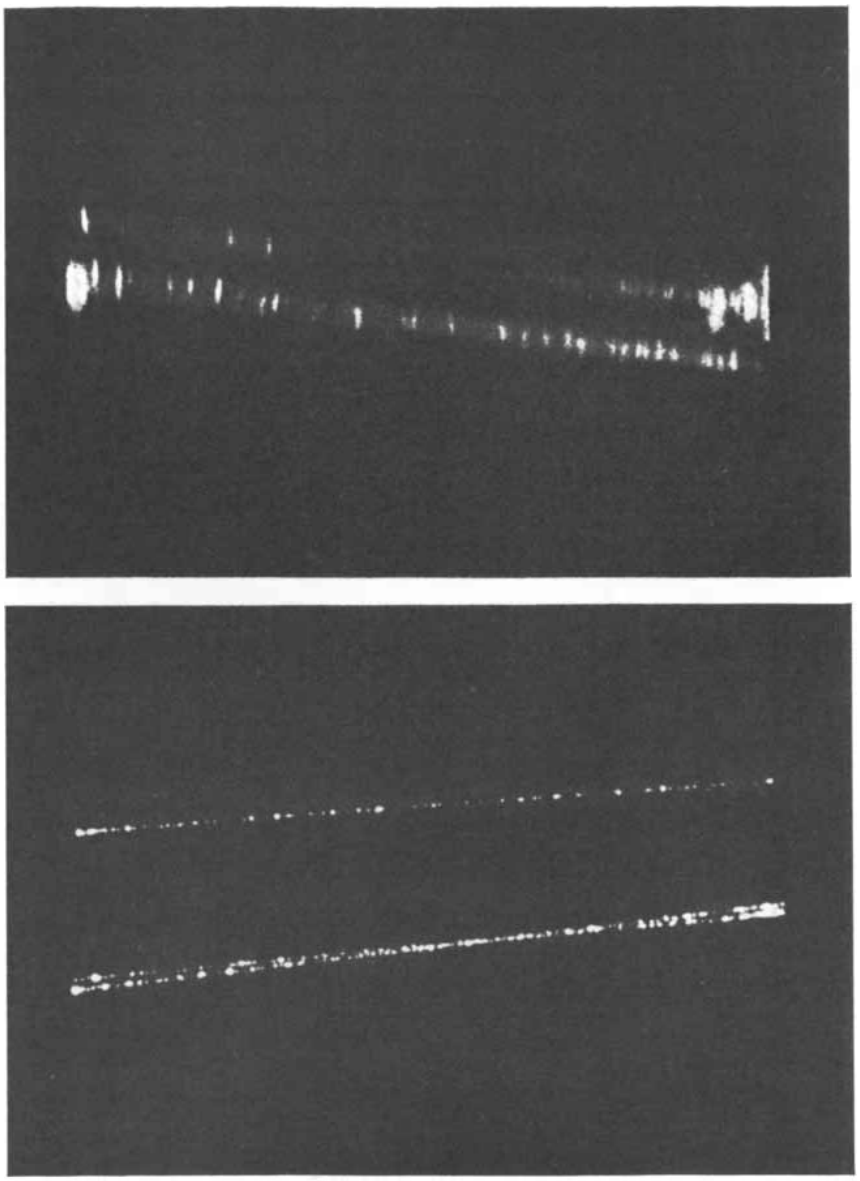
Would it be possible to combine the desirable features of the bubble chamber with those of the spark chamber, that is to say, to design an instrument that would incorporate the isotropy, the high multiple-track efficiency and the high resolution of the former and the triggering capability of the latter? Vigorous research has been directed to this objective, and it has led to the streamer chamber, an outgrowth of the spark chamber.

The first step toward this development was reported in 1963 by A. I. Alikhanian and a group of collaborators in the U.S.S.R., who announced they had built a "wide-gap spark chamber." Using a high-voltage pulse of comparatively long duration, the device amplifies particle tracks that span the distance between the two widely separated high-voltage plates, one positive and the other negative. This chamber produces a continuous (nonsegmented) visible track, and it can show the vertexes, or points of origin, of some events that occur in the gap between the plates. The instrument is capable of high resolution of particle paths. It is necessarily restricted, however, to showing tracks that extend from one plate to the other, and it therefore fails to detect particles whose paths are parallel or nearly parallel to the plates.

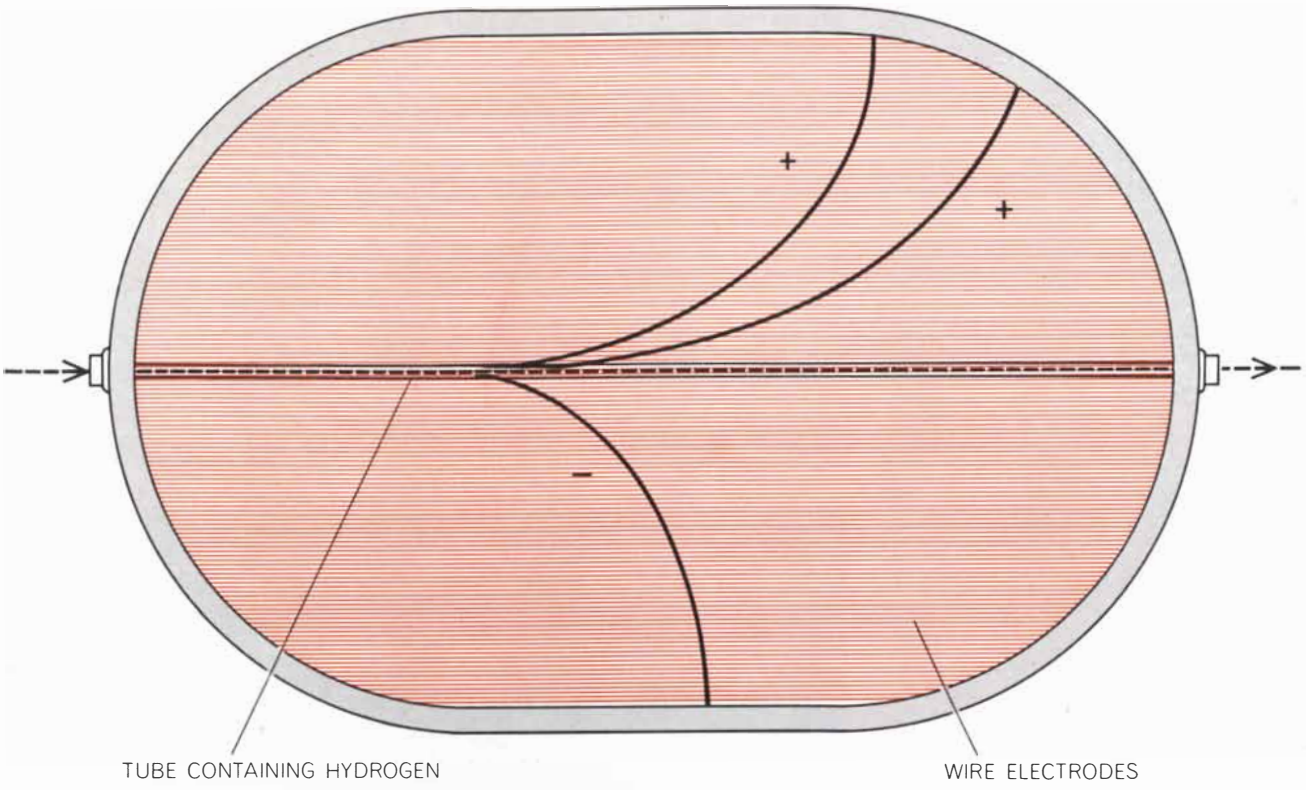
A few months later another group of Russian physicists, led by G. E. Chikovani, announced a further development that they named the "wide-gap streamer chamber." The principal feature of this device is that, by using an extremely short pulse, it produces very short sparks (streamers) that are localized along the particle's path of ionization. In effect it shows the "footprints" in the path. Viewed in the direction perpendicular to that of the electric field, the track is seen as a series of side-by-side streamers; viewed along the field, so that the streamers are seen end on, the track looks like a series of dots [*see illustration below*].

Since the discharges are localized, they can delineate a track in any direction, regardless of whether or not the path extends from one plate to the other. In addition to picturing events that take place anywhere in the gas between the plates, the streamer chamber, unlike the ordinary spark chamber, can record an extensive succession of events involving many tracks.

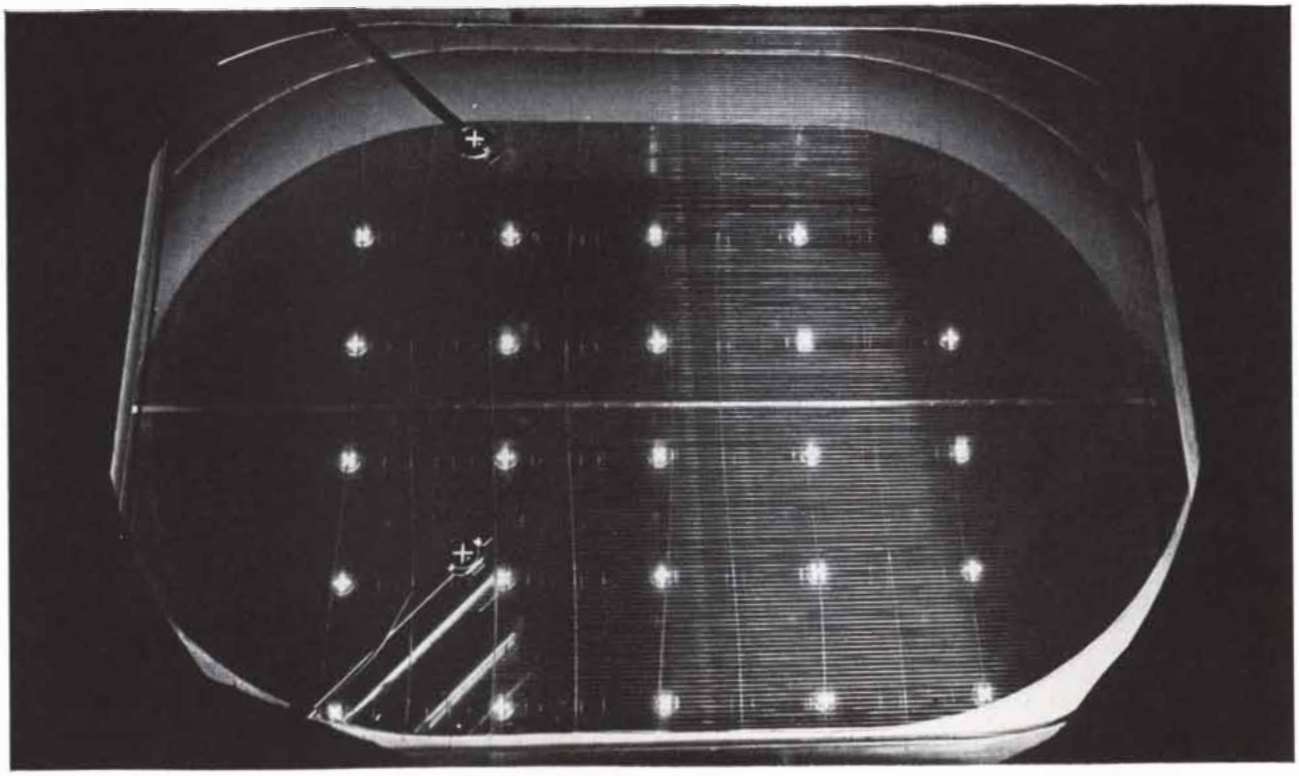
The streamer chamber immediately aroused keen interest at the Stanford Linear Accelerator Center, where the two-mile electron accelerator was under construction. The new device, being a compact, isotropic high-resolution detector, promised to be beautifully suited to the high-energy experiments planned



TWO VIEWS OF STREAMER TRACKS show how the streamers grow parallel to the lines of force in the electric field in the streamer chamber. The tracks at top were photographed from the side, that is, at right angles to the lines of force in the electric field. The tracks at bottom were photographed from the top, that is, parallel to the field. The two pictures were made by Fatin Bulos and his colleagues at the Stanford Linear Accelerator Center.



STREAMER CHAMBER TWO METERS LONG was built by the author and his colleagues at the Linear Accelerator Center. In this top view the target is a long tube filled with hydrogen gas that is placed in the accelerator beam (*arrows*). When a particle in the beam interacts with a proton in the hydrogen, the resulting particles diverge from the beam into the chamber; particles of opposite charge are bent in opposite directions. The chamber is filled with a mixture of 90 percent neon and 10 percent helium. The electrodes consist of wires spaced a centimeter apart; this makes it possible to photograph the streamer tracks from the top. There are three layers of wire electrodes: one at the top, one at the bottom (both negative) and one just below the target tube (positive).



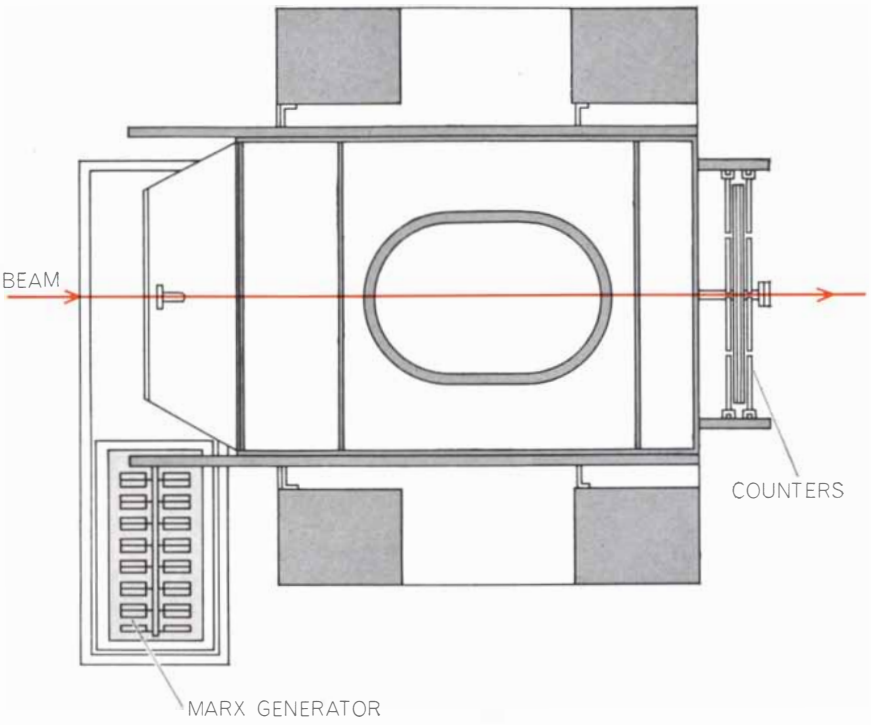
TWO-METER CHAMBER at the Linear Accelerator Center is seen in this photograph made from the top through the hole in its magnet. The bright spots are the cross-shaped fiduciary marks seen in the photograph on page 38. The target tube is visible in center.

for this accelerator, particularly those involving the use of colliding beams at extremely high energies. Soon after the Russian announcements appeared, physicists at the Stanford Center took up further development of the streamer chamber. Among those involved in this program at Stanford have been Fatin Bulos, Robert F. Mozley, Allen C. Odian, Francesco Villa and the author. We also received valuable assistance from Charlie Martin and Ian Smith, two British workers who visited the Stanford Center to help in the development of a system for generating the extremely short, high-voltage pulses required for the streamer chamber.

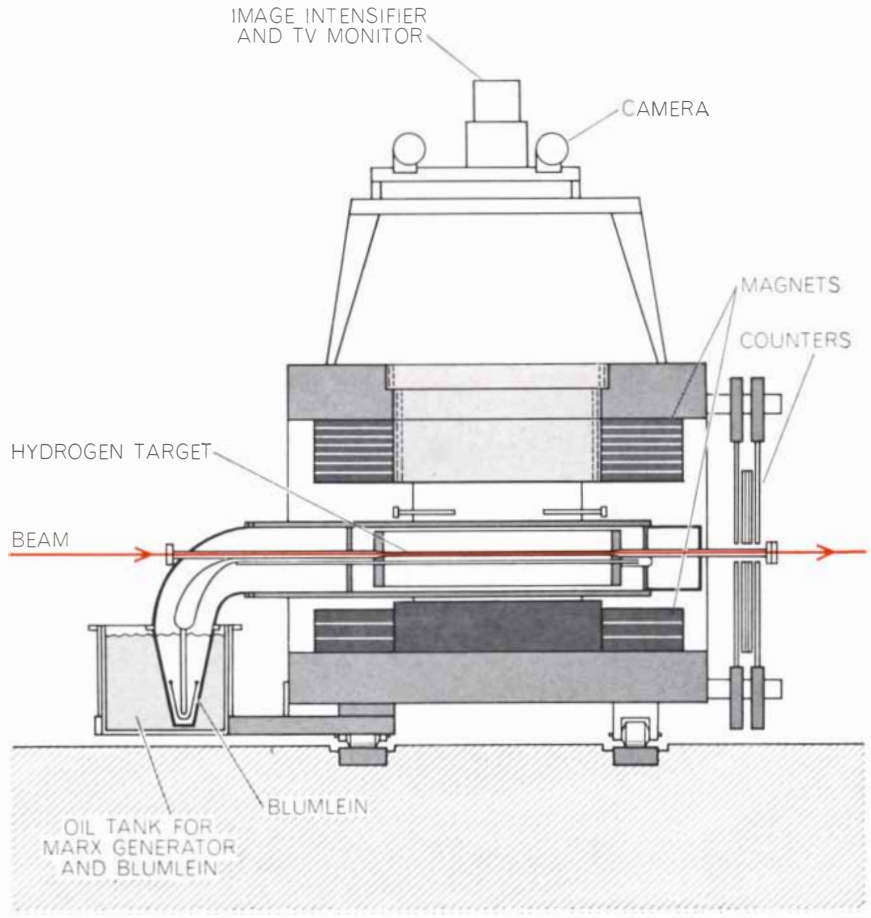
The production of the streamers is a rather complex affair. Let us begin by considering what happens when a strong electric field acts on an electron left by an ionizing particle traveling through a gas. After being accelerated by the field, the electron itself ionizes atoms with which it collides along its path. The secondary electrons freed by these collisions, as well as photons (quanta of high-energy electromagnetic radiation) that are emitted during the collisions, go on to produce more ions. Thus the number of ionizing electrons and photons multiplies. Within 10 billionths of a second, during which the high-energy electrons travel about one millimeter (that is, at about 1/3,000th of the speed of light), there is an exponential increase in the number of free electrons that amounts to a 100-million-fold multiplication: from the original single electron some 100 million secondary electrons result. In addition there are an equal number of positive ions. In short, an avalanche of charged particles one millimeter long has developed.

If the applied high-voltage pulse is somewhat less than 10 billionths of a second in duration, the generation of the avalanche stops at that point. The output of light during avalanche formation is normally insufficient to produce a visible trace even on the most sensitive photographic films available. If the avalanches marking the track in the chamber are to become visible, further amplification is necessary. Fortunately internal mechanisms within the primary avalanches cause them to grow at an enhanced rate until they become photographable streamers.

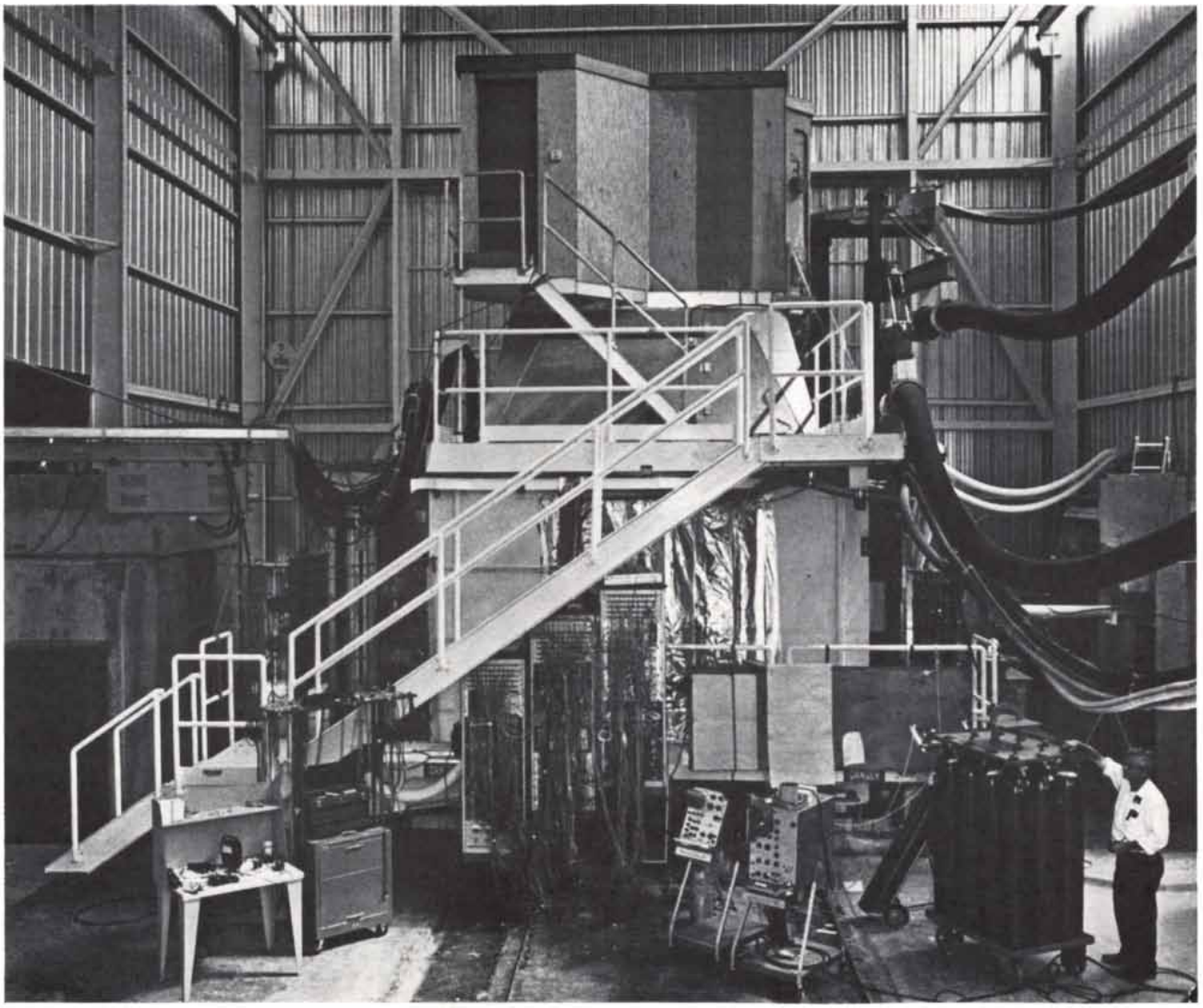
After the primary avalanche of electrons has been formed, photons emitted during the ionization process become the dominant means for producing further ionizations. The additional electrons thus



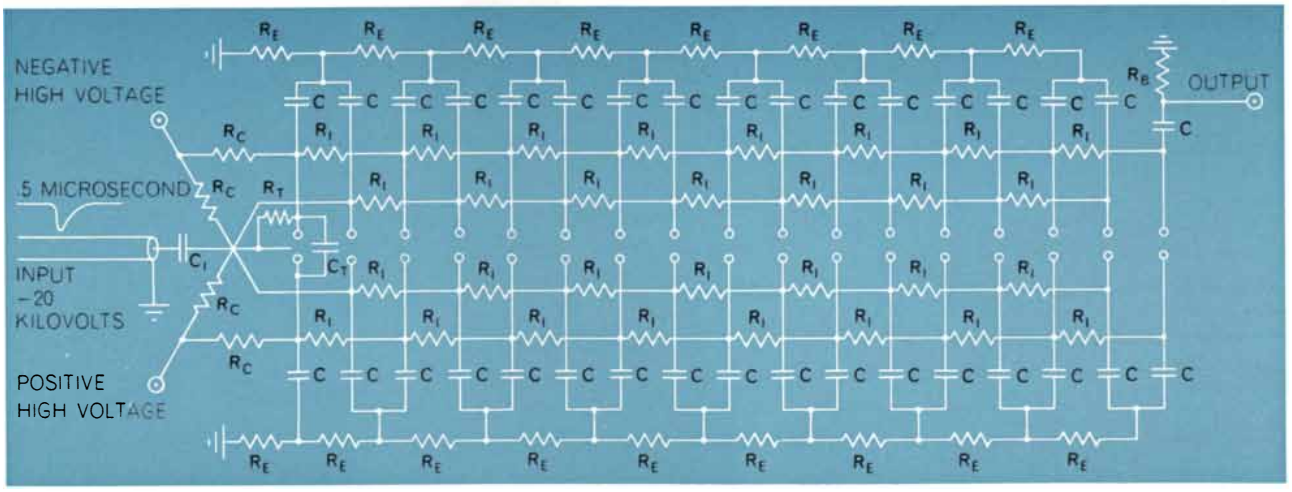
TOP VIEW of the two-meter chamber shows how it is mounted within its auxiliary equipment. The Marx generator at left is its source of high voltage (*see diagram on next page*).



SIDE VIEW of the chamber shows the arrangement of the magnets. The "Blumlein" associated at left with the Marx generator is the network that shapes the pulses from the generator.



IN POSITION FOR AN EXPERIMENT the two-meter chamber is obscured by its auxiliary equipment. The beam from the accelerator is directed into the chamber through the horizontal silver pipe at far right. The wooden structure at top houses chamber's cameras.



CIRCUIT DIAGRAM of the Marx generator shows how its 34 capacitor stages are interconnected. The symbols are as follows: C, capacitor; R_C, charging resistor; R_T, trigger resistor; R_E, external resistor; R_I, internal resistor; R_B, bleeder resistor; C_I, input capacitor; C_T, light-producing capacitor. The input to the generator (*left*) is 20,000 volts in a pulse lasting .5 microsecond. When all the capacitors are discharged through the Blumlein at once, they deliver a pulse of 1.3 million volts to streamer chamber.

freed produce localized secondary avalanches, particularly near the positive and negative tips of the original avalanche, where the space charge intensifies the electric field. The new avalanches feed these tips. Unlike the original avalanche, the streamer grows symmetrically in both directions—toward the positive and the negative high-voltage plates. Streamer development takes place very rapidly, much more rapidly than the pulse-generated formation of the original avalanche, because of the dominance of photo-ionization. At a certain length the streamers, which have developed simultaneously at many points along the particle's path, yield enough light to be photographed.

From theoretical calculations and experiments the basic requirements for a streamer chamber to produce visualizable particle tracks have been determined. The sensitive volume between the high-voltage plates must be filled with a gas containing few undesirable impurities: a mixture of 90 percent neon and 10 percent helium, such as is commonly used in spark chambers, will serve well. In a chamber filled with this gas, with the plates 30 centimeters (just under one foot) apart, one must use a pulse of about 600,000 volts; the pulse must last only 10 billionths of a second and must be applied within one millionth of a second after the particle that is to be tracked has made its ionization trail in the chamber.

The main technical difficulty lies in generating the specified pulse. Conventional generators designed to produce high voltages do not give fast enough pulses. It has therefore been necessary to develop a special type of generator.

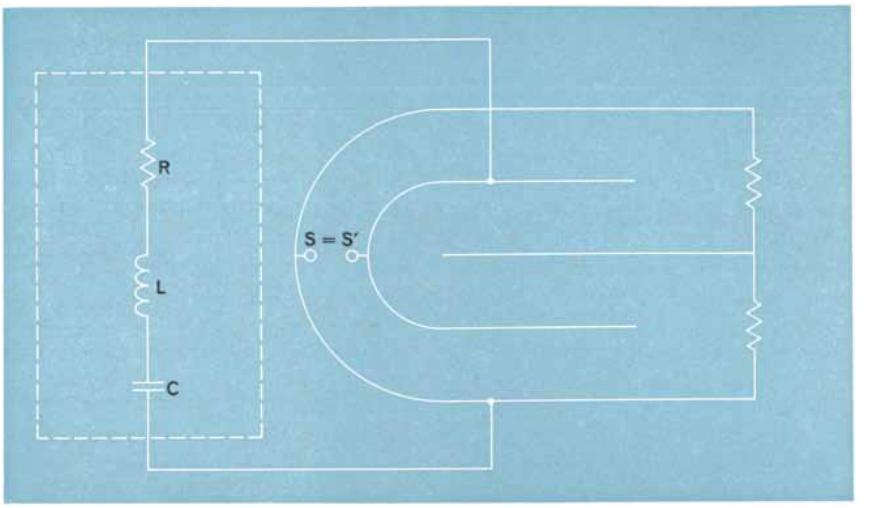
Chikovani's group in the U.S.S.R., the originators of the streamer chamber, devised for the purpose an adaptation of the well-known Marx generator, commonly used for generating high-voltage pulses. Conventionally this generator builds up the voltage by a series of stages, and the process necessarily lengthens the discharge time and consequently the length of the pulse. The Russian physicists succeeded in shortening the pulse by inserting at the end of the series a special capacitor capable of withstanding 200,000 volts and of feeding its spark discharge directly to the plates of their chamber; to sharpen the pulse they used a shunting arrangement that diverted the slow residual discharge coming from the Marx generator after the peak voltage was reached.

At the Stanford Linear Accelerator Center, with the aid of Martin and Smith, a different system for shaping the pulse (that is, determining its amplitude and duration) was developed. This approach conceives of the streamer chamber as a "transmission line" rather than as a capacitor with widely separated plates. It must be so regarded because the extremely brief pulse that is to be transmitted across the chamber is shorter than the time it would take a radio wave to travel from one end of the chamber to the other. In this light it was decided to couple to the streamer chamber a pulse-delivering system in the form of a transmission line such that the electrical characteristics of the drive system could be matched to those of the chamber. The pulse itself would be in the form of a radio wave traveling at virtually the speed of light. The main difficulty in this scheme was that, in matching the impedance of the first transmission line to that of the chamber, half of the charging voltage would be lost. The difficulty was overcome by adopting a voltage-doubling circuit invented by the British worker Alan Dower Blumlein. The Blumlein line (or "Blumlein," as it has come to be called) is essentially a transmission line folded back on itself. Its characteristic pulse duration is determined by the length of its active electrodes, which are charged slowly to the peak voltage of the Marx generator and discharged rapidly by means of a spark gap.

As for the streamer chamber itself, it has been found convenient to introduce a center plate that divides the gas space into two chambers instead of one. The center plate is the high-voltage electrode, and the upper and lower plates and the walls enclosing the system at the sides are grounded. This arrangement doubles the chamber volume without doubling the required voltage; it also provides shielding to prevent the escape of the troublesome radiation represented by the intense radio waves. The "plates" can be arrays of fine piano wire, spaced close enough (one centimeter apart) to transmit and contain the radio waves. These wire arrays are effectively transparent to light, and the events in the chamber are photographed through the arrays as well as through gastight windows of Mylar or some other transparent plastic material.

The most recent streamer chamber built at the Stanford Center has a track-detecting volume 2.3 meters (more than seven feet) long, 1.5 meters wide and 60 centimeters high. The Marx generator that produces the pulses has 34 stages, each containing 16 capacitors, and it is capable of generating a pulse of more than 1.3 million volts, about twice the voltage required to drive the chamber. For a pulse of 600,000 volts the peak current is about 26,000 amperes. The 400-ton magnet surrounding the chamber produces a field of more than 15,000 gauss and consumes about six million watts of power. The chamber is expected to measure the momentum of a high-energy particle (at an energy of 10 billion electron volts) to an accuracy of about 2 percent, and the mass resolution for multiple-particle events will be as high as .5 percent.

The streamer chamber can be sensitive during every pulse of the new two-mile linear accelerator, which can pro-



BLUMLEIN PULSE-SHAPING NETWORK is shown in this circuit diagram. Here the Marx generator is idealized as a charged capacitor (C) that discharges through an inductance (L) and a resistance (R). The voltage built up by the capacitor is switched to the electrodes of the chamber in one or two billionths of a second by a spark gap ($S=S'$).

duce pulses, or bursts of high-energy particles (at 20 billion electron volts), at the rate of 360 salvos per second. One of the virtues of the accelerator's high output is that it can feed several kinds of detector at the same time, switching its beam to deposit a pulse here and a pulse there in rapid succession. Thus with the accelerator in full operation different experiments can be carried out simultaneously in the streamer chamber, in a spark chamber and in a bubble chamber.

The streamer chamber can be used to track particles not only from targets outside the chamber but also from targets located within the chamber itself. In the first streamer chamber experiments at the Stanford Center a photon beam from the accelerator is collimated and directed into the chamber through a "straw," or pipe, 12 millimeters in diameter. The straw can be filled with almost any gas as the target material, which provides an excellent opportunity to use targets that are of the greatest interest to physicists: the nuclei of hydrogen, deuterium and the various isotopes of helium. For other experiments the gas filling the chamber's sensitive volume itself provides an excellent target material. Pure helium and pure neon are among the gases that can be used.

A small streamer chamber at Stanford University has been used to study the production of a "triplet"—an electron and an electron-positron pair—that stems from the collision of a high-energy gamma ray with a neon atom. Solid targets (of nonconducting materials) can also be installed in the sensitive volume of the chamber.

A particularly interesting event was photographed recently at the Stanford Linear Accelerator Center in the two-meter streamer chamber. The impact of a high-energy gamma ray on a proton resulted in an electromagnetic interaction that produced a "five-prong vertex" indicating the creation of five strongly interacting particles, followed by a "two-prong" decay by means of a weak interaction. Hence this single event included all the principal types of interaction among elementary particles.

It seems fully appropriate that the successful completion of the two-mile electron accelerator should be accompanied by the coming of age of a new elementary-particle detector—a detector particularly well suited to the exploitation of the accelerator's new and unique features.

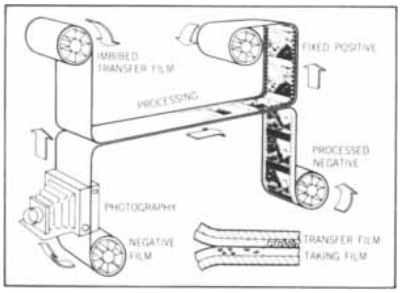
TWO-MILE ACCELERATOR is seen from the air. The long structure resembling a highway houses the accelerator tunnel. In the foreground are the two target buildings, into which the 20-billion-electron-volt electron beam is directed by a bending-magnet "switchyard." The accelerator was formally dedicated on September 9. It has been used in actual experiments for about four months.

The hope of doing each other some good prompts these advertisements

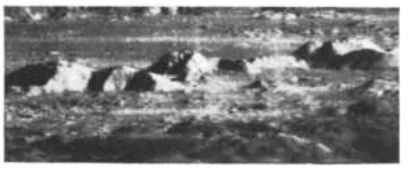
Imbibing apparatus ready

NASA Lunar Orbiter picture of earth from space using Kodak photo system, August 23, 1966.

When we displayed this now familiar photograph in 18 x 60-foot size in New York's Grand Central Terminal, more than one scurrying commuter was overheard speculating as to which was the moon and which the earth. In stimulating widespread thought about questions like that, the picture was fulfilling a purpose. Another purpose it fulfills is to demonstrate what a nice job of processing fairly conventional negative film can be done by bringing it in contact with imbibed KODAK BIMAT Transfer Film, viz.:



Clicking away inside Lunar Orbiters, this principle turns out work that has drawn additional favorable notice, such as the view of Copernicus:



Heartened by these and less widely publicized triumphs of imbibed BIMAT Transfer Film, we have placed our imbibing apparatus in a state of quick readiness. Other apparatus for working with BIMAT Transfer Film, including some for those who prefer to do their own imbibing, is waiting in the shops and warehouses of other manufacturers.

Delighted to send you their names. Also word on possibility of seeing the positive within 15 seconds after contact. Inquire of Industrial Photo Methods, Eastman Kodak Company, Rochester, N. Y. 14650.

In the interests of solvent customers and mild air

Defenders of air pollution are now scarcer than foes of motherhood or friends of sin. Something will doubtless be done about automotive fumes. Furthermore, attention is turned to how you pollute the air when you paint your dwelling and all that solvent evaporates. As a maker of solvents we feel involved. We sympathize with our paint-and-lacquer-manufacturing customers, with the regulatory authorities, and with the innocent public, which includes us too. The issues are not only ethically and economically complex but also chemically so.

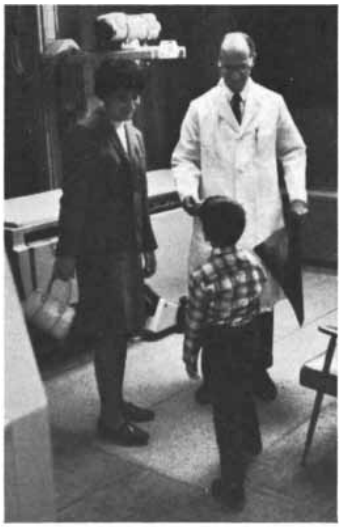
On the roof of the laboratory of the National Center for Air Pollution Control in Cincinnati, plastic containers of air are exposed to the sun. The air in the boxes has been loaded with about the number of parts per million of various olefins and aldehydes that might be encountered in a vicinity where people are earning a livelihood, maintaining their possessions, or just strolling in the park. The solar radiation below 340mμ turns out to be quite capable of oxidizing aliphatic aldehydes to intermediates that react with olefinic and aromatic hydrocarbons at these dilutions to produce significant levels of mucosal irritants and phytotoxicants. This process, some fear, could thwart efforts to sweeten the air by regulating nitrogen oxide effluvia.

Slightly ahead of regulatory action in less populous areas, Los Angeles County meanwhile has put into effect quantitative restrictions on the sale and use of photochemically reactive solvents. These are spelled out: 1) any hydrocarbons, alcohols, aldehydes, esters, ethers, or ketones with olefinic or cycloolefinic unsaturation; 2) aromatics of 8 or more carbons; 3) toluene; 4) trichloroethylene; 5) branched-chain ketones.

We are big both in branched-chain ketones and in competitive instinct. The latter has forced us to outperform competitors in helping solvent customers work out effective replacement formulas with the least rise in cost—even when necessary to include competitors' solvents in our suggestions.

Companies that wish to keep in touch with those suggestions should register their interest with Eastman Chemical Products, Inc., Kingsport, Tenn. 37662 (Subsidiary of Eastman Kodak Company).

Meanwhile, the reception room is full



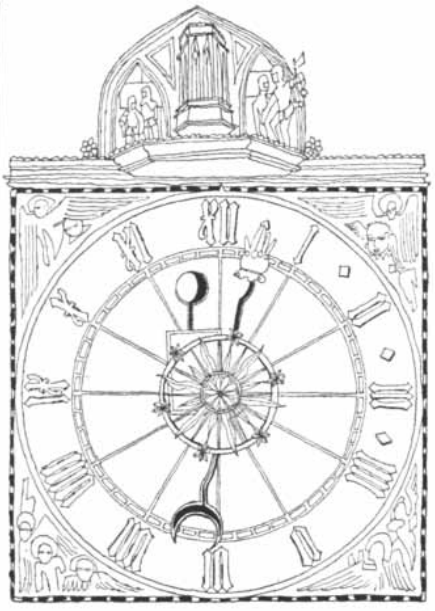
The physician is one figure, the businessman another.

As businessmen beyond denying, we ourselves are best acquainted with those physicians—radiologists—who have dedicated their minds and eyes to the use of x-rays. They buy our x-ray film. They buy a lot of it. Since x-ray film isn't the cheapest stuff to manufacture properly and since proper x-ray equipment costs what it does, the radiologist who scorns economics may find his attention regrettably diverted from his patients. So, though our service to him is basically through the technology we deliver, he and we and the hospital administrators talk business.

Result: All over the country, machines we make to process x-ray film in 90 seconds are being installed. "Waiting for the x-rays" is becoming less of a stock phrase, and the costly x-ray generating equipment need spend less time idle. At the expense of some damage to older traditions, some principles common in industrial management come into play, but a population of doctors that falls far short of rising with the general population manages to provide it with far more effective medical care than might be expected.

Kodak

SCIENCE AND



Antiproliferation

In agreeing on the draft of a treaty designed to prevent the spread of nuclear weapons the U.S. and the U.S.S.R., as the major nuclear powers, have taken another limited step to restrain the nuclear arms race. Nuclear powers that ratified the treaty would agree "not to transfer to any recipient whatsoever nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly or indirectly; and not in any way to assist, encourage or induce any nonnuclear-weapon state to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices." Nonnuclear signatories would undertake not to receive or manufacture nuclear weapons or to seek advice on the manufacture of such weapons.

The U.S. proposed an antiproliferation treaty to the 17-nation disarmament committee in Geneva two years ago. For months the U.S.S.R. declined to commit itself, apparently out of concern that agreement on the proposal would provide China with further opportunities to charge the U.S.S.R. with collusion with the U.S. In the end, with the Geneva conference seemingly about to bog down, the U.S.S.R.'s interest in restraining the spread of nuclear weapons evidently prevailed.

If the treaty goes into effect, it will constitute another small stretch of the long and winding road to the general-disarmament treaty that has been a subject of international discussion for many years. So far the road consists of a treaty to curb nuclear testing and a treaty to forbid nuclear weapons in space. A considerable effort may be needed, however, to put the antiproliferation treaty into effect.

For one thing, the issue of policing the treaty by some means of inspection is unresolved; Article III of the draft treaty, relating to inspection, was left blank. The U.S. and the U.S.S.R. had agreed at one time that inspection should be carried out by the International Atomic Energy Agency, a United Nations body. Several nations in Europe, including Italy and West Germany, objected on the ground that nuclear industrial secrets might be leaked by the inspectors for the agency; those nations proposed inspection by the European Atomic Energy Commission. The Russian negotiators said that would amount to self-inspection.

Another difficulty is that several nations appear unlikely to sign an antiproliferation treaty. France and China, which are in the relatively early stages of developing a nuclear capacity, have said they would not sign, although they are not expected to give away nuclear weapons or information. Nations that might be able to join the "nuclear club" on their own—Italy, Japan, Israel and others—may refuse to sign. India wants assurances of protection from nuclear pressure by China. Brazil asks that the draft be revised to permit "peaceful" nuclear explosions by nonnuclear powers. Even if the 17-nation disarmament committee can agree on a draft treaty, the entire matter must then go to the UN General Assembly.

The Hazards of Smoking (Cont.)

A mass of additional evidence on the effects of smoking has caused the U.S. Public Health Service to go beyond the Surgeon General's report of 1964 in two important particulars, which are set forth in a new report by the service entitled *The Health Consequences of Smoking*. The first is that "the convergence of many types of evidence... strongly suggests that cigarette smoking can cause death from coronary heart disease." The second is that "ciga-

rette smokers have higher rates of disability than nonsmokers, whether measured by days lost from work among the employed population, by days spent ill in bed, or by the most general measure—days of 'restricted activity' due to illness or injury." The report also reinforces the conclusions of the 1964 report that cigarette smoking is a cause of lung cancer, that cigarette smokers have substantially higher death rates than their nonsmoking counterparts and that it helps to stop smoking.

The report was published to take account of some 2,000 studies that have been made of smoking since the 1964 report. Surgeon General William H. Stewart also noted that the new report was designed to provide information to the Secretary of Health, Education, and Welfare, who is required by the Federal Cigarette Labeling and Advertising Act of 1965 to submit regular reports to Congress on the effects of smoking. The report drew in particular on four extensive population surveys: one of 293,658 American war veterans followed for 8½ years by the late Harold F. Dorn of the National Institutes of Health; a study of 1,003,229 persons by E. Cuyler Hammond of the American Cancer Society; a British study of nearly 41,000 men and women in the medical profession, and a study of some 92,000 Canadian pensioners.

In 1964 the evidence was insufficient to establish a causal connection between cigarette smoking and heart disease. According to the new report recent evidence "confirms that cigarette smokers have substantially higher death rates from coronary heart disease than do nonsmokers." In addition, according to the report, the evidence suggests how cigarette smoking can cause heart disease: Nicotine causes an increase in the demand of heart tissues for oxygen while "at the same time the carbon monoxide absorbed from smoking may cause a decrease in the supply of available oxygen from the blood."

In 1964 there was no information on the relation between smoking and disability. Beginning in July of that year the Public Health Service included questions about smoking in its annual National Health Survey of 42,000 families representing a cross section of the

population. Data from the survey, the new report says, "provide a base for estimating that in one year in the United States an additional 77 million man-days were lost from work, an additional 88 million man-days were spent ill in bed and an additional 306 million man-days of restricted activity were experienced because cigarette smokers have higher disability rates."

Is "Mysterium" the Message?

If radio engineers on a planet with a technology more advanced than ours wanted to establish an intragalactic communication network, they might look for a set of physical conditions somewhere in the interstellar medium that could be exploited as a giant maser. In this way small input signals might be enormously amplified to span vast reaches of space. Is it conceivable that earthbound radio astronomers have accidentally stumbled on such an interstellar "hot line"?

Farfetched as the idea may seem, it is very much on the minds of radio astronomers who have been trying to make sense of intense emissions of an extraordinary character discovered at a wavelength of 1,665 megacycles. This is the wavelength of one of four closely spaced emission lines that can be produced by the hydroxyl radical (OH). The first curiosity is that the relative strengths of these four lines, as observed by radio telescope, are not in the expected ratio. Typically the 1,665-megacycle line is 10 or more times stronger than anticipated. In fact, one of the first groups to discover the hydroxyl line named it "mysterium" because they did not believe it could be hydroxyl emission.

The hydroxyl radiation is not widely distributed throughout the galaxy but is found only near stars so hot that the surrounding hydrogen is almost completely ionized. In this state hydrogen is designated H II. About a third of the H II regions so far studied show hydroxyl emission. The most closely studied H II region is known as W3. It has now been found not only that the 1,665-megacycle emission from W3 is circularly polarized but also that the polarization approaches 100 percent. This seems far beyond anything that could be produced by interstellar magnetic fields, a possible cause of such polarization. To account for the intense hydroxyl emission from W3 the hydroxyl radicals must have a "brightness" temperature of about 10^{12} degrees centigrade. Such a temperature is probably not physical in the usual sense but implies a maser action. Moreover, the bandwidth of the radiation is only 600 cycles, another feature characteristic of a maser. Finally, the W3 emission arises from several closely spaced sources rather than from a single large source. The most intense source has an apparent size of less than .02 second of arc, corresponding to a linear dimension less than half the diameter of the solar system.

All observers agree, however, that the hydroxyl radiation from W3 does not show any variation in strength. Thus the most obvious requirement for an information-bearing signal seems to be lacking. There could nevertheless be more subtle variations in the W3 source. In other H II regions the hydroxyl emissions have been reported to fluctuate on a time scale of a few days or weeks. This, however, is not confirmed by all observers.

Current knowledge of hydroxyl radiation is reviewed in a recent issue of *Science* by Alan H. Barrett of the Massachusetts Institute of Technology. He is careful to say that "there is no evidence that the OH radiation is really interstellar signaling, and I am making no such proposal." He nonetheless adds: "If one grants that such things are possible, then perhaps the initial evidence of interstellar communication would be our detection of a vast interstellar communication network, which would someday accept us as its newest member. Is it possible that we are getting close?"

Enzymic Oscillators

Delicate measurements have shown that certain enzymatic reactions in the living cell oscillate vigorously, producing sinusoidal wave patterns of considerable uniformity. When the enzyme system is removed from the cell, the wave forms become more regular still. In one cell-free system oscillations of constant amplitude continue for hours at a steady rate of 12 cycles per hour. Discussing "enzymatic oscillations" in the journal *IEEE Spectrum,* Britton Chance, Kendall Pye and Joseph J. Higgins of the University of Pennsylvania School of Medicine examine the possibility that such oscillators may underlie the timing mechanism for the biological clocks that seem to regulate the activities of animals, including man.

To record the wave forms of the enzymatic oscillators it was necessary to find a biological component whose concentration could be detected in trace amounts and monitored continuously. One component that meets the requirement is the reduced form of diphosphopyridine nucleotide, known as DPNH. When DPNH is exposed to ultraviolet radiation, it emits a bright blue fluorescence. With a sensitive microfluorometer as few as 10,000 DPNH molecules can be detected. The first persistent sinusoidal wave form from a biochemical event in living cells was reported in 1964 by A. K. Ghosh, R. W. Estabrook and Chance, who monitored the DPNH level in the yeast *Saccharomyces carlsbergensis.*

The longest period yet observed for an enzymatic oscillation is about two hours. Chance and his colleagues cautiously conclude that "at present we cannot fully justify the speculation that [even] one-day biological clocks operate according to the mechanism that we have demonstrated for this 'enzymatic' oscillator."

Onward to Element 126

A new kind of particle accelerator called the omnitron has been proposed to test the possibility of creating new elements much heavier than mendelevium 258, the recently synthesized isotope of element 101 that has in its nucleus 101 protons and 157 neutrons. The synthetic element having the most protons (103) is lawrencium; its heaviest isotope (mass 257) was created by bombarding element 98 (the synthetic element californium) with element 5 (boron). Recent theoretical studies suggest that elements containing either 114 or 126 protons in their nucleus, together with 184 neutrons, may be comparatively stable. Since the number of protons defines the atomic number of an element, these hypothetical substances would be elements No. 114 and No. 126.

To produce such heavy elements it will be necessary to accelerate ions (atoms stripped of one or more electrons) that are much heavier than those of boron. One possible reaction involves bombarding thorium 232 (element 90) with ions of krypton 84 (element 36). This should yield element 126 with 184 neutrons in its nucleus and hence an element of total mass 310. Six neutrons would be left over from the reaction.

The obstacle to conducting such reactions is the difficulty of removing enough electrons from elements as heavy as krypton to make efficient acceleration possible. Changes are now being made in the heavy-ion linear ac-

Winner's secret.

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Humble's talent for friendly, thorough assistance can do as much for your company as it can for a keyed-up racing team. Next time you need fuels, lubricants, solvents or waxes, try the "secret ingredient" you get from the company that's first in resources, first in capability.

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There's a cycle at work in the steel industry. It begins the moment a customer places an order.

When it ends is critical, because today quality in the steel industry is universally high. Prices are competitive. The big difference is customer service. The crucial question is: how fast can you deliver? The answer depends chiefly on how fast work begins on the customer's order.

Before computers came onto the scene, the order cycle took three weeks. (Often, time was lost just determining if and when room could be found for the customer's order.)

Today the sales division of one of the world's giants in the steel industry relies on a UNIVAC® 490 to shorten this cycle.

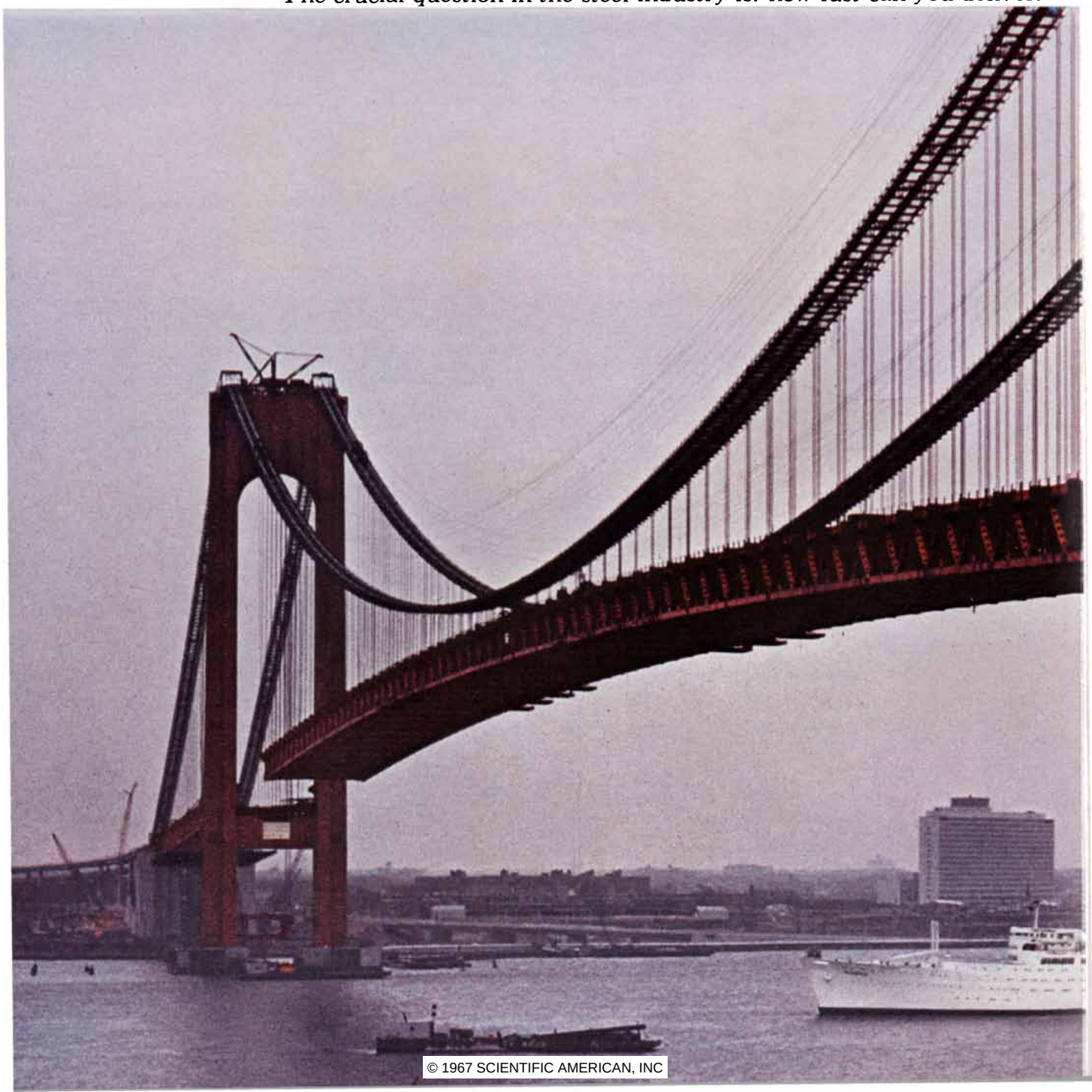
Now, in 85% of the cases, the three week wait has shrunk to a maximum of 48 hours.

Now data (and lots more data) can be accessible to remote locations on request. And when the requirements of a customer's order change, a lot of people who need to know about it will know about it simultaneously.

A hypothetical case: A customer needs his order of steel cable sooner than expected because progress on

Next time you order a

The crucial question in the steel industry is: how fast can you deliver?



the bridge he's building has been accelerated by a warm weather spell.

This means a shift in scheduling which affects plant availabilities, cost factors, date of shipment, and ultimately, invoicing.

The new data is fed into the UNIVAC 490, a real-time system. Information from then on is revised to be up-to-the-minute. Any outlying plant with a terminal device can have that information instantaneously.

This particular 490 has been in operation for 3½ years. It has been used twenty hours a day, five days a week and 16 hours on Saturday. During all that time the machine has been "down" only once.

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Univac is saving a lot of people a lot of time.

bridge you'll get it faster.

The answer depends chiefly on how fast work begins on the customer's order.

How did the world begin?

This giant telescope in Puerto Rico may bring you the answer within five years.

When Columbus set off to find new worlds, he discovered Puerto Rico.

Now scientists searching for still newer worlds are discovering the Commonwealth's unique radio-radar telescope. It may reveal how the world began. It may even tell when the world will end.

THE telescope in our photograph is the world's biggest "ear." It could detect a bicycle as far from the Earth as the Moon.

This incredible instrument fills a valley near the port of Arecibo. It has been in operation only three years but already it's turning science topsy-turvy.

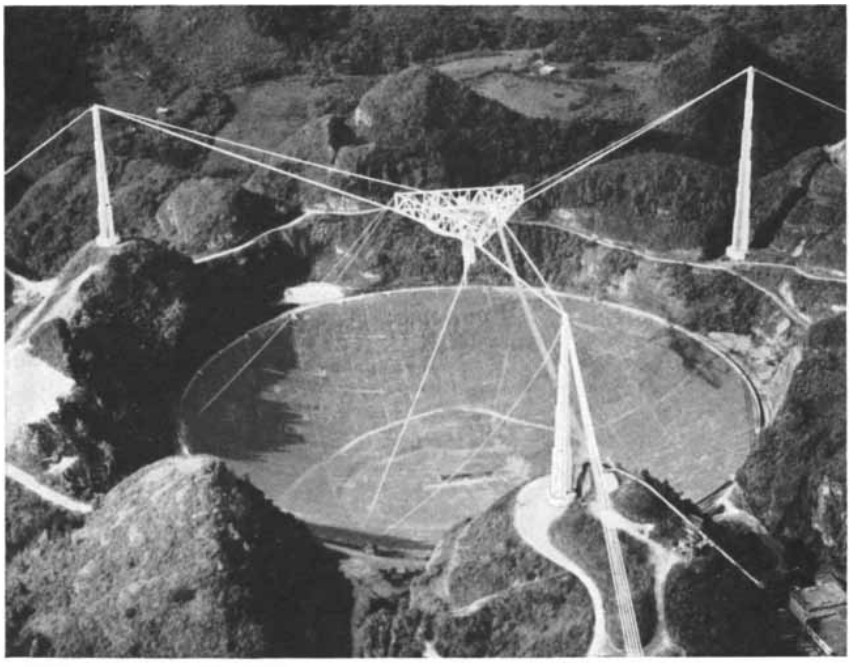
Open last year's encyclopedia and you will read that Venus revolves counter-clockwise like any normal planet. The Arecibo telescope showed that Venus revolves *clockwise*.

Turn to the chapter on Mercury and you will learn that this planet rotates on its axis in 88 days. Arecibo says 59 days.

At this minute, Puerto Rico's giant telescope may be tracking the plasma line in the ionosphere. Or jabbing radar blips *onto* the Moon to help space experts chart one complete hemisphere of the satellite.

> *Or it may be picking up radio emissions from objects far, far out on the very edge of the known universe.*

The Arecibo telescope is several times larger than any similar radio telescope. It lets astronomers "see" farther into space than man has ever seen before. And what it finds there may well be a picture of the universe as it existed near the time of its formation—because it has taken the radio emissions billions of years to reach Earth.



Arecibo Ionospheric Observatory fills natural "bowl," covers an area larger than 56 city blocks. Antenna, 435 feet above the ground, weighs twice as much as the Statue of Liberty.

Some scientists theorize that the universe began with a big bang—about 12 billion years ago.

Many take the "big bang" theory one stage further. They claim that the universe also expands and contracts, like the beating of a mammoth heart.

With the information gathered day and night by the Arecibo telescope, astronomers may be able to confirm whether the "big bang" theory is correct, or whether a pulsating universe will one day collapse again.

If it's the "pulsating" theory, they can calculate when the world will end.

Probably 70 billion years from now.

Memo to astronomers: Puerto Rico has been called a "showcase to the new nations" because its experience in building an industrial society from scratch is available to anyone.

Likewise, any qualified scientist from any country may apply for time at the Arecibo telescope. Last year, scientists from France, Italy, India, Sweden and Australia came to Puerto Rico to pursue advanced studies at the telescope. Applications to Director, Arecibo Ionospheric Observatory, Arecibo, Puerto Rico.

Memo to vacationers: If you'd like to visit a spot where history is being made, the Arecibo Ionospheric Observatory is open to the public every Sunday between 2 and 4:30 p.m. Admission free. The Observatory is about 2½ hours by car from San Juan.

Commonwealth of Puerto Rico
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← **Technician wears water skis** to walk across telescope reflector. This reflector receives radio signals measuring 1/1000 of a millionth of a millionth of a watt—yet it's made with *chicken wire*. The telescope is operated by Cornell University and sponsored by the U. S. Advanced Research Projects Agency.

PHOTOS BY TOM HOLLYMAN

celerator (HILAC) at the University of California at Berkeley to enable it to accelerate up to 100 billion krypton ions per second, 1,000 times its present capability. Even this, however, may be marginal for testing the krypton-thorium reaction.

To do the job right it may be necessary to build the omnitron, conceived in 1964 by Robert M. Main, Bob Hugh Smith and Albert Ghiorso of the University of California at Berkeley. The omnitron combines a synchrotron with a storage ring—a ring in which accelerated particles can be held until needed—to produce high-energy ions that need not be highly stripped of electrons. The storage ring allows a beam of heavy ions to be removed for experiments at a slow rate (hence efficiently) without slowing down the acceleration process in the synchrotron. A second and higher-energy mode of operation is also possible in which ions are highly stripped by being passed through a thin metal foil and then reaccelerated.

Nature's Sleeping Potion?

Recent investigations by workers at the Harvard Medical School show that an animal deprived of sleep produces a "humoral factor" in the cerebrospinal fluid that will induce sleep when the fluid is administered to other animals. The effect was first demonstrated in 1913 by the French workers R. Legendre and H. Pieron, who used dogs as subjects, but efforts to duplicate their work in the late 1930's were frustrated by the severe strain that was imposed on donor and recipient animals by the methods of tapping and infusion then available. Reporting in *Proceedings of the National Academy of Sciences,* John R. Pappenheimer, Tracy B. Miller and C. A. Goodrich of Harvard point out that today's technique of implanting permanent channels overcomes these difficulties.

The Harvard group used goats as donors. After drawing and filtering cerebrospinal fluid from rested goats and from others that had been kept awake for 72 hours, they injected small amounts of the fluid into the brains of rats and noted the effect on the rats' normally nocturnal pattern of activity. During the 12 hours following injection—from 9:00 P.M. to 9:00 A.M.—most of the rats receiving fluid from sleep-deprived goats shifted to a routine of rest typical of daylight hours. They curled up to sleep in their cages, waking occasionally for food and water. When they were handled or exposed to noise,

New Anglo-American engine joins the U.S. Air Force.

Model of the A-7D Corsair II now under development for the U.S. Air Force

Before long, the incredibly versatile A-7D Corsair II will take to the air. LTV Aerospace Corporation, a subsidiary of Ling-Temco-Vought, Inc., is building it. Rolls-Royce designed the engine. It is being developed and produced in the U.S. in collaboration with the Allison Division of General Motors. Read how this new plane came into existence—starting with performance requirements that border on the unbelievable.

The U. S. Navy got the ball rolling in 1963. They wanted a light-attack fighter-bomber that could support ground forces, destroy tactical targets in battle areas, deliver large ordnance loads, take off from carriers and land bases, fly long range or loiter over target areas, and be easy to maintain.

The Navy asked a number of aircraft companies for design proposals. One of them was Vought Aeronautics Division of LTV Aerospace Corporation in Dallas.

Within 18 months, the company had a new plane in the air. And what a plane it was.

27 percent more thrust

It wasn't long before the Air Force asked for its own version, which would be called the A-7D. One major change, though. The Air Force needed an engine that would give about 27 percent more thrust—for improved land-based performance. And that's where Allison and Rolls-Royce enter the picture.

Powers a variety of aircraft

Rolls-Royce makes a superb fan-jet engine called the Spey. It was specifically designed for low fuel consumption and maintenance costs, reliability under short-haul conditions, easy handling and rapid response to pilot requirements during takeoff and landing.

Since its introduction in 1962, the Spey has been fitted to a wide variety of aircraft. It powers the BAC One-Eleven used by American, Braniff, Mohawk and Aloha Airlines. Fitted with reheat for supersonic performance, it was installed in the McDonnell Douglas F-4 Phantom ordered by the British Government for the Royal Navy and Royal Air Force. Other versions power the Hawker Siddeley Trident, the Fokker F-28 and the Royal Navy's Hawker Siddeley Buccaneer.

Together, Rolls-Royce and Allison set to work to develop the Spey to fit the A-7D. Joint engineering teams were formed both here and in England. They are now carrying forward development of the new engine, called the TF-41. Allison will manufacture it in the U.S. Soon a remarkable new plane will take to the air—powered by an equally remarkable new Anglo-American engine.

The Rolls-Royce multifuel engine that powers this self-propelled gun can run on any of four different fuels.

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they awakened normally but resumed sleep when the disturbance ended. At the end of 24 hours the depression of motor activities produced by the injection was no longer evident.

Pappenheimer and his associates write that the action of the humoral factor is an interspecific one of fundamental importance to an understanding of the sleep mechanism. Preliminary attempts to concentrate the active factor in cerebrospinal fluid have yielded material of considerably increased potency, leading to the expectation that its chemical analysis and synthesis will eventually be possible.

Stellar Birthplace

Infrared observations at a wavelength of 22 microns have disclosed a small, cool nebula embedded in the luminous Orion nebula. These observations may represent the first detection of an interstellar cloud undergoing rapid contraction and evolution. At 22 microns the cloud is the brightest object yet observed outside the solar system. The discovery is reported in *The Astrophysical Journal* by D. E. Kleinman and Frank J. Low of Rice University.

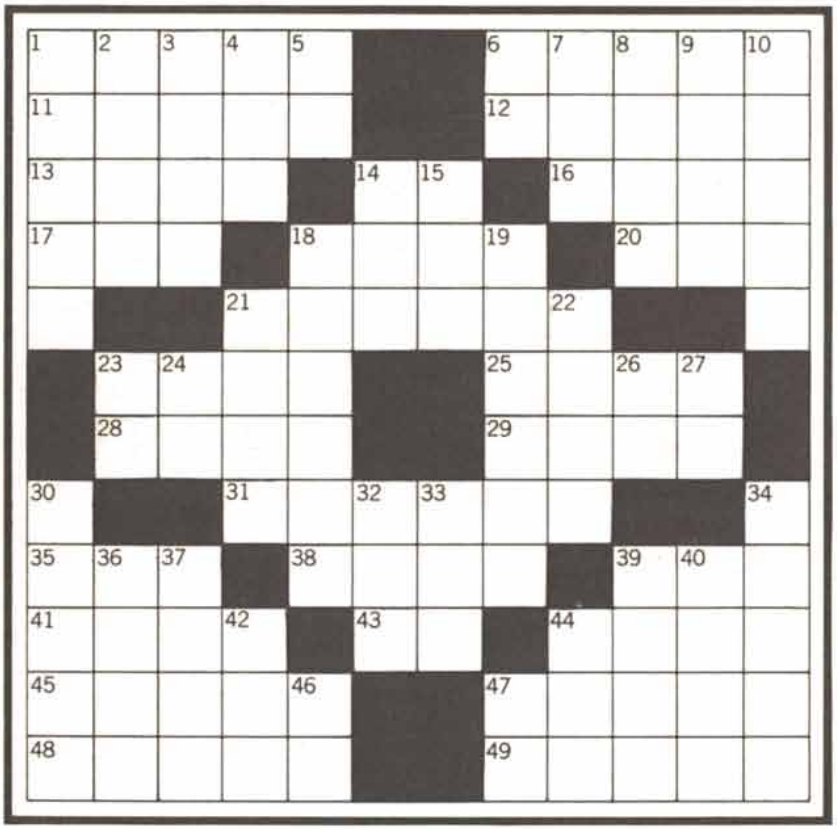
The temperature of the new nebula is probably less than 70 degrees Kelvin (degrees centigrade above absolute zero), which compares with a temperature of about 5 degrees K. for a typical interstellar cloud. The mass of the nebula appears to lie between 100 and 1,000 solar masses, its diameter is perhaps 100 times that of the solar system and its total energy output is about 10,000 times that of the sun.

There are theoretical reasons for believing that a mass this small could not produce energy at the observed rate simply as a result of gravitational contraction. It seems likely, therefore, that a cluster of stars has already begun to form near the center of the cloud but is totally obscured by the surrounding dust. Thus the cloud is absorbing starlight and reradiating it at a much longer wavelength. It is thought that the lifetime of such objects may be as short as 2,000 years and that there may be no more than 10 or so at any one time in our galaxy.

Up from the Wasp

Two 100-million-year-old ants, found embedded in a lump of Upper Cretaceous amber on the New Jersey seashore, have doubled the span of the ant family's fossil record and confirmed

Kill some time while waiting in line at No.1. Compliments of Avis.



Or rent a shiny new Plymouth from Avis. (The line at our counter is shorter.)

ACROSS

1. Rabbit or knockout
6. Florida city
11. Hollywood statue
12. Command
13. Man's first name, Ponce's last name
14. The spirit of____.
16. Kiss Me____.
17. Printed persuaders
18. Couples
20. Non-women
21. Railway stations
23. Sherlock Holmes' Baker St. address
25. Girl's name
28. How many Arabian nights?
29. Metal
31. Bends over
35. A limb
38. Hurt
39. Female deer
41. To judge
43. LXX
44. The Jones and the Sawyer boy
45. Mr. Stevenson
47. A flat cap for men or women
48. Cowboy circus
49. Baked, lima, or jelly____.

DOWN

1. White bear
2. Second-hand
3. Sergeants
4. Tin container
5. Sixty minutes (Abbr.)
6. U. S. State (Abbr.)
7. Annoy
8. First man
9. To allot
10. Girl's name
14. Soft drink
15. Into the valley of death rode the____.
18. Entries of debt
19. Privates have one
21. God (Spanish)
22. Gentlemen
23. Voting age
24. XX
26. Preposition
27. In grammar, an article
30. Electronic eye
32. Killer's license number
33. Gold (Spanish)
34. Lies down
36. Do over
37. Canasta term
39. The dumb girl
40. A portent
42. Girl's name
44. Golf term
46. Downing St. address
47. Ammunition for toy gun

entomologists' suspicions that these social insects arose from an ancestral form of solitary wasp. Until Mr. and Mrs. Edmund Frey discovered the New Jersey specimens the most ancient ant fossil known was from an Eocene formation in Tennessee some 50 million years old. Named *Sphecomyrma freyi* both to indicate their intermediate position between wasp and ant and to honor their discoverers, the ancient ants have been described in *Science* by William L. Brown of Cornell University and Edward O. Wilson and Frank M. Carpenter of Harvard University. The quarter-inch insects' "waists" are antlike, but their heads carry wasplike jaws and antennae.

Hostile Gifts

Perhaps with the approaching holidays in mind, Barry Schwartz of the University of Pennsylvania has summarized much of the unwelcome but inescapable evidence that giving gifts is as often hostile as it is friendly. Writing in *The American Journal of Sociology,* Schwartz cites in addition to such traditional examples as the naked aggressiveness of the potlatch exchange of gifts among the Northwest Coast Indians of America elements of similar hostility within Western cultures. Item: Insofar as a gift represents the donor's conscious self-sacrifice, it is a form of self-punishment. Item: Bondage to the donor is so implicit in the acceptance of gifts that street-gang leaders, among other calculating gift-givers, take pains never to let followers pay off all obligations. Item: Prison inmates must go to great lengths to return unsolicited gifts of cigarettes if they wish to avoid domination by the donor. Item: The traditional gold watch at retirement is a sort of "gilded 'pink slip,' " freighted with the implicit message "Good riddance." Item: Gifts to children are frequently used as a form of punishment ("Mummy and Daddy are giving you a present even though you've been a bad boy!"), for which the child may seek vengeance in later life by presenting "inferior" gifts on such "status-recognizing" occasions as Mother's Day and Father's Day. Item: The "greatest of all gift-givers," Santa Claus, with his "powers of surveillance and ability to grant and withhold benefits," is used by parents as an instrument of control over children. Schwartz quotes with sympathy Ralph Waldo Emerson's observation: "The hand that feeds us is in some danger of being bitten."

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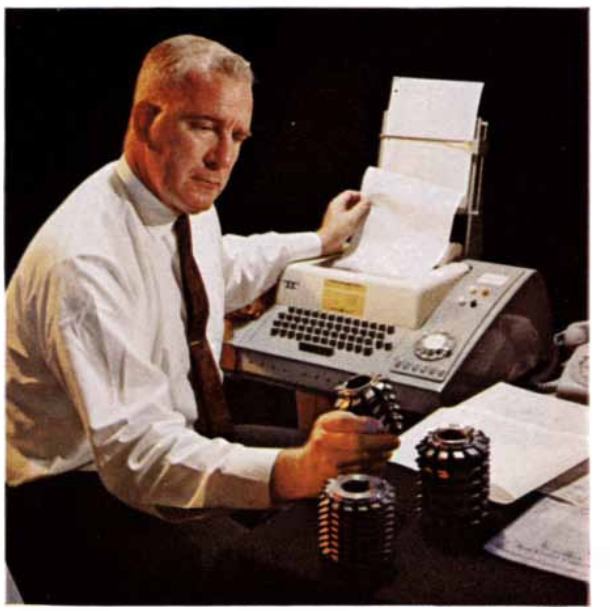

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The Shape of the Earth

As is well known, the earth is a slightly flattened sphere, but it also departs from the spherical in other interesting ways. These departures have been most clearly revealed by the orbits of artificial satellites

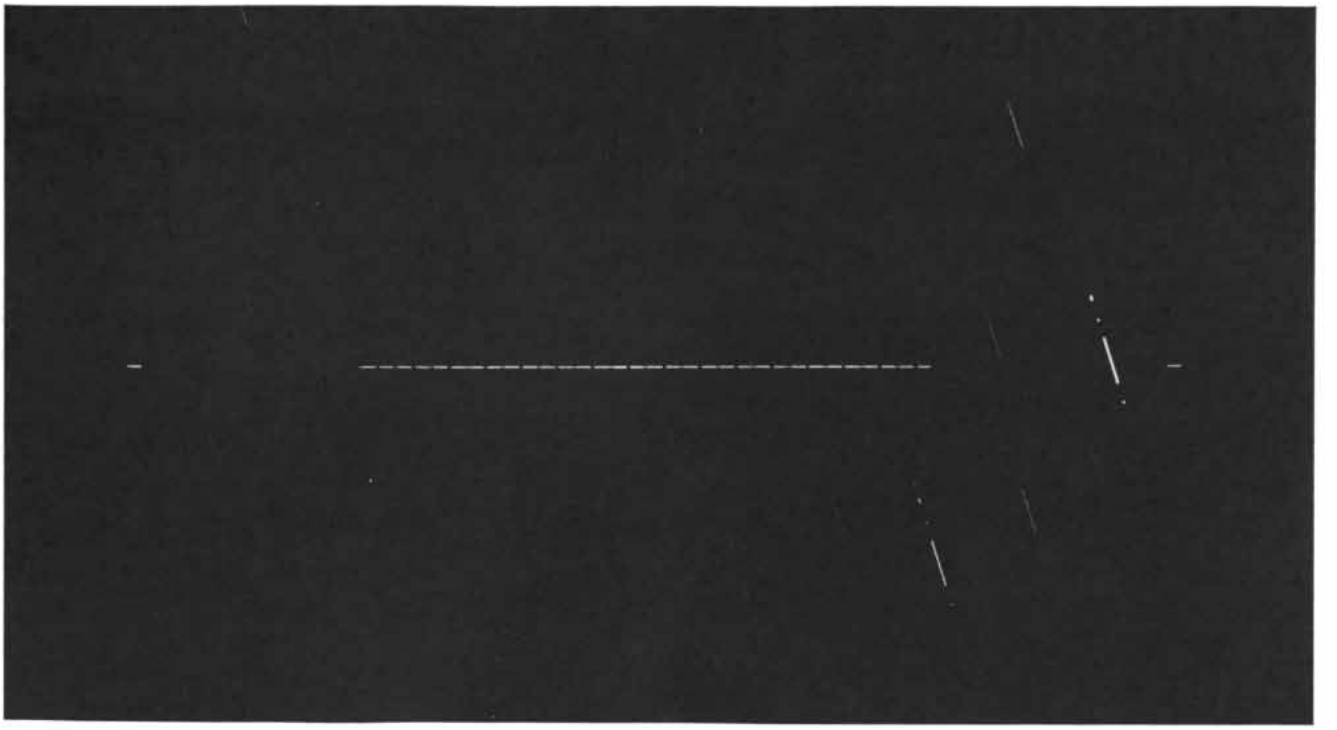
by Desmond King-Hele

From the earliest times human beings have wondered about the shape of the earth. At first they believed it was flat, and their recognition that it is round was a great advance. In recent centuries it was learned that the earth is an imperfect sphere, slightly flattened at the poles and distended at the Equator. Then the orbits of the first artificial satellites, launched in 1957 and 1958, showed that the flattening is less than had been thought and that the earth has a slight tendency toward being pear-shaped. Subsequent studies with satellites have revealed many humps and depressions previously unknown. In the coming years it should be possible to refine these studies even further.

I should make it clear at the outset that in discussing the shape of the earth I am concerned not with the mountains and valleys but with the shape of the sea-level surface, continued under the land in a logical fashion. This is the surface usually called the geoid.

Early Speculations

Millions of years ago some of our semihuman ancestors, hunting in the highlands of Kenya, may have stopped in their tracks and wondered: Does the land go on forever, or does it come to an end in a bottomless gorge? We shall never know their answer. Perhaps, however, there was a genius among them. Such a supremely bright individual might have discovered that the earth was gently curved. He (or perhaps she) need only have stood on the shore of a large lake, looking at a low island, and then noted how it disappeared from view when he went swimming. Experience had already taught him that light travels in straight lines, and so he would



GEODETIC SATELLITE is tracked in flight over Iran by a K-50 camera of the Smithsonian Astrophysical Observatory. The satellite appears as the broken horizontal line; the slanting lines around it were made by stars. The trail begins at far left with a one-second exposure, followed by 14 seconds in which shutter is closed. Then there is a 32-second exposure (*center*), another 14 seconds with the shutter closed and a one-second exposure. Another shutter system interrupts the exposures every second to indicate the timing.

leap to the right conclusion without any of the qualms about refraction that might inhibit a modern observer.

The first real evidence on ideas about the shape of the earth comes much later, from the Babylonians only a few thousand years ago. The Babylonians lived on a flat plain, and its frequent flooding gave them plenty of opportunity to notice the curvature of water surfaces. Moreover, some Babylonians were skilled astronomers and could have seen the earth's circular shadow creeping across the moon at an eclipse. And surely someone must have noticed that by traveling farther south he could see stars that were below the horizon at home. These phenomena may have been observed, but if they were, the observers never succeeded in convincing the authorities. The accepted belief among the Babylonians was that the earth was flat.

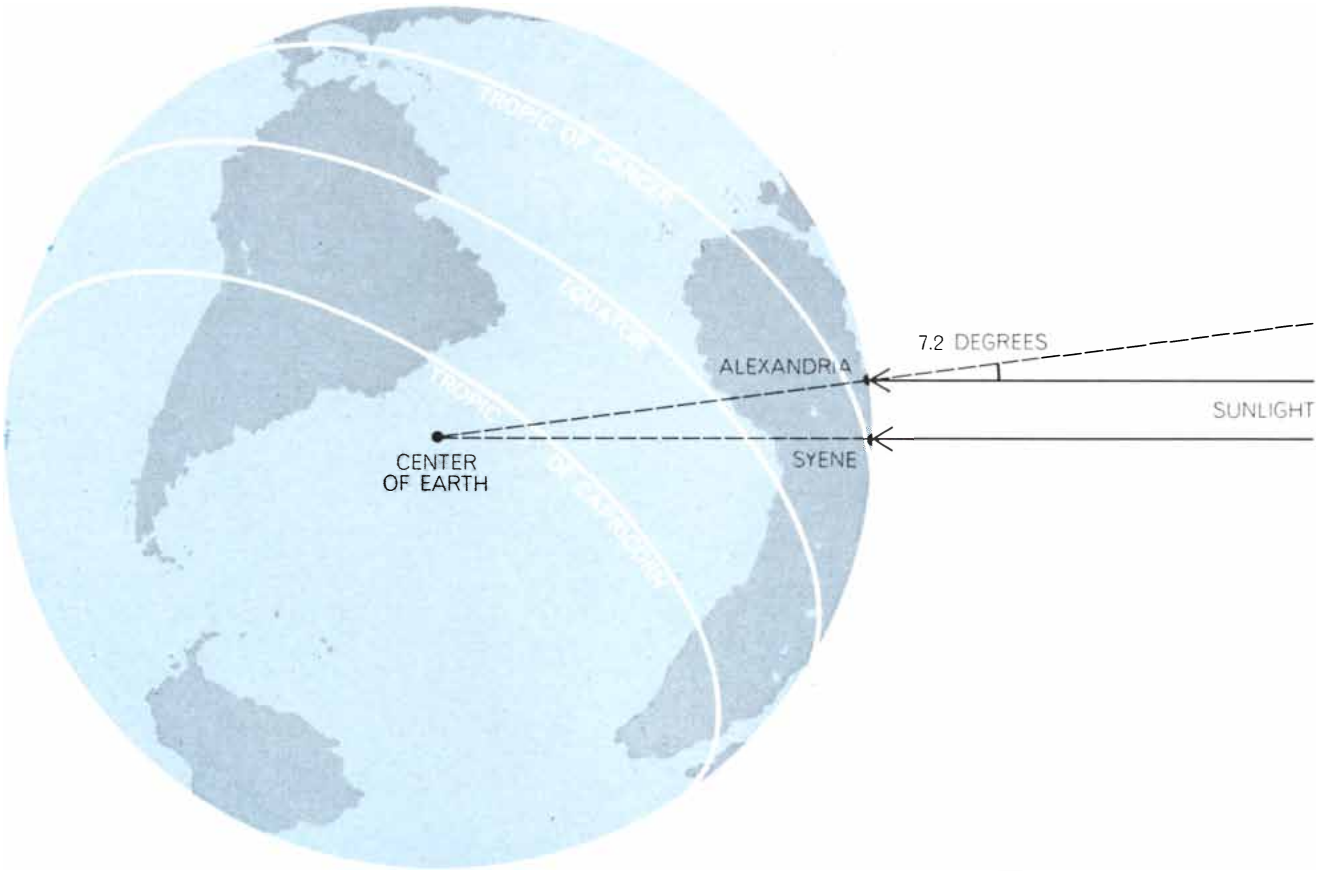
The credit for the idea that the earth is spherical is usually given to Pythagoras and his school in the sixth century B.C., although others had no doubt proposed it in vain before. The Pythagoreans did not take much notice of the observed facts; they just had a fixed idea that the sphere was the perfect shape, and so they concluded that the earth, like the sun and the moon, must be spherical. However shaky its basis, the idea of a spherical earth was adopted by many Greek philosophers, notably Aristotle, who even gave an estimate of the earth's circumference in his *On the Heavens*. (The estimate was inaccurate.)

The first great earth-measurer was Eratosthenes of Alexandria. The method he used in the third century B.C. was correct in principle and picturesque in detail. Eratosthenes noticed, or perhaps someone told him, that at noon the midsummer sun was directly overhead at Syene, or Aswan as we know it today, and shone down a deep well. At Alexandria the sun was not quite overhead in midsummer. It was a fiftieth of a circle, or 7.2 degrees, away [*see illustration below*].

With these facts, plus the assumption that the sun was a long way off, Eratosthenes deduced that the earth's circumference was 50 times the distance from Alexandria to Syene. But what was that distance? He knew that camel trains, which usually traveled 100 stadia per day, took 50 days to reach Syene. So the distance from Alexandria to Syene was 5,000 stadia and the circumference of the earth was 250,000 stadia.

The length of a "stadium" is not exactly known, but the measurement made by Eratosthenes may well correspond to 24,700 miles, very close to the correct value of 24,860 miles. He deserves every praise for his work: the principle was correct and its execution was beautifully economical, even though a few details were wrong. (For example, the sun would not have been exactly overhead at Syene, and camels are not to be recommended as measuring instruments.)

The method of Eratosthenes was applied again by Poseidonius, who used the bright star Canopus as a reference point. Similar calculations were made by the Arabs in the ninth century A.D. The method was refined by the Dutch mathe-



ERATOSTHENES' METHOD was one of the first attempts at measuring the earth. Knowing that the sun was almost directly overhead at Syene (now Aswan), he measured the angle of it from the vertical at Alexandria to be 7.2 degrees, or a fiftieth of a circle. If the sun's rays are assumed to be parallel, the arc between Syene and Alexandria will subtend the same angle of 7.2 degrees at the center of the earth. With an estimate of the distance between Syene and Alexandria, Eratosthenes was able to calculate the circumference of the earth. His calculation, made in stadia, is believed to be equivalent to about 24,700 miles, which is nearly correct.

matician Willebrord Snell in the 17th century and still offers one of the best methods of finding the earth's radius.

The idea of a spherical earth adopted by the Greek philosophers managed to survive in Europe throughout the conquests and confusions of the next 1,500 years. This was chiefly because of the fortunate accident that the Christians, who came to dominate Europe, chose the works of Aristotle as their guide to the physical world. He was an unreliable guide—a fact they never discovered because their chief aim was to prepare for a world to come rather than to comprehend the world they lived in. Aristotle was nonetheless right about the shape of the earth and so some at least of the scientific writings of the Middle Ages were near the truth.

The idea of a spherical earth also had its dangers. A sphere has a center, and that center all too easily became regarded as the hub of the entire universe. So developed the medieval picture of an earth surrounded by concentric spheres, on which the sun, moon and planets moved. This picture was flattering to man's self-esteem, and its destruction was grievously felt, particularly by those who were tortured for upholding Copernicus' idea that the earth moved around the sun.

The Flattened Sphere

Later ideas about the shape of the earth have gained acceptance more easily. The first of them was the concept of flattening. Unlike many words given a scientific meaning, "flattening" as applied to the earth means what it says. It is a measure of the amount by which the earth is flattened, or squashed in, at the poles. Numerically the flattening is defined as the difference between the equatorial diameter and the polar diameter, divided by the equatorial diameter. Since the equatorial diameter is 7,926.4 miles and the polar diameter is 7,899.8 miles, the difference is 26.6 miles and the flattening is 26.6/7,926, or 1/298. The flattening is always given as a fraction, 1/298, or described as one part in 298; it is not stated as a decimal.

The first inkling that the earth might be flattened at the poles came in 1672 from a French expedition to Guiana. The explorers found that pendulum clocks that kept good time in Paris lost 2½ minutes a day at Cayenne, near the Equator. At the time no one quite knew how to interpret the observation.

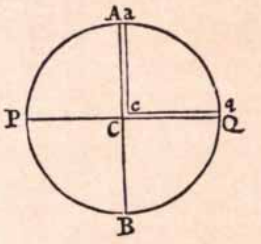
Help was soon at hand in the person of Isaac Newton. In one of the finest of the many brilliant analyses in his *Principia* of 1687, Newton deduced the earth's shape theoretically, without the need for expeditions to the Equator or anywhere else. His method was to imagine a canal, or tube of water, running from the North Pole to the center of the earth and from there to the Equator [*see illustration above*]. Since the oceans show no signs of rushing from Equator to pole or vice versa, the two arms of Newton's canal must balance each other at the center of the earth. The effect of the centrifugal force caused by the earth's rotation tends to reduce gravity slightly in the equatorial arm, which therefore needs to be longer than the polar one if they balance. Newton made the calculations and came up with the result that the equatorial radius would be one part in 230 longer than the polar radius. This value is in fact about 30 percent too large, because Newton—as he himself realized—did not allow for the increased density in the earth's interior. For more than a century, however, his was the best and most soundly based value for the flattening of the earth.

As soon as Newton's theoretical value for the flattening was known, many people were anxious to confirm it (or preferably to refute it) by actual measurement. The obvious method was to measure the length in miles of one degree of latitude both near the Equator and near a pole. If the earth is flattened, one degree of latitude will be slightly longer at the poles (69.4 miles) than at the Equator (68.7 miles).

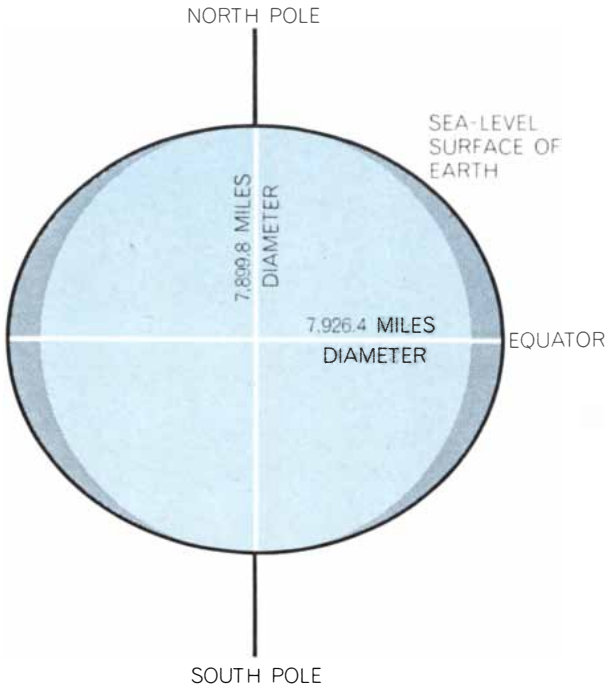
In the 18th century the French were very keen about making such measurements. Unfortunately the first attempts (by members of the famous Cassini family of astronomers) in northern and south-

Invenire proportionem axis Planetæ ad diametros eidem perpendiculares.

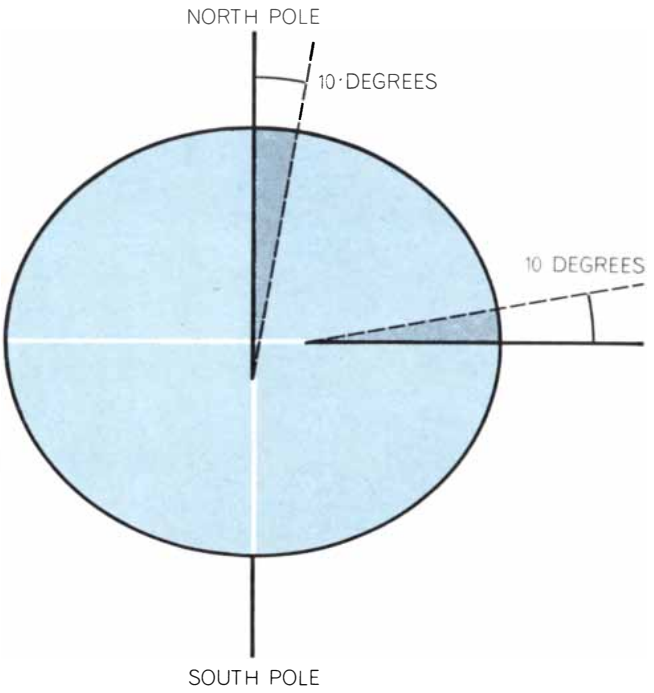
Ad hujus Problematis ſolutionem requiritur computatio multiplex, quæ facilius exemplis quàm præceptis addiſcitur. Inito igitur calculo invenio, per Prop. IV. Lib. I. quod vis centrifuga partium Terræ ſub æquatore, ex motu diurno oriunda, ſit ad vim gravitatis ut 1 ad $290\frac{4}{5}$. Unde ſi $APBQ$ figuram Terræ deſignet revolutione Ellipſeos circa axem minorem PQ genitam; ſitque $ACQqca$ canalis aquæ plena, à polo Qq ad centrum Cc, & inde ad æquatorem Aa pergens: debebit pondus aquæ in canalis crure $ACca$ eſſe ad pondus aquæ in crure altero $QCcq$ ut 291 ad 290, eò quòd vis centrifuga ex circulari motu orta partem unam è ponderis partibus 291 ſuſtinebit & detrahet, & pondus 290 in altero crure ſuſtinebit partes reliquas. Porrò (ex Propoſitionis XCI. Corollario ſecundo, Lib. I.) computationem ineundo, invenio quod ſi Terra conſtaret ex uniformi materia, motuque omni privaretur, & eſſet ejus axis PQ ad diametrum AB ut 100 ad 101: gravitas in loco Q in Terram, foret ad gravitatem in eodem loco Q in ſphæram centro C radio PC vel QC deſcriptam, ut $126\frac{2}{15}$ ad $125\frac{2}{15}$. Et eodem argumento gravitas in loco A in Sphæroidem, convolutione Ellipſeos $APBQ$ circa axem AB deſcriptam, eſt ad gravitatem in eodem loco A in Sphæram centro C radio AC deſcriptam, ut $125\frac{2}{15}$ ad $126\frac{2}{15}$. Eſt autem gravitas in loco A in Terram, media proportionalis inter gravitates in dictam Sphæroidem & Sphæram, propterea quod Sphæ-



NEWTON'S CALCULATION of the flattening of the earth appeared on this page of his *Principia* of 1687. He imagined a "canal" of water *ACQ*, with arm *AC* running from the North Pole to the center of the earth and arm *CQ* from there to the Equator. Since the oceans do not flow either way, the arms must be balanced. The centrifugal force of the earth's rotation counteracts gravity somewhat in the arm *CQ*, which therefore must be longer than the arm *AC*. Newton calculated that the flattening amounted to one part in 230.



FLATTENING OF THE EARTH, which can also be described as an equatorial bulge, is shown at left in exaggerated form. The equatorial diameter is 26.6 miles more than the polar diameter.

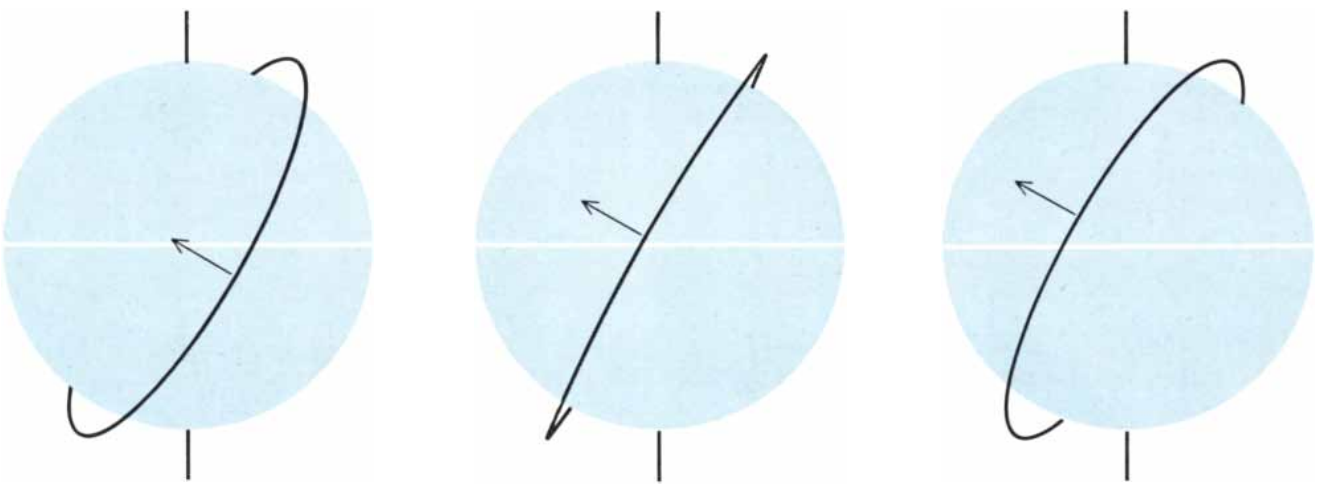


Flattening is also shown (*right*) by measurement of land distances; if the earth is flattened at the poles, 10 degrees of latitude at the Equator represents less distance than 10 degrees at the poles.

ern France were not accurate enough. According to their measurements the earth was not flattened at the poles but elongated, like an egg or a lemon. In 1720 Jacques Cassini gave the value of the flattening as *minus* one part in 95.

This result provoked a good deal of controversy. In order to try to settle the arguments the French Academy of Sciences sent out two expeditions in the 1730's, one to Lapland under the command of the astronomer P. L. M. de Maupertuis and the other to Peru. Both expeditions suffered severe hardships during the laborious work of surveying the unknown terrain. Maupertuis's party, which included the eminent mathematician Alexis C. Clairaut, was plagued by insects in summer, almost frozen to death in winter and finally shipwrecked. They returned in 1737, however, after 18 months of work, and their measurements proved that the earth was flattened at the poles. Voltaire hailed Maupertuis as "flattener of the poles and the Cassinis." As it happened, Maupertuis went a little too far: his value for the flattening was one part in 178, which was more than 60 percent too large and less accurate than Newton's.

The Peruvian party suffered even worse hardships. They had to wait on mountain peaks, sometimes for days or even weeks, until the mists cleared and they could observe the marks they had set up. Moreover, the three Academicians with the party—C. M. de la Condamine, Pierre Bouguer and Louis Godin—tended to work independently instead of cooperating. It was 10 years before the party returned to Paris in 1748, only to quarrel violently over the results. La



GRAVITATIONAL EFFECT of the equatorial bulge is to make the orbit of a satellite that is moving eastward swing to the west. The tendency is indicated in the successive series of orbits from left to right. The first satellite to reveal the shift accurately was *Sputnik II*. The shift proved to be less than had been expected, so that the flattening of the earth was less than had been calculated.

Condamine remarked in despair that 10 years of toil in the New World were followed by 10 years of dispute in the Old. The values the group obtained for the flattening ranged from one part in 179 to one part in 266.

The flattening continued to be measured by this method with gradually improving accuracy between 1750 and 1950. Among the most important values were that of the British geodesist Alexander Clarke, who in 1866 obtained a value of one part in 295, and that of the American J. F. Hayford, who in 1909 arrived at a value of one part in 297.

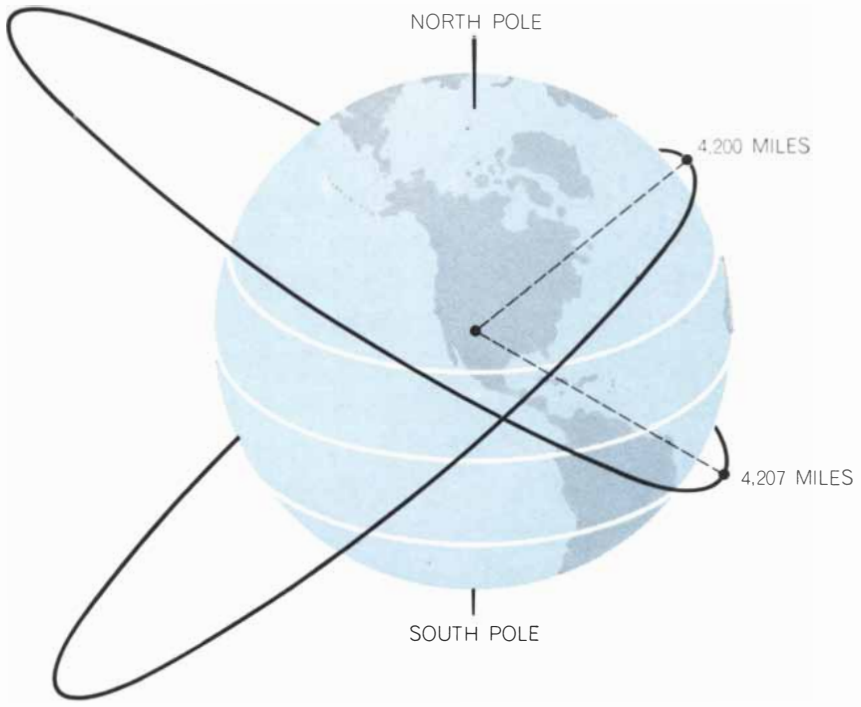
Not all the values were found by measuring arc lengths. Three other methods were used. The first was the measurement of gravity all over the world, for example by noting the behavior of pendulum clocks, which run slow near the Equator. The second method was measurement of certain small irregularities in the motion of the moon. The third was based on the motion of the earth's axis in relation to the stars. Today the earth's axis points very nearly at the star Polaris, whereas 14,000 years ago it was pointing near Vega. The earth's flattening strongly influences this motion.

Combining all four methods, Sir Harold Jeffreys of the University of Cambridge arrived in 1948 at a value for the flattening of one part in 297.1. His calculation must be regarded as the most soundly based of the presatellite values. As events were to show, however, it was not the most accurate.

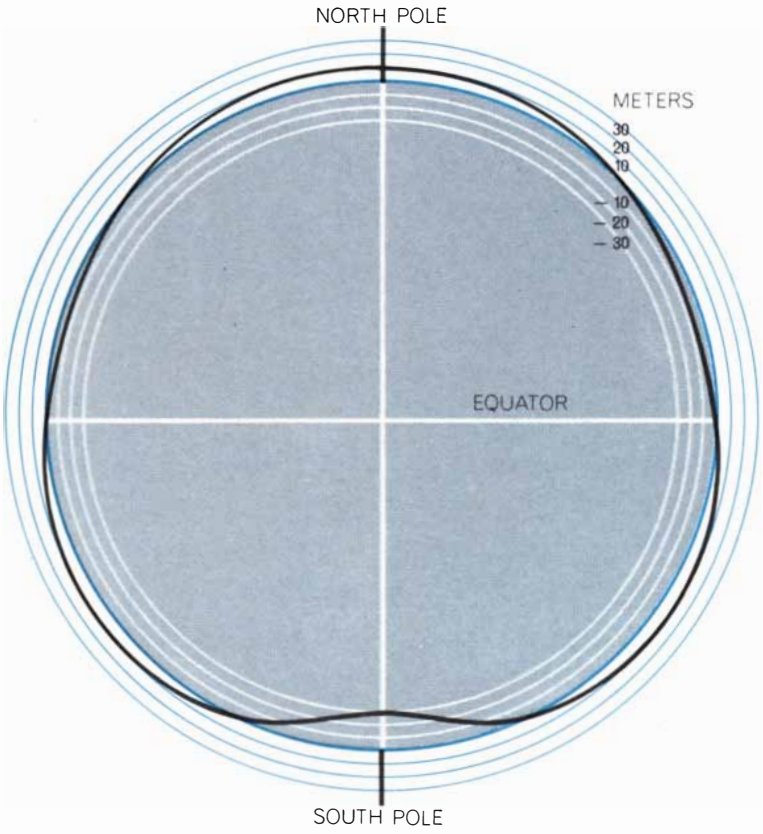
Such was the situation in October, 1957, when the first Sputnik was launched. Artificial satellites close to the earth offered a new and far more accurate instrument for measuring the earth's flattening. The key to the technique was to observe perturbations in the orbits of the satellites.

If the earth were perfectly spherical and had no atmosphere, a satellite would pursue the identical orbit month after month. (This assumption ignores the small attractions of the sun and moon.) Because the earth departs from a spherical form, however, its gravitational pull must vary with latitude, and the orbit of the satellite is therefore distorted.

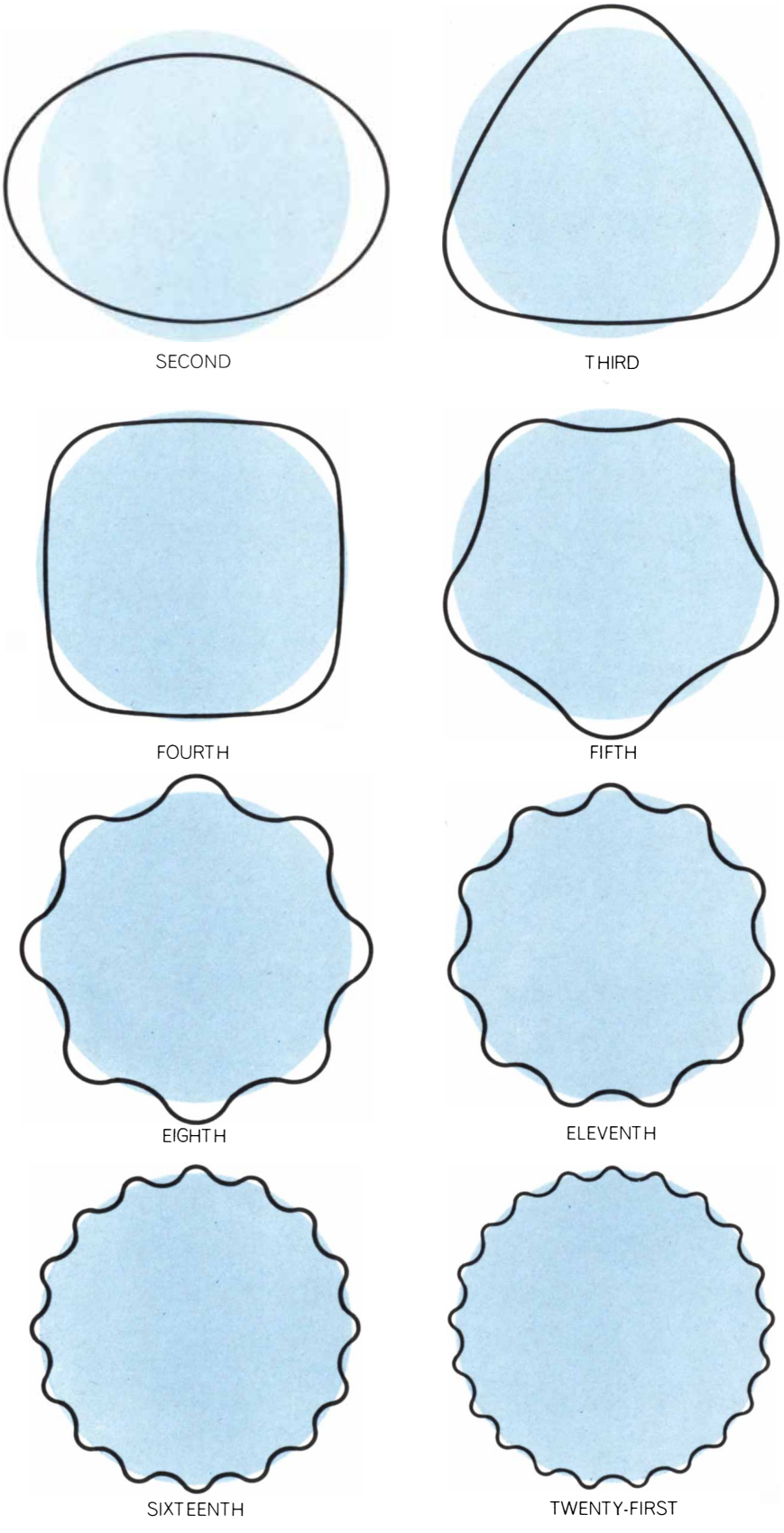
By far the largest departure of the earth from a spherical form is due to the flattening, or equatorial bulge. The gravitational pull of the equatorial bulge makes a satellite's orbit rotate around the earth's axis in the direction opposite to the satellite's motion [*see bottom illustration on opposite page*]. An observer in the depths of space looking at a satellite orbiting the earth would see the orbit of



SATELLITE ORBIT indicates the extent to which the earth is pear-shaped. Suppose that the orbit is inclined 40 degrees to the Equator and that the satellite's perigee, or closest approach to the earth, is 4,200 miles from the earth's center when perigee is farthest north; a few months later, when the perigee is farthest south, the distance is 4,207 miles.



CROSS SECTION of the earth through an arbitrary line of longitude would reveal the shape shown by the black line. Configuration is that of the geoid, or sea-level surface. Its deviations above and below a spheroid flattened one part in 298.25 are given in meters.



HARMONICS provide a way of determining mathematically the distortions of the earth's shape shown by satellites. The second harmonic reflects the equatorial bulge; the third, the fact that the earth is pear-shaped. By superposing an indefinite number of harmonics on the basic spherical shape of the earth one can build up any shape and any pattern of gravity representing departures from the sphere. Values to 21 harmonics have been calculated.

an eastward-moving satellite gradually drifting to the west. The more flattened the earth, the faster the drift. Since the actual drift is quite rapid—it can be as much as eight degrees per day—we can measure its numerical value very accurately by allowing it to build up for several weeks or even months.

Effects of the Satellites

The launching of *Sputnik I* in October, 1957, was a surprise to most people outside the U.S.S.R., and its orbit was not very accurately determined. A month later came *Sputnik II*. It was a bright object, and in Britain an extensive series of accurate observations was made with kinetheodolites, which are photographic instruments normally used for tracking missiles. From these observations the orbit of the satellite was accurately determined. By early 1958 it had become clear that the westward drift of the satellite's orbit was about .7 percent less than it ought to be if the previously accepted value of the flattening were correct.

The first American satellites, *Explorer I* and *Vanguard I*, were launched early in 1958 and were accurately tracked by the Minitrack radio system, now operated by the National Aeronautics and Space Administration. Within two or three months it became obvious that their orbits too were not drifting westward as fast as expected. Both the British and the American results suggested that the flattening of the earth was closer to one part in 298 than to one part in 297. In fact, this early finding has proved to be correct. The value is now known to be one part in 298.25.

There was little practical significance in the discovery that the earth was not quite as flattened as had been thought. Anyone contemplating a journey from the Equator to the pole and back again would travel 600 yards less than he might have expected to. The scientific consequences of the new value for the flattening were not so trivial. The geodesists, who made precise surveys of the continents, liked their measurements to be accurate to within 10 yards, and an error of several hundred yards at the very root of their calculations was not to be taken lightly. For this and other reasons the improved value of the flattening found in 1958, so soon after the first satellite launchings, was the prelude to a long series of analyses that have revealed the shape of the geoid in considerable detail.

What has been learned from the recent analyses is that it is a great over-

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International Telephone and Telegraph Corporation, New York, N.Y.

ITT

HARMONICS	KOZAI (1964)	KING-HELE AND COOK (1965)	SMITH (1965)
2ND	1,082.63	1,082.68	1,082.64
4TH	−1.63	−1.61	−1.70
6TH	.59	.71	73
8TH	−.15	−.13	−.46
10TH	−.15	−.09	−.17
12TH	−.29	−.31	−.22
14TH			19

EVEN HARMONICS are calculated as mathematical coefficients by Yoshihide Kozai of the Tokyo Astronomical Observatory and the Smithsonian Observatory, the author and a colleague, and David Smith of the Radio and Space Research Station in Slough, England.

simplification to describe the earth merely as a flattened sphere. The sphere has a number of irregularities that are also reflected in perturbations of the orbits of satellites. Although it may seem paradoxical, the best way to analyze the irregularities is by imposing on the basic spherical shape of the earth the regular but increasingly complex series of shapes called harmonics. In summing up the effect the harmonics would have on the orbit of the satellites, one arrives at a conception of the actual shapes that are affecting the satellites.

Complexities of the Geoid

Let us assume for the moment that the earth is symmetrical around its axis and apply the harmonics to the basic sphere [*see illustration on page 72*]. The first harmonic is always zero if, as is customary, the earth's center of mass is taken as being in the plane of the Equator. The second harmonic represents a tendency toward an ellipse rather than a circle. This harmonic is another way of describing the flattening. The second harmonic is by far the largest of the series.

The third harmonic represents a tendency toward a triangle, often called a pear shape because if it were exaggerated it would look like a pear. The fourth harmonic is, as it were, square, with four "corners." The fifth harmonic has five "petals." The sixth harmonic with six petals, the seventh with seven, and so on, can easily be visualized. In investigating the shape of the earth by analyzing satellite orbits we assume that the shape is made up of a large number of these harmonics and then find the numerical value of each one by measuring the characteristic changes it causes in satellite orbits.

We have already seen that the most important effect of the second harmonic —the flattening—is to make the orbit drift westward. All the even harmonics—the second, fourth, sixth and so on—have a similar effect. Therefore the values of the even harmonics are found by measuring the orbital drift of a number of satellites at different inclinations to the Equator. The successive harmonics have different effects at different inclinations, and so they can be sorted out from one another.

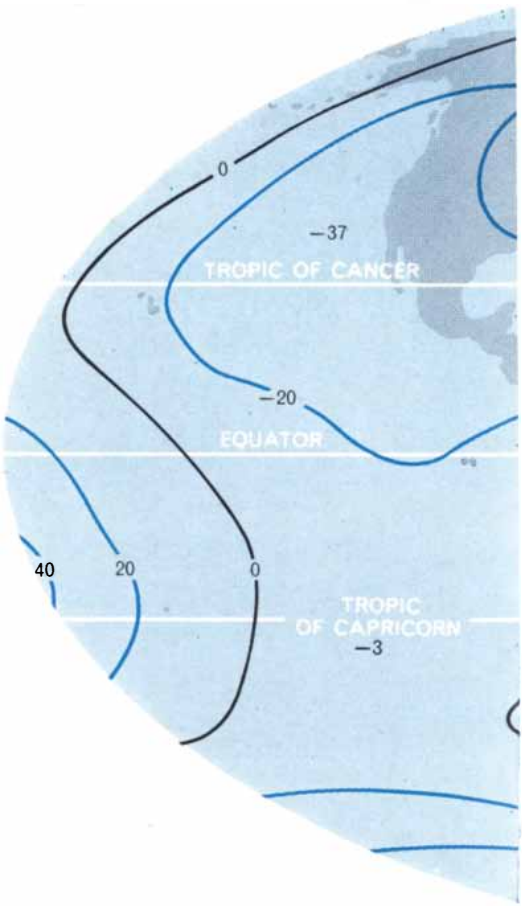
The best values obtained in three recent investigations show close agreement up to the eighth harmonic [*see illustration above*]. There is good reason for the differences between the values of the eighth harmonic and the higher ones in the three sets, namely the lack of near-equatorial orbits close to the earth. If someone would launch a satellite inclined at 10 degrees or less to the Equator, better values of the harmonics could be found. Either the American or the Russian launching agencies could easily send up a near-equatorial satellite orbiting at a height of about 600 miles. Unfortunately neither nation seems eager to secure the credit for this most unspectacular space first, and it may be left to the French, using their proposed equatorial launch site in Guiana.

The agreement among the three sets of values of even harmonics is really more important than the discrepancies. The values for the second harmonic, which gives the flattening, now agree to within one part in 40,000. The fourth and sixth harmonics are also in good agreement.

The Odd Harmonics

So much for the even harmonics. The odd harmonics—the third, fifth, seventh and so on—are found by analyzing quite a different feature of satellite orbits. The odd harmonics give rise to different shapes in the Northern Hemisphere and the Southern Hemisphere and so to gravitational pulls that differ in the two hemispheres. The main effect of the unequal pulls is to make a satellite approach closer to the earth's center when its perigee, or point of nearest approach, is in the Northern Hemisphere [*see top illustration on page 71*]. Suppose that when perigee is at its maximum latitude north, the distance from the center of the earth is 4,200 miles. As time goes on the perigee gradually moves; after a few months it travels south of the Equator. If the distance from the earth's center is measured, it is found to be about 4,207 miles—seven miles more than before.

This tendency was first noticed in the orbit of *Vanguard I* in the late summer of 1958. The little six-inch "grapefruit" satellite thus had the distinction of demonstrating that the earth is pear-shaped. The observed change implied that the tendency to a pear shape amounted to about 120 feet. That is, if you dug a hole through the ice at the North Pole and fell



MAP OF GEOID indicates the major humps and depressions found on the basic spheri-

into the sea, you would be about 120 feet farther from the Equator than someone who drilled through the 10,000 feet of ice to reach sea level at the South Pole.

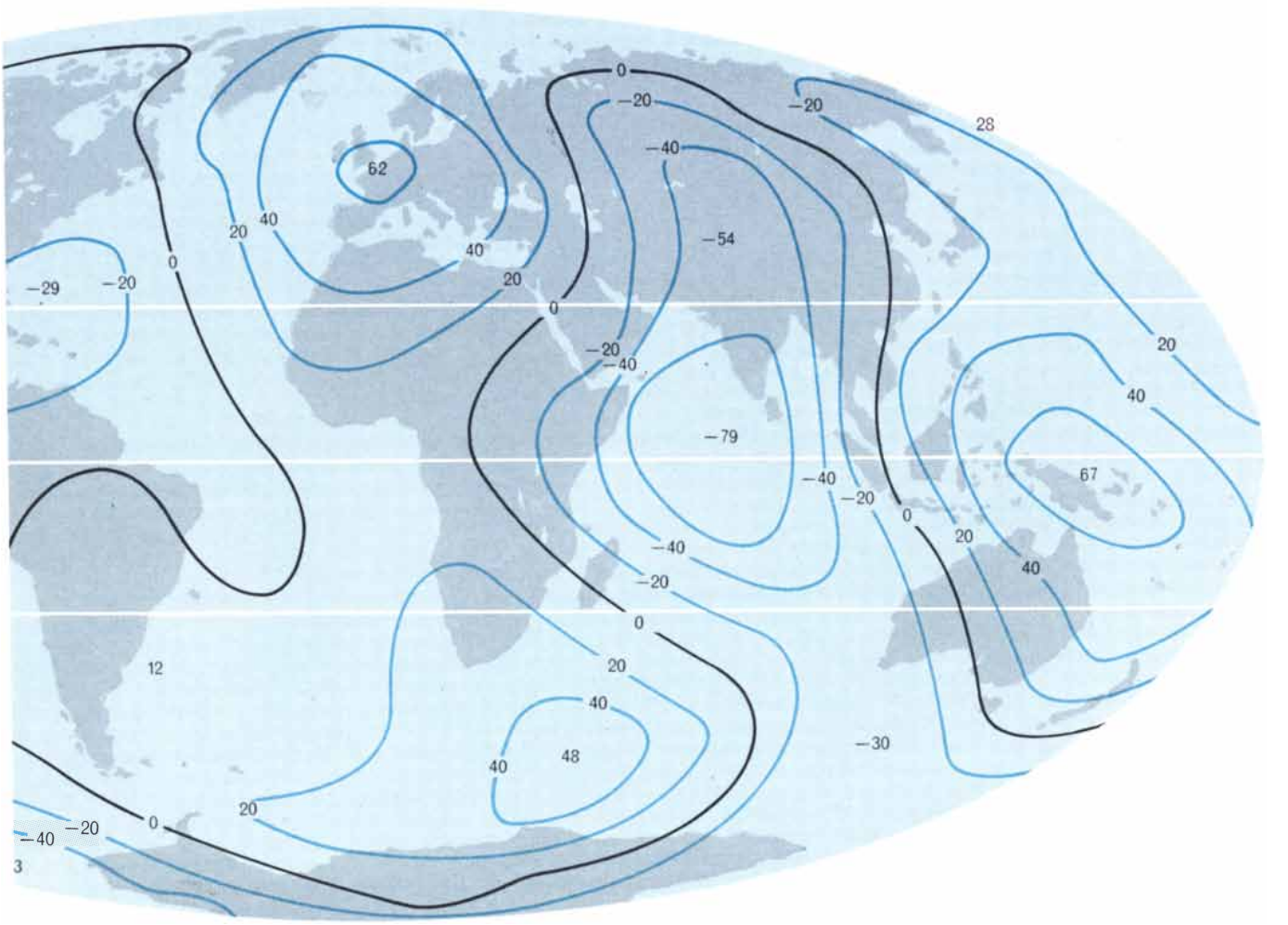
It came as a surprise to almost everyone that the earth was pear-shaped. Speculations that it might be so, however, go back a long way—to about 1500, a century and a half before even the flattening was recognized. The suggestion was made by Christopher Columbus, who gave it as his opinion that the earth was "not round in the way that is usually written, but that it has the shape of a pear (*la forma de una pera*)." Although he was merely guessing, his idea was strangely prophetic.

The third harmonic and all the other odd harmonics help to alter the distance of perigee from the earth's center as the perigee point swings from the Northern Hemisphere to the Southern Hemisphere. By measuring several orbits at different inclinations to the Equator we can find the values for the third, fifth, seventh and higher odd harmonics. The latest set of values goes up to the 21st harmonic, although we cannot yet be sure that the values beyond about the ninth harmonic are accurate [*see top illustration on next page*].

One interesting feature of the values of the odd harmonics is the large value of the 21st harmonic, which corresponds to a shape with 21 "petals." It is not really surprising that such high harmonics are important; the distance between two successive petals of the 21st harmonic is still about 1,200 miles. There are plenty of irregularities in the earth's surface that recur at distances of 1,200 miles or even less.

When we add up all the harmonics, the resulting shape of the earth is quite complicated. The bottom illustration on page 71 shows the earth's shape at sea level: the profile that would be seen if one could cut the earth in half through the poles, just as if it were a pear with the stalk at the North Pole. The cut shown in the illustration is not made at any specific longitude but represents an average over all longitudes. The scale of the illustration is exaggerated; the earth is not really concave at the South Pole. The illustration does show, however, that even after all the harmonics are included there is still a "stem" at the North Pole about 10 meters (33 feet) high, and that at the South Pole the sea-level surface is depressed by about 30 meters (100 feet). Humps and depressions have now revealed themselves at other latitudes as well. No one has yet satisfactorily explained why the "stem of the pear" is at the north rather than the south, but the alternate melting and solidifying of the south-polar ice down through the ages may well have had some influence.

This picture may seem complicated enough, but it is in some ways greatly oversimplified. So far we have taken no account of variations with longitude, having assumed that the Equator is an



cal shape of the earth by observation of satellites. The map is based on one prepared by William M. Kaula of the University of California at Los Angeles. The contours give the amount in meters by which the geoid differs from a sphere flattened one part in 298.25.

HARMONICS	VALUE
3RD	−2.50
5TH	−.26
7TH	−.40
9TH	0
11TH	−.27
13TH	.36
15TH	−.65
17TH	.30
19TH	0
21ST	.58

ODD HARMONICS are presented as they are currently calculated. Values of the third through the ninth harmonic are regarded as quite accurate; harmonics from the ninth onward may be revised with further data.

exact circle. Such variations are much smaller than the flattening, and much less easily measured, but a fairly clear picture has now emerged.

Even before the launching of satellites, the shape of the Equator could in principle have been found by taking a gravimeter—an instrument for measuring gravity—right around the Equator at sea level. Actually the project was quite impracticable, for two reasons. First, gravity could not at that time be measured accurately at sea, so that nearly 80 percent of the Equator was ruled out. Second, the thought of marching in a straight line from the mouth of the Amazon to Quito or through the African tropical forest was too daunting, and anyway most of the land was well above sea level. As a result surveys of gravity were confined to limited areas and the conclusions drawn were equally limited.

At first the advent of satellites did not help, because the variations of gravity with longitude have little effect on satellite orbits. The reason is that a satellite orbit tends to remain nearly fixed in space while the earth spins below it, so that the satellite tends to sample all longitudes equally during the course of a day. As a result it averages out the effects of variations with longitude.

	MILES
AVERAGE EQUATORIAL DIAMETER	7,926.42
POLAR DIAMETER	7,899.83
AVERAGE EQUATORIAL RADIUS	3,963.21
MAXIMUM EQUATORIAL RADIUS	3,963.25
MINIMUM EQUATORIAL RADIUS	3,963.16
NORTH POLAR RADIUS	3,949.93
SOUTH POLAR RADIUS	3,949.90

SUMMARY OF DATA on the shape of the earth as ascertained by observation of satellites is given in this table. The maximum equatorial radius is north of New Guinea; the minimum radius, south of India.

Determinations from Satellites

If the satellite can be observed every few hours, however, its response to the variations of gravity with longitude can be detected. Such observations were first achieved in 1961 by means of accurate optical observations made with the Baker-Nunn satellite-tracking cameras of the Smithsonian Astrophysical Observatory. Shortly afterward good results were obtained from the radio tracking of the U.S. Navy's navigational satellites. Both methods have subsequently been improved and refined, chiefly by workers in the U.S. Quite detailed maps have been made of the humps and valleys of the geoid.

A recent map of the geoid derived from satellite observations by William M. Kaula of the University of California at Los Angeles is shown in the illustration on the preceding two pages. (Other maps are available; they differ in detail but agree in their main features.) The map shows the height, in meters, of the geoid (mean sea-level surface) above a spheroid with a flattening of one part in 298.25, which is the best simple approximation of the earth's basic shape.

A good way of getting to know the map is to take an imaginary walk around the Equator at sea level, starting in Africa at longitude 20 degrees East and traveling east. At the starting point you are on the zero contour and therefore at the "correct" distance from the earth's center, 3,963.21 miles. As you battle your way across the Congo (or rather tunnel your way; remember, you must stay at sea level) and then swim across the Indian Ocean, you get steadily closer to the earth's center, reaching the bottom of the "valley" south of India, at 70 degrees East, where you are 79 meters, or 260 feet, closer to the earth's center, that is, 3,963.16 miles away. You then begin the climb toward the hump 67 meters (220 feet) high north of New Guinea. You are now 3,963.25 miles from the earth's center, 480 feet farther than when you were south of India. The rest of the journey is uneventful: you return to normal by mid-Pacific, then descend a depression a mere 20 meters deep off South America. From there onward you stay within 10 meters of the normal distance from the earth's center.

Away from the Equator, the highest hump is centered in western Europe. It is about 200 feet high. There are also two depressions, one near the South Pole about 175 feet deep and another, about 120 feet deep, off California.

This, then, is the present picture, arrived at by carefully analyzing the movements of satellites, deducing the exact pull of gravity on them and so finding the shape of the earth's free sea-level surface. The main statistics are summarized in the bottom illustration on this page.

Other Techniques

We should not forget another method of using satellites to measure the earth: the purely geometric technique. If a satellite is observed at exactly the same time by cameras in several different places, a triangulation network can be built up, just like the triangulation used by surveyors in map-making, except that with satellites the process is in three dimensions instead of two. This work has been pushed forward most vigorously by the U.S. Army Map Service, using the bright Echo satellites as the main targets, and by the Smithsonian Astrophysical Observatory, using their Baker-Nunn cameras to observe fainter satellites. Similar programs are also under way in eastern and western Europe. The chief aim is to determine the position of one ground station with respect to another. Such determinations are now being made with an accuracy of about 10 yards over distances of 1,000 miles or more. The procedures are also being applied over greater distances with the Pageos satellite. The use of lasers, which generate an intense beam of light that can be timed with great precision as it travels between a satellite and a ground station, has been started; these observations should yield distances accurate to perhaps one yard. Such methods are helping to fill in the detail in the world maps provided by analyzing the movements of satellites, which give the overall picture but do not show much detail within, say, a 1,000-mile square.

What can we say of future progress in determining the earth's shape from observations of satellites? Perhaps the safest prophecy is that progress will be rapid, for the new methods show no sign of being played out. The satellites were the first instruments to make a truly worldwide inspection of the earth, and the immediate successes of 1958 and 1959 have been followed up by more careful and detailed analyses. Every year brings better and better answers to the age-old problem of the earth's shape.

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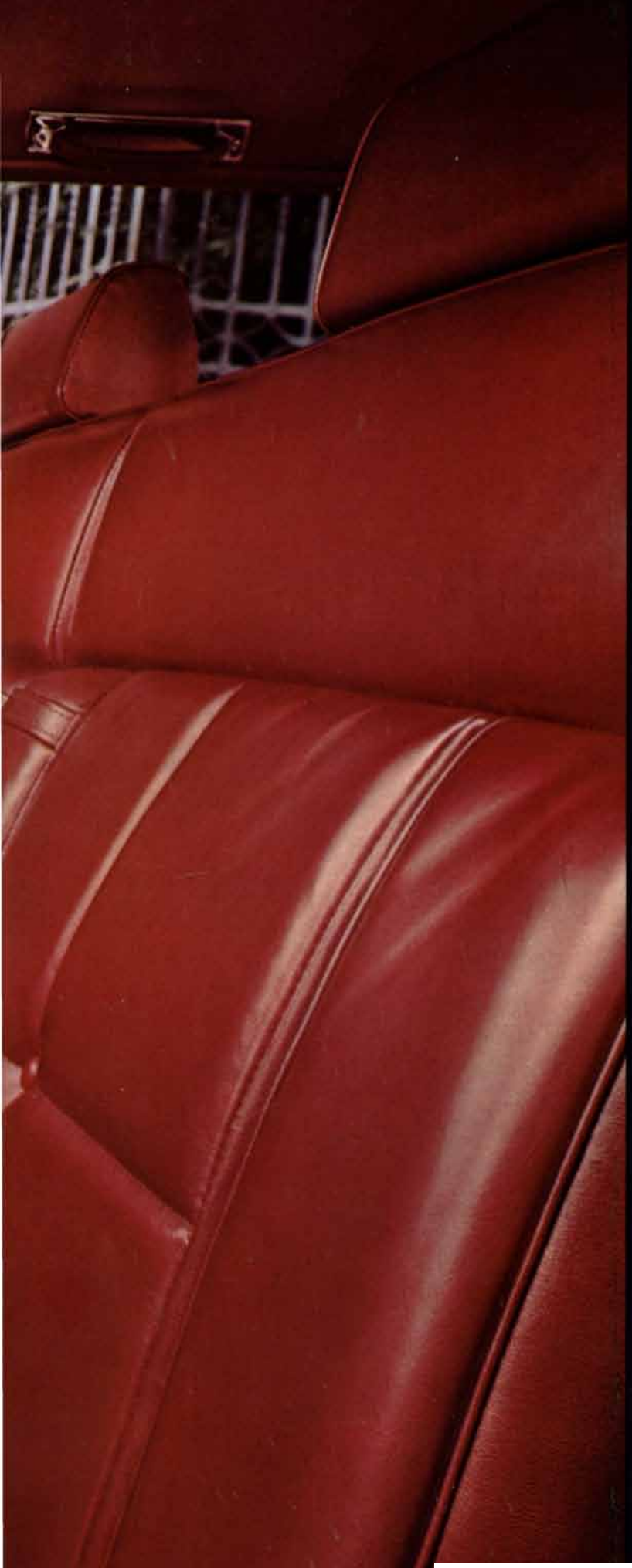

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You do not choose between the greater or the lesser.
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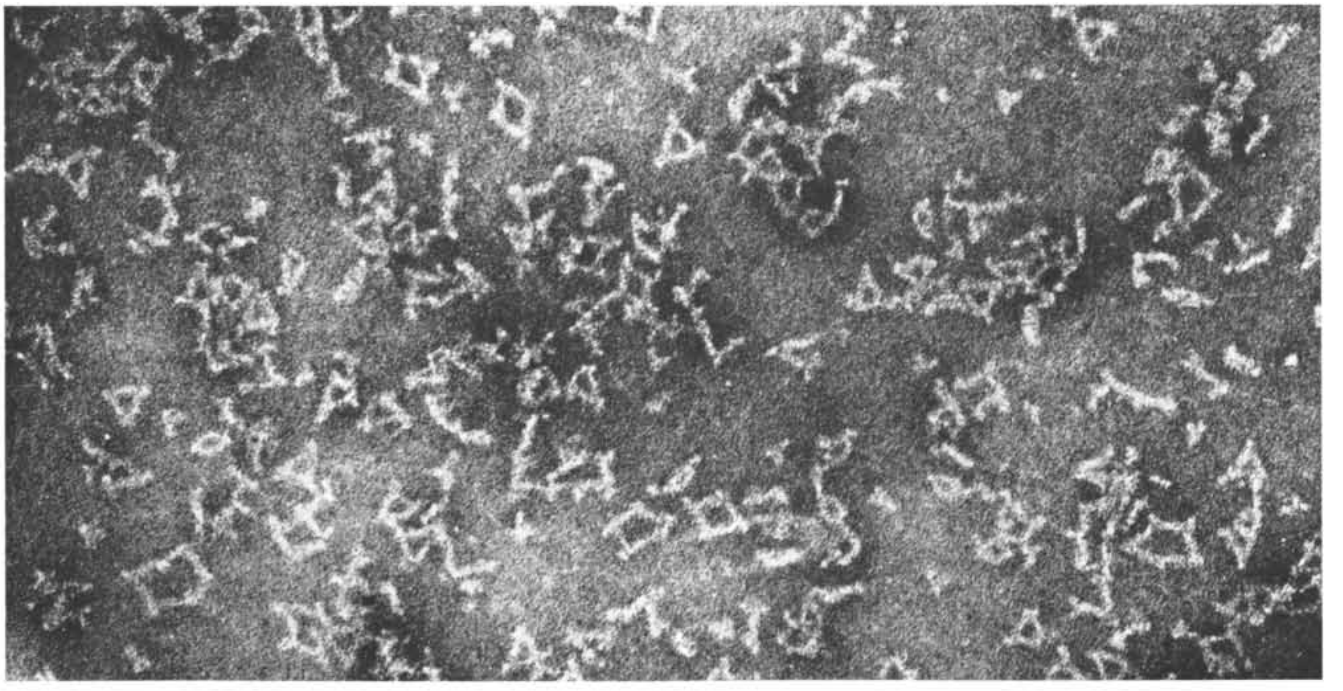
The Structure of Antibodies

The basic pattern of the principal class of molecules that neutralize antigens (foreign substances in the body) is four cross-linked chains. This pattern is modified so that antibodies can fit different antigens

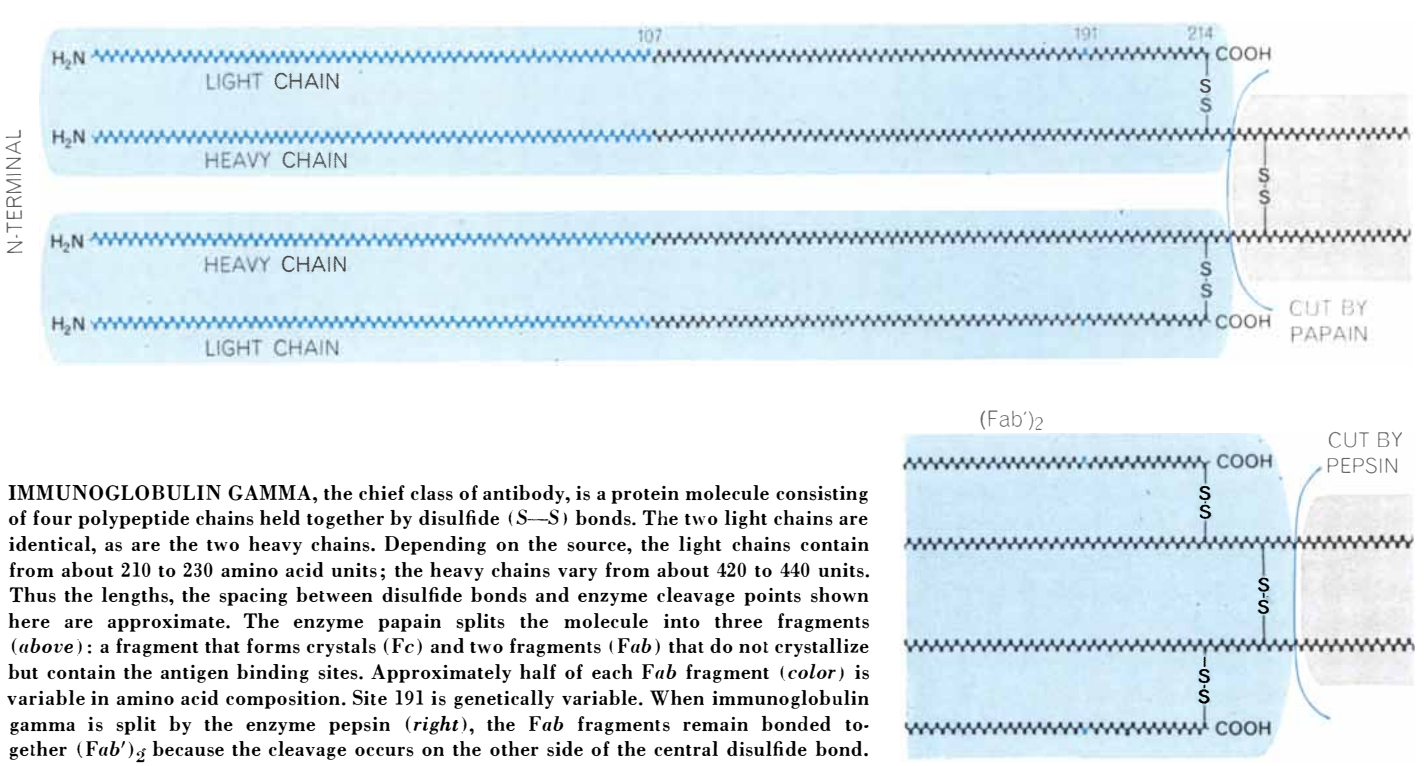
by R. R. Porter

It has been known for millenniums that a person who survives a disease such as plague or smallpox is usually able to resist a second infection. Indeed, such immune people were often the only ones available to nurse the sick during severe epidemics. A general understanding of immunity had to await the discovery that microorganisms are the causative agents of infectious disease. Then progress was rapid. A key step was taken in 1890 by Emil Von Behring and Shibasaburo Kitasato, working in the Institute of Robert Koch in Berlin. They showed that an animal could be made immune to tetanus by an injection of the blood serum obtained from an animal that had survived the disease and had developed immunity to it. Serum is the clear fluid that is left behind when a blood clot forms; it contains most of the blood proteins. Thus immunity to tetanus is a function of a substance or substances in the blood. These substances were named antibodies.

Antibodies are produced by all vertebrates as a defense against invasion by certain foreign substances, known collectively as antigens. The most effective antigens are large molecules such as proteins or polysaccharides (and of course the microorganisms that contain these molecules). The demonstration of the appearance of antibodies in the blood is most dramatic if the antigen is a lethal toxin or a pathogenic microorganism: the immune animals live and the nonimmune die when injected with the antigen. Innocuous substances such as egg-white protein or the polysaccharide coat of bacteria, however, are equally effective as antigens. The antibodies formed against them can be detected by their ability to combine with antigen. This can be shown in many ways. Perhaps the simplest demonstration is provided by the precipitate that appears in a test tube when a soluble antigen combines with antibody contained in a sample of serum. The most remarkable aspect of this phenomenon is the specificity of the antibody for the antigen injected. That is, the antibody formed will combine only with the antigen injected



ANTIBODIES BOUND TO ANTIGENS are depicted in this electron micrograph made by Michael Green and Robin Valentine of the National Institute for Medical Research in London. The antigen itself is too small to be visible, but it evidently acts as the coupling agent that binds antibody molecules together to form the various multisided structures. The magnification is about 275,000 diameters.



IMMUNOGLOBULIN GAMMA, the chief class of antibody, is a protein molecule consisting of four polypeptide chains held together by disulfide (*S—S*) bonds. The two light chains are identical, as are the two heavy chains. Depending on the source, the light chains contain from about 210 to 230 amino acid units; the heavy chains vary from about 420 to 440 units. Thus the lengths, the spacing between disulfide bonds and enzyme cleavage points shown here are approximate. The enzyme papain splits the molecule into three fragments (*above*): a fragment that forms crystals (Fc) and two fragments (Fab) that do not crystallize but contain the antigen binding sites. Approximately half of each Fab fragment (*color*) is variable in amino acid composition. Site 191 is genetically variable. When immunoglobulin gamma is split by the enzyme pepsin (*right*), the Fab fragments remain bonded together $(Fab')_2$ because the cleavage occurs on the other side of the central disulfide bond.

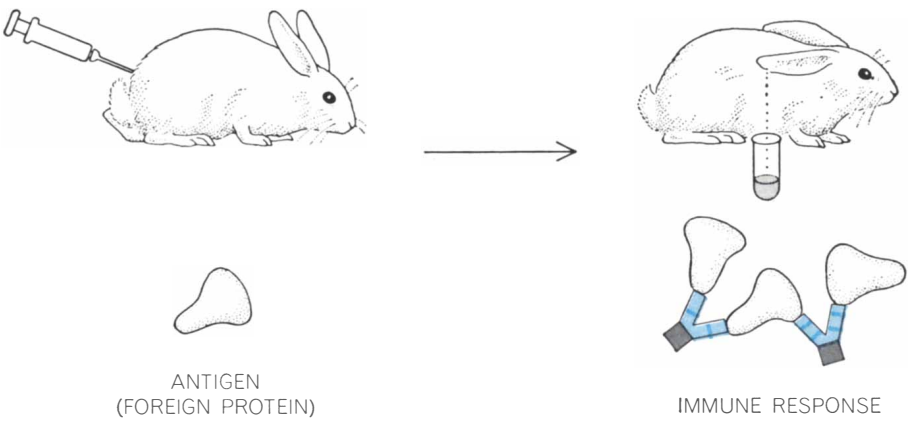
or with other substances whose structure is closely related.

Numerous different antibodies can be formed. Although an individual animal may respond poorly, or perhaps not at all, to a particular antigen, there is no known limit to the number of specific antibodies that one species, for example the rabbit, can synthesize. Conceptually there is a great difference between the capability of one species to synthesize a very large but limited number of antibodies and the capacity to synthesize an infinite number, but an experimental decision as to which is correct is not possible at present.

All antibodies are found in a group of related serum proteins known as immunoglobulins. The challenge to the protein chemist lies in the fact that antibody molecules are surprisingly similar even though they possess an enormous range of specific combining power. Although it is clear that there must be significant differences among antibodies, no chemical or physical property has yet been found that can distinguish between two antibody molecules: one able to combine specifically, say, with an aromatic compound such as a benzene derivative and the other with a sugar, although the benzene compound and the sugar have no common structural features. Antibodies of quite unrelated specificity appear to be identical, within the limits of present experimental techniques, except, of course, in their specific combination with antigen.

An antibody can be isolated from the serum of an immunized animal only by using the special property of allowing it to combine with the antigen, freeing the complex from the other serum proteins and then dissociating and separating the antibody and antigen. This can be done by allowing a precipitate to form, washing the precipitate well with salt solution and then suspending the precipitate in weak acid. Under these conditions the antibody-antigen precipitate will dissolve and dissociate, and the antibody and antigen can be separated from each other to yield the purified antibody. As we shall see, however, even this purified material usually contains a variety of antibody molecules that differ slightly in their molecular structure.

If an animal has not been immunized, it will still have a good concentration of immunoglobulin in its blood, usually about 1 percent by weight. This material is believed to be made up of many thousands of different antibodies



MIXTURE OF SIMILAR ANTIBODIES can be produced by injecting a rabbit or other animal with a purified antigen, typically a large protein of foreign origin. In response the animal produces antibodies, primarily immunoglobulin gamma, that are able to bind specifically to the antigen. Evidently a given antigen provides many different binding sites, thus giving rise to many different antibody molecules. If blood is removed from the animal

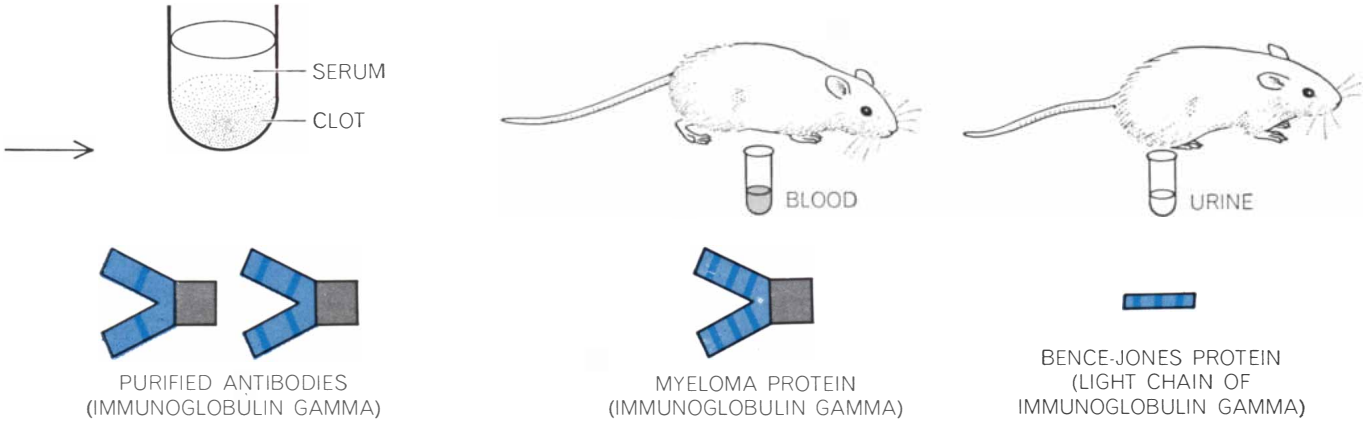
against microorganisms the animal has encountered during its lifetime or against other antigenic substances that accidentally entered its body. Evidence that this view is correct comes from experiments in which small animals have been born and raised in an entirely germ-free environment. Under these conditions the immunoglobulin content of the blood is much lower, perhaps only 10 percent of the immunoglobulin in the blood of a normal animal, suggesting that mild infections are the main source of antigens.

The immunoglobulins can be isolated from serum by the usual methods of protein separation. Hence the protein chemist has available for study two general kinds of immunoglobulin fraction: a complex mixture of many antibodies and purified antibodies that have been isolated by virtue of their specific affinity for the antigen. It would seem to be a relatively straightforward task, after the great progress made in the techniques of protein chemistry in recent years, to carry out detailed studies of such material and pinpoint the differences. Clearly structural differences responsible for the specific combining power of antibodies must exist among them and should become apparent.

Major difficulties have arisen, however, because the immunoglobulins have been found to be a very complex mixture of molecules and the complexity is not necessarily due to the presence of the many different kinds of antibody. One difficulty is that there are three main classes of immunoglobulins distinguished chemically from one another by size, carbohydrate content and amino acid analysis. Antibodies of any specificity can be found in any of the classes; hence there is no correlation between class and specificity. The class present in the largest amounts in the blood and the most easily isolated is called immunoglobulin gamma. Since most of the work has been done with this material I shall limit my discussion to it.

Immunoglobulin gamma has a molecular weight of about 150,000, corresponding to some 23,000 atoms, of which a carbohydrate fraction forms no more than 2 or 3 percent. Chemical studies have shown that the immunoglobulin gamma molecule is built up of four polypeptide chains, which, as in all proteins, are formed from strings of amino acids joined to one another through peptide bonds. The four chains are paired so that the molecule consists of two identical halves, each consisting of one long, or heavy, chain and one short, or light, chain. The four chains are held to one another by the disulfide bonds of the amino acid cystine [*see illustration at top of these two pages*]. If the disulfide bonds are split, the heavy and light chains are still bound to each other. If, however, they are put in an acid solution or one containing a substance such as urea, they dissociate and can be separated by their difference in size.

Immunoglobulin gamma molecules can also be split by proteolytic enzymes such as papain, which breaks the molecule into three pieces of about equal size. Two, known as F*ab* (for "fragment antigen binding"), appear to be identical, and the third, known as F*c* (fragment crystalline), is quite different. F*ab* is so named because it will still combine with the antigen although it will not pre-

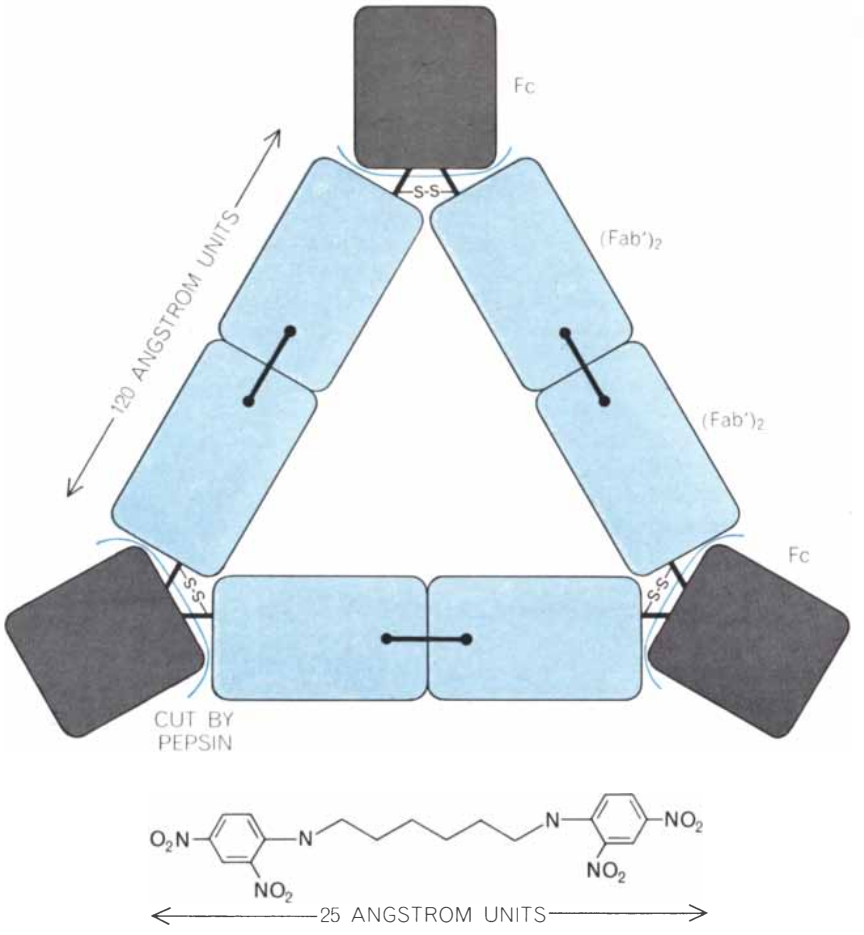


and allowed to coagulate, antibodies can be isolated from the serum fraction. Even when purified by recombination with the original antigen, immunoglobulin gamma molecules produced in this way vary slightly.

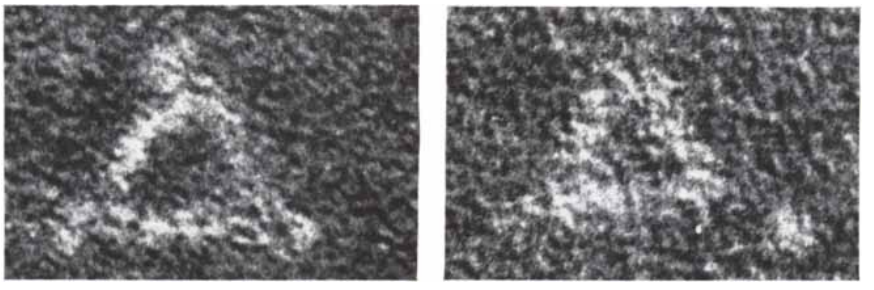
IDENTICAL ANTIBODY-LIKE MOLECULES are produced in large numbers by mice and humans who suffer from myelomatosis, a cancer of the cells that synthesize immunoglobulin. These abnormal immunoglobulins, all alike, can be isolated from the animal's blood (*left*). Often an abnormal protein also appears in the urine (*right*). Called a Bence-Jones protein, it seems to be the light chain of the abnormal immunoglobulin.

cipitate with it. Each F*ab* fragment carries one combining site; thus the two fragments together account for the two combining sites that each antibody molecule had been deduced to possess. The F*c* fragment prepared from rabbit immunoglobulin gamma crystallizes readily, but neither the F*ab* fragments nor the whole molecule has ever been crystallized.

Since crystals form easily only from identical molecules, it was guessed that the halves of the heavy chain that comprise the F*c* fragment are probably the same in all molecules and that the complexity is mainly in the F*ab* fragments where the combining sites are found. The enzyme papain, which causes the split into three pieces, can hydrolyze a great variety of peptide bonds, and yet only a few in the middle of the heavy chain are in fact split; it looks as if in the F*ab* and F*c* fragments the peptide chains are tightly coiled in such a way that the enzyme cannot gain access. This suggests a picture in which three compact parts of the molecule are joined by a short flexible section near the middle of the heavy chain.



ANTIBODY-ANTIGEN COMPLEX seen in electron micrographs (*below and page 81*) is thought to have this triangular structure. Below it, drawn to a large scale, is the synthetic antigen: a six-carbon chain carrying a dinitrophenyl group at each end. Three such antigen molecules appear able to bind together three immunoglobulin gamma molecules.



EFFECT OF PEPSIN COMPLEX is demonstrated in electron micrographs taken by Green and Valentine. In the normal complex formed by immunoglobulin gamma and the dinitrophenyl compound (*left*) a typical triangular structure contains a small lobe, or lump, at each corner, which is thought to be the F*c* part of the immunoglobulin molecule. If the antibody is first treated with pepsin, which splits off the F*c* fragment, the remaining (F*ab'*)$_2$ molecule still reacts with the antigen but the corner lobes are missing (*right*).

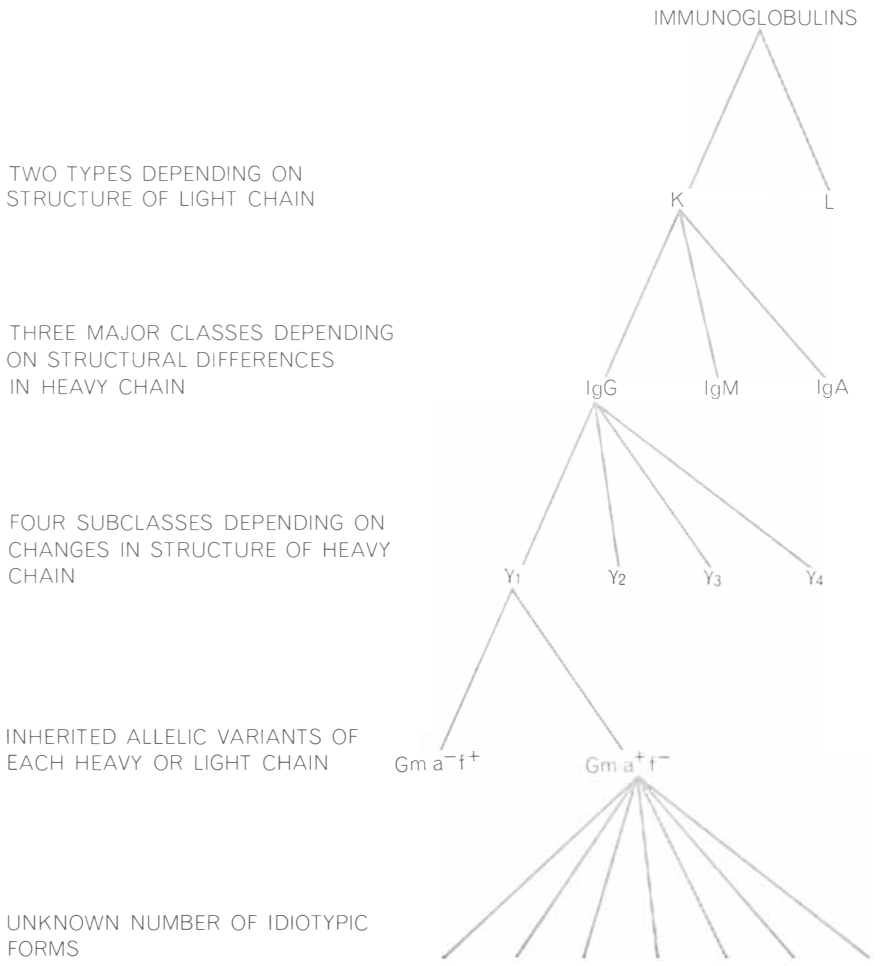
The full structure of a protein molecule showing the arrangement in space of the peptide chains and the positioning of the amino acids along them can at present only be achieved by X-ray crystallography. Such work has been started at Johns Hopkins University with the F*c* fragment. Electron microscopy, however, can provide much information about the shape of protein molecules, and successful electron microscope studies have been made recently with rabbit antibodies. When the antibodies are free, no clear pictures are obtained, which suggests that the molecules have a loose structure that is without definite shape. If they are combined with antigen, however, good pictures can be made. Michael Green and Robin Valentine of the National Institute for Medical Research in London prepared antibodies in rabbits that would combine with a benzene derivative known as a dinitrophenyl group. This can be done, as Karl Landsteiner showed many years ago, by injecting into the rabbit a protein on which dinitrophenyl groups have been substituted. Antibodies are formed, some of which combine specifically with the substituent dinitrophenyl coupled onto other proteins or into smaller molecules.

Green and Valentine investigated the smallest compound carrying two dinitrophenyl groups that would cross-link two or more antibody molecules. This proved to be a six-carbon chain with a dinitrophenyl group at each end. This material does not form a precipitate with antibody, but with the electron microscope one can see ringlike structures that appear to contain three to five antibody molecules [*see illustrations on page 81 and at left*]. The small antigen molecule is not visible. The three-component structure is believed to consist of three antibody molecules linked by three molecules of invisible antigen. The lumps protruding from the corners are thought to be F*c* fragments. This interpretation is supported by using the proteolytic enzyme pepsin to digest off the F*c* fragment, leaving two F*ab* molecules held together by a disulfide bond and referred to as (F*ab'*)$_2$. When these (F*ab'*)$_2$ molecules are combined

with antigen, rings are formed as before, but the lumps at the corners are now gone, confirming the idea that they were indeed the F*c* part of the molecule.

Since most interest centers on the antibody combining site, the next problem to solve is whether the site is to be found in the light chain, which is entirely in the F*ab* fragment, or in the half of the heavy chain that is also present, or whether the site is formed by both chains together. It has not been possible to get a clear answer to this problem because the chains cannot be separated except in acid or urea solutions; this causes a partial loss of the affinity for antigen, which is not recovered even after the acid or urea is removed. Present evidence suggests that the heavy chain is the most important but that the light chain plays a role. This may be because it actually forms a part of the site or because it helps to stabilize the shape that the heavy chain assumes and hence plays a secondary role that may be only partially specific.

In any case, the field is clear for a direct attempt at comparative studies of the chemical structure of the light chain as well as of the half of the heavy chain that lies in the F*ab* part of the molecule. The shape and hence the specificity of the combining site must depend on the configuration of the peptide chains of the F*ab* fragment; this is believed to be determined only by the sequence of the different amino acids in the chain. Therefore it is reasonable to expect that if the amino acid sequence is worked out for the F*ab* half of the heavy chain and perhaps also for the light chain, then in some sections sequences will be found that determine the configuration of the combining site and that will be characteristic for each antibody specificity. Attempts to carry out such sequence studies, however, seemed unattractive because of convincing evidence that all preparations of immunoglobulin gamma—even samples of purified antibodies obtained by precipitation with a specific antigen—were actually mixtures of many slightly different molecules with presumably different amino acid sequences.



SUBDIVISIONS OF HUMAN IMMUNOGLOBULIN presented investigators with a difficult problem to unravel. For simplicity, subdivisions are shown for only one branch at each level. The abbreviation "*IgG*" stands for immunoglobulin gamma, the antibody found in largest amounts and the one most easily isolated. Idiotypic forms are apparently unique to individual animals and may involve alterations in both the light and the heavy chains.

Although the complexity of immunoglobulin gamma (and of the other classes of immunoglobulins) has presented investigators with a most difficult puzzle, considerable progress has now been made in solving much of it [*see illustration on this page*]. First, there are two kinds of light chain, named kappa and lambda, but in any one molecule both light chains are of the same type. The molecules containing kappa chains are known as *K* type and those with lambda chains as *L* type. Then in some species (probably in all) the immunoglobulin gamma class contains several subclasses; four have been identified in human gamma globulin. The subclasses differ in their heavy chains, which carry not only the characteristic features of the class but also small differences that distinguish the subclasses. In any one individual, molecules will be found of both *K* and *L* type, and they belong to all the subclasses. In addition each of the kinds of chain shows differences, known as allelic forms, that are inherited according to Mendelian principles. In an individual homozygous for this property only one allelic form of, say, the kappa chain will be present, but in a heterozygous individual there will be two forms of the kappa chain. It scarcely need be stressed that all these phenomena lead to a very complex mixture of molecules of immunoglobulin gamma in the serum of any individual. Yet there is still another kind of complexity termed idiotypic. In certain circumstances it is possible for an animal to synthesize antibody molecules that are unique to itself, distinct from other antibody molecules of the same specificity in other individuals of the same species—and distinct from all other immunoglobulins in its own blood.

Perhaps the most remarkable aspect of all of this is that the complexity seems to bear no relation to the structure of the antibody combining site. As far as we know at present, any antibody specificity may be found on any of these many different kinds of molecule.

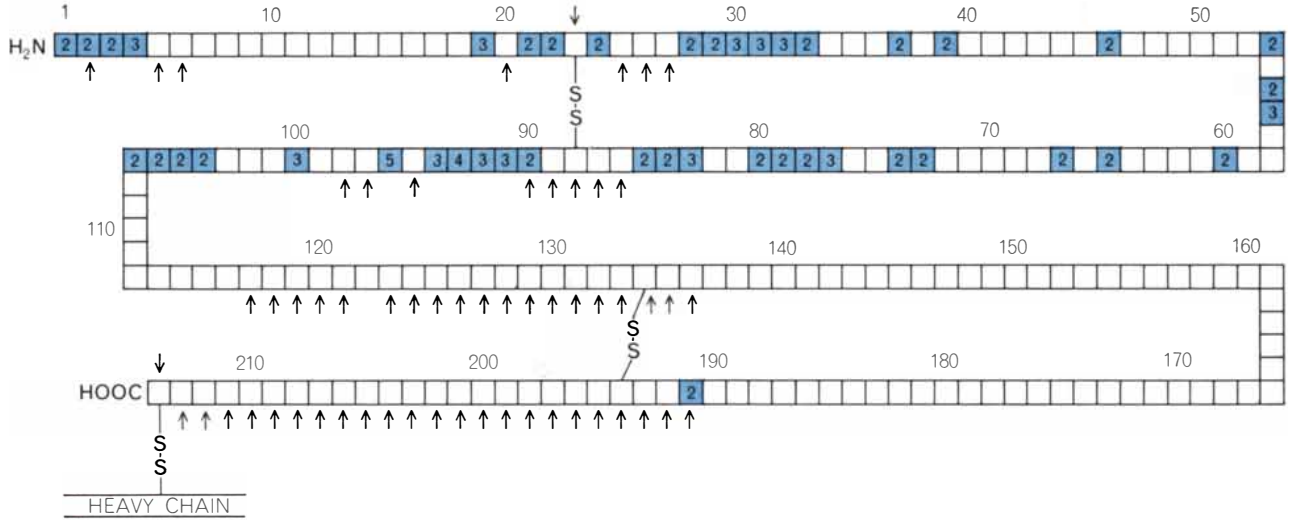
All such variations are likely to be based on differences in amino acid sequence, and already some differences relating to subclass and allelic changes have been identified. The structural differences are so small, however, that it is not possible to separate out single kinds of molecule by the methods available for the fractionation of proteins.

Thus it was a great step forward when it was recognized that in certain forms of cancer, immunoglobulin molecules of apparently a single variety appear in the blood. Such immunoglobulins have only one type of light chain and one subclass of heavy chain, and each chain belongs to one or the other allelic form. As far as we know each chain has only one amino acid sequence and therefore belongs to only one idiotypic form.

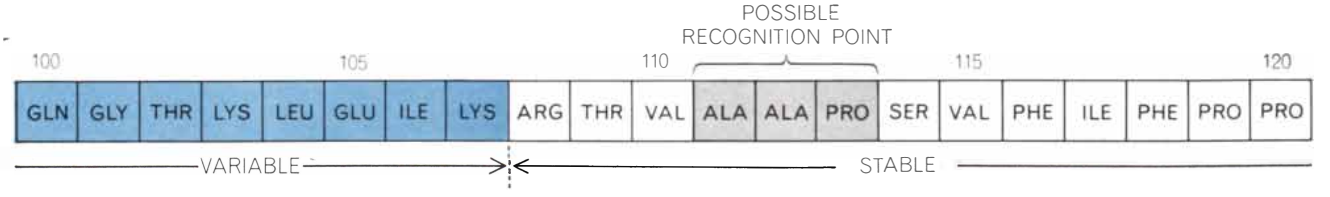
The disease responsible for this unique production of antibody is known as myelomatosis. Observed in both mice and men, it is a cancer of the cells that synthesize immunoglobulin, often those in the bone marrow. Apparently a single cell, one of the great number that synthesize immunoglobulins, starts to divide rapidly and leads to an excessive production of a single kind of immunoglobulin. This provides evidence, incidentally, that the complexity of immunoglobulin molecules arises from their synthesis by many different kinds of cells. These abnormal immunoglobulins are known as myeloma proteins. Because they are often present in the blood in a concentration several times higher than all the other immunoglobulins together, they can be isolated rather easily.

Moreover, in about half of all myeloma patients an abnormal protein appears in the urine in large amounts. This substance was first observed by Henry Bence-Jones at Guy's Hospital in London in 1847 and has been known ever since as Bence-Jones protein. Its nature, however, was not recognized until five years ago, when Gerald M. Edelman and J. A. Gally of Rockefeller University and independently Frank W. Putnam of the University of Florida showed that Bence-Jones protein is probably identical with the light chains of the myeloma protein in the serum of the same patient. Because Bence-Jones proteins can be obtained easily, without any inconvenience to the patient, they were the first materials used for amino acid sequence studies.

Although complete sequences have been worked out for only two Bence-Jones proteins in the mouse and only three human Bence-Jones proteins, perhaps 20 more have been partially analyzed. A remarkable fact has emerged. It seems that all Bence-Jones proteins of the same type have exactly the same sequence of amino acids in the half of the molecule that ends in the chemical group COOH (hence known as the C-terminal half) but show marked variation in the half that ends in the group



IMMUNOGLOBULIN LIGHT CHAIN, represented by analyses of human Bence-Jones proteins of the *K* type, has 214 amino acid units. Colored squares show where amino acids have been found to vary from one protein to another; blank squares show where no variation has yet been found. Numbers in the squares indicate how many different amino acids have been identified so far at a given site. Arrows mark positions where a particular amino acid has been found in at least five different proteins. Complete amino acid sequences are now known for three human Bence-Jones proteins and partial sequences for about 20 others. All variations occur in the first half of the chain with one exception, the variation at position 191. This is related to the allelic, or inherited, character of light *K* chains, hence differs from the alterations in the variable half of the chain. The diagram is based on one recently published by S. Cohen of Guy's Hospital Medical School in London and C. Milstein of the Laboratory of Molecular Biology in Cambridge.



ALA ALANINE
ARG ARGININE
GLN GLUTAMINE
GLU GLUTAMIC ACID
GLY GLYCINE
ILE ISOLEUCINE
LEU LEUCINE
LYS LYSINE
PHE PHENYLALANINE
PRO PROLINE
SER SERINE
THR THREONINE
VAL VALINE

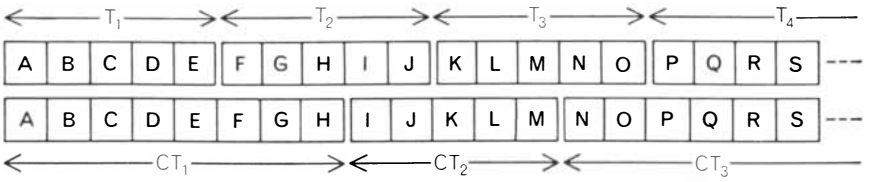
MIDDLE PART OF LIGHT CHAIN, as determined for one human Bence-Jones protein (*K* type), includes the amino acids at positions 111, 112 and 113 that are common to both *K*- and *L*-type Bence-Jones proteins of humans and to *K*-type Bence-Jones proteins of mice. It has been suggested that the section of the gene coding for this sequence may provide a special "recognition point" for the joining of two different genes responsible for the variable and stable sections of the light chain or, possibly, for bringing into play a mechanism to change the amino acid sequence in the variable section **(*see illustration on page 90*).**

NH_2 (the N-terminal half). Of 107 amino acid positions in this half, at least 40 have been found to vary. No two Bence-Jones proteins have yet been found to be identical in the N-terminal half, so that the possibility of molecular variation is clearly great. Given the possibility of variation at 40 sites and supposing that only two different amino acids can occupy these sites, it would be possible to construct 2^{40}, or more than 10 billion, different sequences. Actually as many as five different amino acids have been found to occupy one of the variable sites [*see upper illustration on opposite page*].

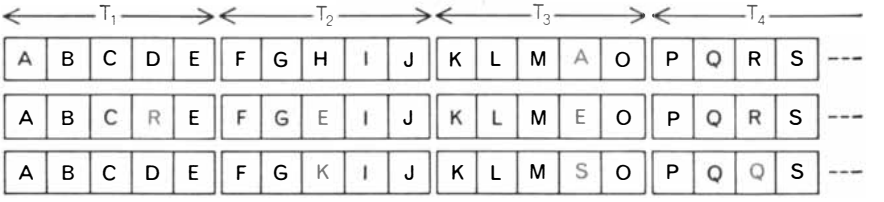
The amino acid sequence studies of the heavy chain are less advanced than those with the Bence-Jones proteins because the material is more difficult to obtain and is more than twice the length. Results with the heavy chain of two human myeloma proteins, however, have shown them to have many differences in sequence for more than 100 amino acids from the N-terminal end, whereas the remainder of the chain appears to be identical in both cases. Accordingly it seems certain that the heavy chains will show the same phenomena as the light chains; it is possible that the length of the variable section in both chains will be similar.

Inasmuch as both variable sections are in the F*ab* fragment of the molecule it seems obvious that these sections must participate in creating the many different antibody combining sites. All the work discussed here has been done with myeloma proteins, and since each has a single amino acid sequence in both heavy and light chains, it would follow that each will be a specific antibody against one of an untold number of different antigenic sites. The chances, therefore, of finding a myeloma protein in which antibody specificity is directed to a known, well-defined antigenic site seemed small. Nevertheless, several myeloma proteins have recently been found to possess antibody-like activity against known antigens. A comparison of the sequences of their heavy and light chains may give a lead as to where the combining site is located.

It has been believed with good reason that myeloma proteins are typical of normal molecules of immunoglobulin gamma, each being a homogeneous example of the many different forms present. It thus seemed likely that any attempt to determine the amino acid sequence of immunoglobulin gamma from a normal animal would be impossible, especially in the variable region that is of particular interest. One would expect normal immunoglobulin gamma to be a mixture of many thousands of different molecules, each with a different sequence in the variable region.



DETERMINATION OF AMINO ACID SEQUENCE in the polypeptide chains of proteins depends on the use of enzymes that cleave the chains into short fragments next to particular amino acids. The sequence in the resulting fragments can then be established. Thus trypsin might split a chain into fragments T_1, T_2, T_3 and T_4. Another enzyme, chymotrypsin, might split the same chain into fragments CT_1, CT_2 and CT_3. Since these fragments must overlap one can establish their order unequivocally and thereby the sequence of the entire chain.



IMMUNOGLOBULIN SEQUENCE should be amenable to analysis even though a particular antibody sample might contain a variety of slightly different molecules. Slight variations at certain positions (*color*) should not prevent the ordering of similar fragments.

One can see that if this method were attempted with a protein that was in fact a mixture of many slightly different proteins, each with a different sequence, a hopelessly confusing picture would probably result. The work with the myeloma protein suggested, however, that there would be a constant part as well as a variable part, and it seemed worthwhile to see what progress could be made in determining at least the constant part. Work at Duke University showed that the whole of the F*c* section of the heavy chain of normal rabbit immunoglobulin gamma gave a coherent sequence and was therefore part of the stable section, as had been expected. Recent work in our laboratory has now shown that the coherence continues well into the other half of the heavy chain. Although the work is far from complete, it seems possible that a full sequence will be established right through the entire heavy chain. Variations have been picked up in a number of positions and no doubt many more will be found, but the results are not completely confusing, as might have been expected if normal immunoglobulin gamma were a mixture of many thousands of myeloma proteins, each with substantially different sequences in the variable parts of the chain. The conflict between the results with the myeloma proteins and the recent results with normal rabbit immunoglobulin may be more apparent than real.

What does all this mean in terms of the structure of antibodies and their power to combine specifically with antigens? The phenomenon of a variable section and a stable section in both heavy and light chains is extraordinary and is unique to immunoglobulins; the variable section is in the part of the molecule known to contain the combining site. It therefore seems certain that this must be the basis of the specific configuration of the combining site.

It should be emphasized that all this work is very incomplete. In another year or so it will undoubtedly be much easier to see just how different one myeloma protein is from another in both the heavy and the light chains. It may be that the differences between any two

KLH launches an inquiry into "Subjective Value."

(SURVEY)

Question #1

How much would you pay to keep your wife one more year?

DO YOU REMEMBER the game kids used to play in school where you were asked how much money it would take to get you to sell your country's secrets? (Assuming no torture.) Or your dog?

It was a way of thinking about the value you *really* placed on a thing.

One of the first things you learned was that "features" had very little to do with it. (For example, if your country had had 20 more rivers, or your dog's tail wagged at 86 Per Minute—six less than an "average" dog's—the answer would hardly have changed.)

When KLH began making stereo equipment ten years ago, our founders (K., L., and H.) noticed that grownup manufacturers talked as though features had *everything* to do with value. We hated that. We still do.

"Feature:" Injecting 380 horsepower into cars that have no plausible market save those who commute back and forth over the Bonneville Salt Flats.

Or Again: Advertising 300 watts of power in a high priced stereo console unit to give it the *appearance* of value. (Neglecting to mention that large numbers of watts have nothing to do with hearing the music accurately, or even loudly, both of which depend on what kind of equipment you've squeezed the watts into. 35 watts in good equipment will do far better.)

42-22-36

To define worth solely in terms of features is like determining the "market value" of a wife from her height, age, weight, width of smile, tendency to suntan evenly, and the number of pounds of food she is capable of cooking up in an evening.

It's true enough we all like to have *something* explicit to help our thinking. Even Consumer Reports will sometimes find itself detailing competitive features and statistics; akin to Playboy's 42-22-36 ratings.

But studying the centerfold and accompanying data simply doesn't give us all the information we really need. What does? Well, probably nothing short of a few years in the same house together.

BASEBALL PLAYER

Packard had it right, way back in the twenties, when its advertising rested on the confident slogan "Ask The Man Who Owns One."

(It was a new kind of "testimonial" but it's been watered down since. How is a man today to depend on testimonials to choose, say, his cigarette brand when dozens of equally beloved baseball players can't get together about which is best?)

Still, the principle of determining value through testimonials makes very good sense:

Economists, for instance, say value can be understood as "some measure of the sense of loss one experiences after being deprived of a commodity or service," or, ask the man who owns one how much he'd dislike losing it. (The boy contemplating his dog's worth figured it out the same way.)

Any other way of measuring value, like establishing a ratio between features and price, is at best only a guess, made *before* anyone could possibly know.

DEPRIVED OF YOUR WIFE

What we propose, then, is a technique of *measuring* the sense of loss as a way of thinking about "Subjective Value;" i.e., what a commodity means to someone who has it.

So. Assume for a moment that you are about to be deprived of your wife. (Substitute husband or "good friend" where applicable.) How much would you pay in dollars to keep her one more year? When you're through thinking about that one, fill in No. 1 and have a look at the rest of the questionnaire.

You see what we're up to here.

We began on this idea because we already have evidence (based upon a comparison of the number of hours owners sit listening to KLH phonographs as opposed to other brands) that our $300 stereo system is cherished somewhat more than at least one $400 system we could name; and perhaps twice as much as another $300 set.

Doubtless the same situation exists among magazines—some are surely valued more than others—or sewing machines, or autos, or toothpaste. Toothpaste? Well, we'll soon see, and if you're interested we will be pleased to let you know what we learn.

QUESTIONNAIRE

If one or more of these questions interests you, then kindly fill in the blank spaces that apply and mail to the address we have listed at lower right. For our part, we will gladly send you a tally of the results of this questionnaire, and others we are doing in subsequent ads, if you also add your name and address. Thank you.

1 (See Headline). _____.

2 Are you a subscriber to this publication? _____. If not, do you read every issue of it? _____. If your answer is yes to either of these, and you were informed that because of financial difficulties the publication might discontinue publishing, how much would you be willing to pay for one more issue rather than be deprived of it? _____. One more year's subscription? _____.

3 Do you have telephone service at home? _____. If yes, assume you now pay an average of $20 monthly for this service. How much additional would you pay, rather than be deprived of it? _____.

4 The automobile you now own was purchased in what year? _____. At what price? _____. What make? _____. Assuming it's in good running order, and that you couldn't get another one like it, how much would you pay to keep it during the upcoming year? _____.

5 Do you own a piano? _____. What kind? _____. How much did you pay for it? _____. How long ago? _____. How much would you pay to keep from being deprived of it? _____.

6 Do you regularly use a particular brand of toothpaste? _____. If yes, which brand? _____. Assuming you were informed that because of financial difficulties your brand of toothpaste might go out of business. How much would you be willing to pay, above its present cost, to have one more tube, rather than be deprived of it? _____.

7 Assume for the moment that an offer was being made for your wife's wedding dress. How much would you be willing to sell it for? _____. What does your wife say? _____.

8 Do you own stereo equipment at home? _____. A console? _____. A one-piece table model? _____. A three-piece system? _____. Components? _____. Which make(s)? _____. How much did it cost you to buy? _____. How long ago? _____. If you were about to be deprived of the set you now own, and knew you could not get another of the same kind, how much would you be willing to pay to keep it? _____.

(If you worry that by putting your name below you may be subjecting yourself to a barrage of KLH literature, or that we may send a salesman around, or sell your name to some "list house," rest easy. We won't. Though if you would like to have a catalog and the name of the store near you that sells our equipment, please so indicate in the appropriate box.)

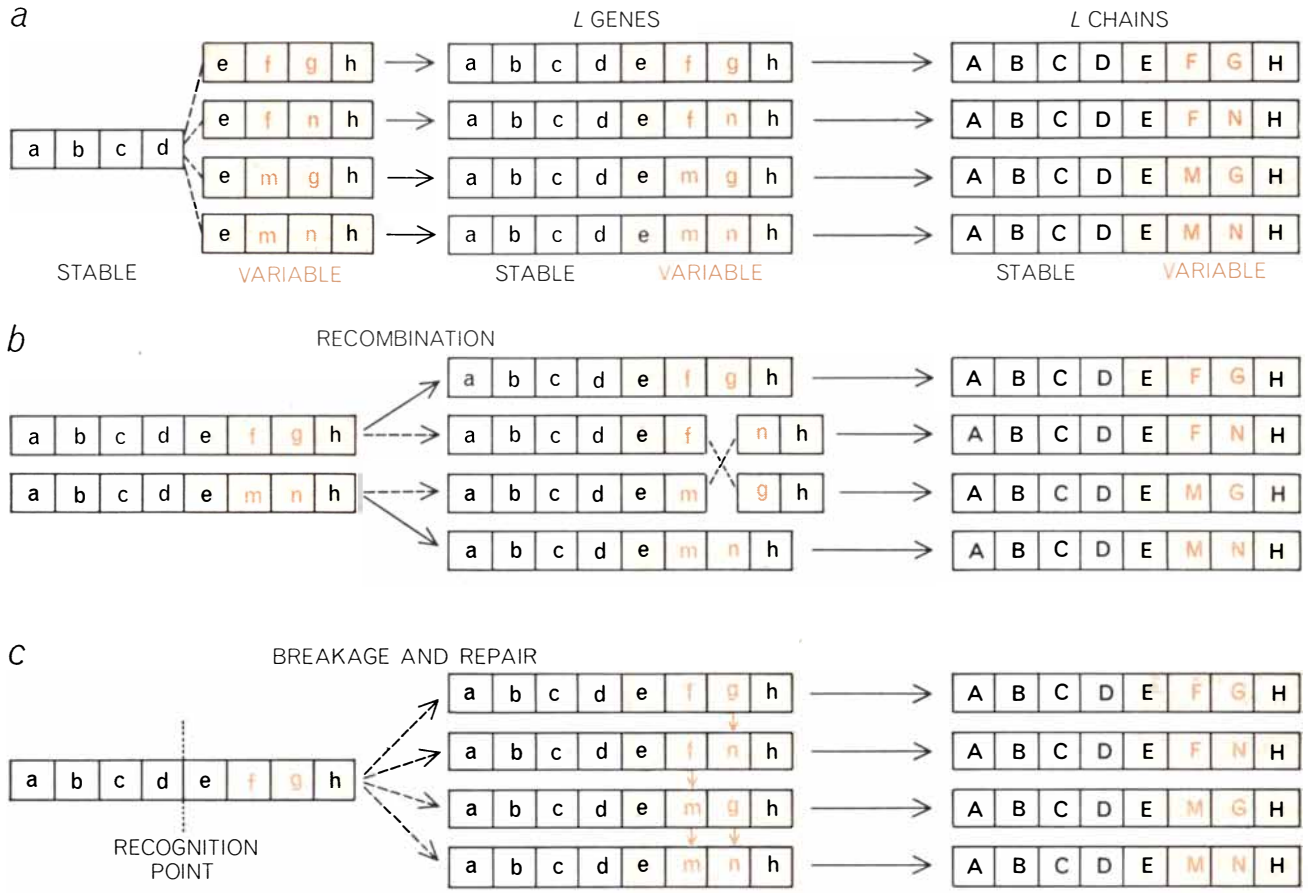
Name _____

Address _____

City _____ State _____ Zip _____

☐ Please send catalog ☐ Forward survey results

Mail to: Henry M. Morgan, Pres., KLH Research and Development Corp., 30 Cross St., Cambridge, Mass. 02139



VARIABILITY OF IMMUNOGLOBULIN MOLECULES has been explained by three principal hypotheses. The simplest (*a*) suggests that one gene codes for the stable section of each chain and that a great number, perhaps hundreds of thousands, code for the variable section. A second idea (*b*) is that several genes are divided into stable and variable sections and that the latter interchange parts during cell division. A third proposal (*c*) suggests that there may be a recognition point in the gene (*see lower illustration on page 86*) and that an enzyme partially splits, or breaks, the gene on the variable side of that point. When repaired by other enzymes (*arrows*), mistakes are made, thus giving rise to many different amino acid sequences in the antibody molecule.

will on the average be small, so that for a mixture of many molecules the amino acid in any one position will be common to 80 or 90 percent of the molecules [*see lower illustration on page 87*]. Presumably this explains how it is possible to find a comprehensible amino acid sequence in normal immunoglobulin gamma.

It may also be, however, that myeloma proteins are not quite typical of normal antibodies. Because they are the result of a disease they may exaggerate a normal phenomenon. Although they are invaluable in drawing attention to a fundamental mechanism, they may mislead us by exhibiting greater variability than is present in normal immunoglobulin gamma.

Whatever the answer, the existence of a stable section and a variable section, which has been shown so clearly in the Bence-Jones proteins and which also occurs in the heavy chains, is a remarkable phenomenon. The mechanism of its biological origin has aroused intense interest. Many hypotheses have been put forward, but there are perhaps three principal ones [*see illustration above*].

A straightforward mechanism would be to have a single gene coding for each stable section in the antibody molecule and as many genes as necessary (tens of thousands or hundreds of thousands) coding for the variable sections. The cell would also be provided with a means for fusing the product of the two kinds of gene to construct the complete immunoglobulin molecule. (In this as in the other suggestions, the presence of an antigen would somehow trigger production of the appropriate antibody.)

A second proposal invokes the concept of genetic recombination, which involves the exchange of parts of genes. One can imagine several genes that are divided into a stable portion and a variable portion. During cell division, when genes are pairing and duplicating, the variable portion would interchange sections, thereby giving rise to many different genes capable of coding the variable parts of the antibody molecule.

The third suggestion visualizes that the gene for, say, the light chain may contain a "recognition point" midway in its structure [*see lower illustration on page 86*]. This might provide a specific attachment site for an enzyme that can split the nucleic acid of the gene only on the side coding for the variable section. When the broken portion is repaired by other enzymes, mistakes are made, thereby giving rise to many different sequences of nucleotides—the nucleic acid building blocks that embody the genetic message. These differences are then translated into different amino acid sequences in the variable portion of the antibody molecule.

There is no clear answer as to which methods, if any or all, are the operative mechanisms, but a continuation of the structural studies may provide a clearer understanding. When this understanding is attained, it should lead to ideas about how to change, stimulate or suppress immune reactions as medical practice requires and therefore should be of great practical value as well as solving one of the most intriguing problems in biology.

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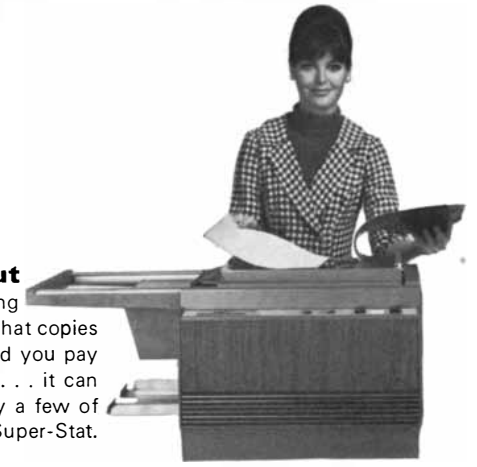

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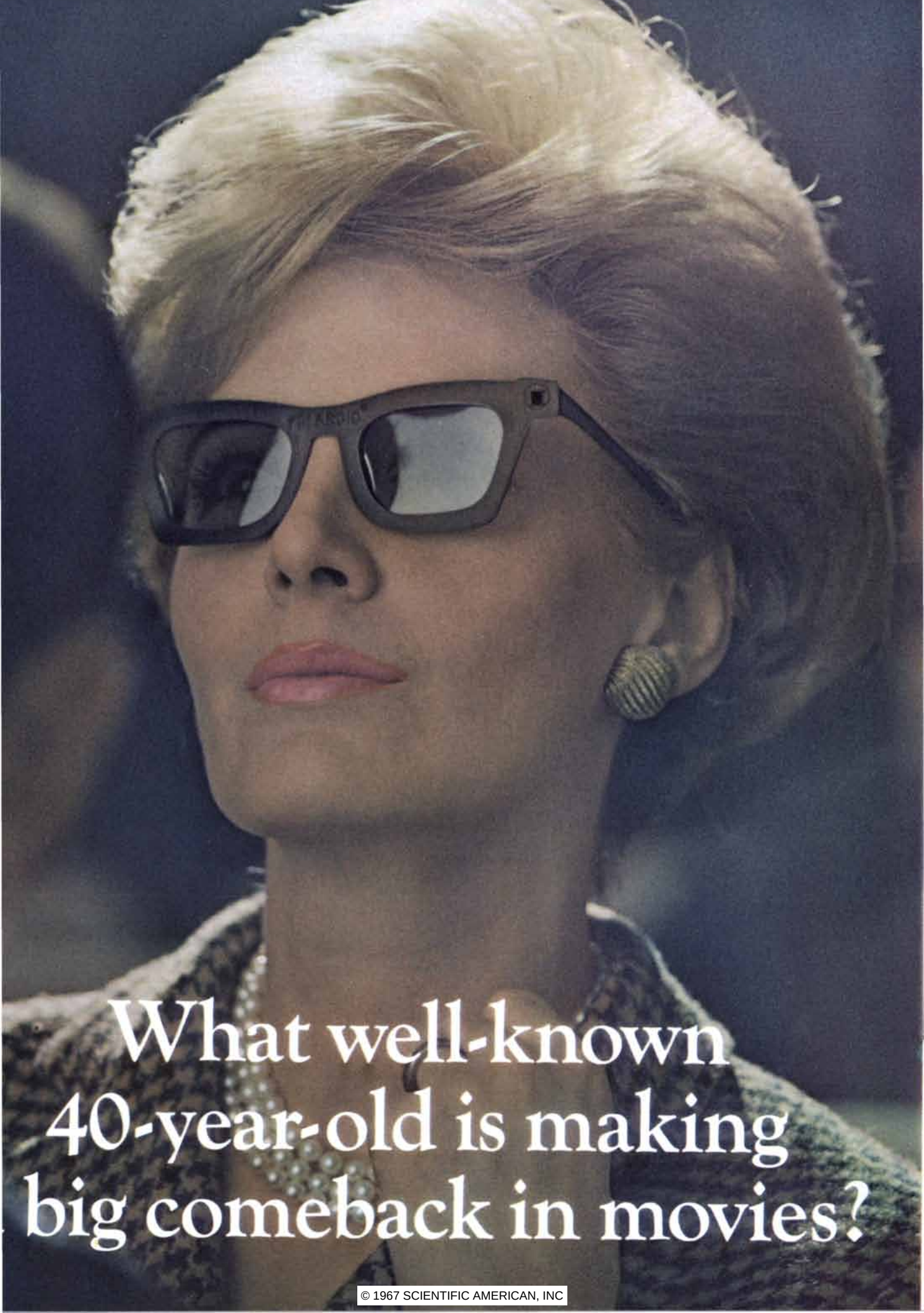


The 40-year-old isn't the lady. It's the glasses she's wearing. They contain Polaroid linear polarizing filters which were invented in 1927.

Each filter contains a molecular grid which excludes all light rays except those which vibrate perpendicularly to the bars in the grid. This characteristic has given polarizing filters a wide range of uses in science and industry.

In the 1950's the Polaroid filter found a new commercial application It made 3-D movies in color possible. Here's how the process worked:

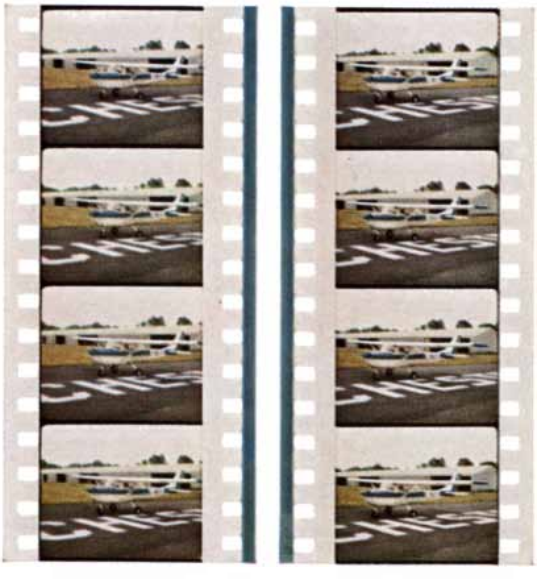
Perception of depth starts from the fact that the right eye point of perspective is different from the left eye point of perspective. The brain translates this difference into perception of a three-dimensional world.

To duplicate this phenomenon, the 3-D movies of the 1950's were made by filming a scene simultaneously with two cameras (placed to correspond to the right and left eyes of a viewer).

The resulting right and left images were then superimposed on the movie screen through a pair of movie projectors.

In order to code the right and left images for the respective right and left eyes of the audience, the right image was projected through a polarizing filter having its polarizing axis at 45 degrees clockwise from the vertical, and the left image was projected through another filter with its polarizing axis 45 degrees counterclockwise. The screen had an aluminized surface so that it did not depolarize the light.

Old technique: left eye and right eye images on their respective filmstrips.



Polarizing stereo glasses with lenses oriented right and left to correspond to the right and left projection filters were placed over the eyes of the viewer to decode the image on the screen. Thus, the right eye saw only what was "seen" by the right camera, and the left eye saw only what was "seen" by the left camera.

New technique: left eye and right eye images alternating on a single filmstrip.

Under ideal conditions, 3-D gave an excitingly realistic illusion of depth to the screen.

Unfortunately, conditions were seldom ideal. It was almost impossible to maintain perfect synchronization and registration of images with two films running through two projectors. And 3-D was more apt to give eyestrain than pleasure.

But now there's a new 3-D process, SPACE-VISION (utilized in "The Bubble," a film by Arch Oboler). The right and left images are photographed through two lenses as before. However, through the use of prisms, the images are recorded one above the other on a *single* strip of film. The film is then projected through another set of prisms and lenses which superimpose the right and left images on the screen.

With both images on one film, and with prisms and lenses in fixed positions, synchronization and registration can be perfect.

In addition, the proportions of this image (as compared with the old 3-D image) provide the widest possible picture on the screen. This extends the picture to the area of the viewer's peripheral vision and further enhances the illusion of depth.

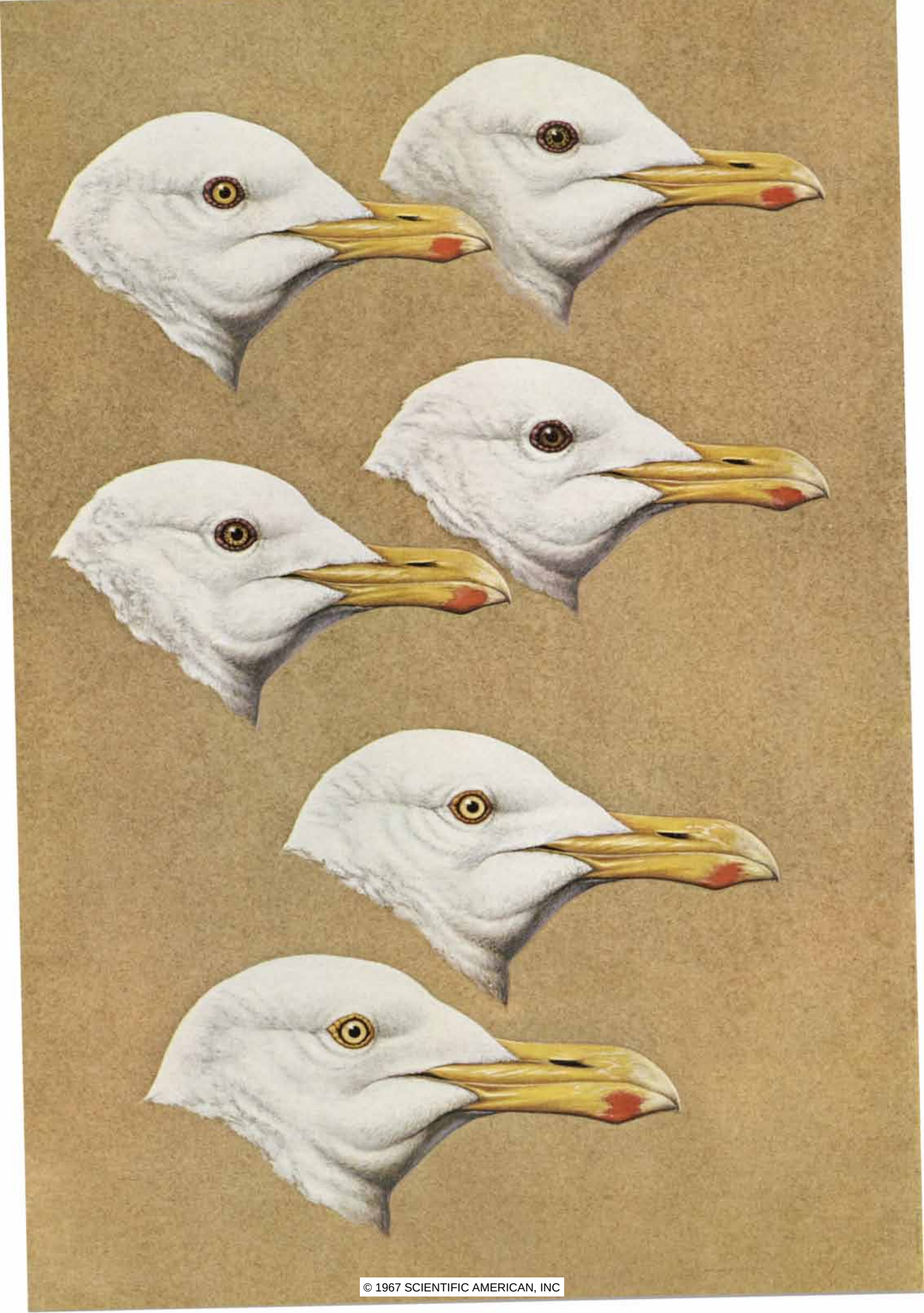
Coding and decoding the right and left images is still accomplished with the kind of Polaroid polarizing filters that made the first 3-D movies possible.

Our present viewers are slightly larger than their predecessors (to encompass the wider screen). And the original paper frames have been replaced with plastic (so they fit comfortably, even over eyeglasses).

Those are the only improvements they needed. (How many other 40-year-olds in show business hold up that well?)

POLAROID CORPORATION

CAMBRIDGE, MASS.



VISUAL ISOLATION IN GULLS

Some species of gulls live together and look alike, yet they do not interbreed. How do the species remain isolated? Experiments in the Arctic indicate that they do so by recognizing subtle visual signals

by Neal Griffith Smith

Gulls look remarkably alike. That was the problem. Differences in appearance among the large gulls of the genus *Larus* can be subtle: a slight variation in size or a change in the color of the wing tips or of the eye and the small fleshy ring around the eye. Observing differences of this kind, an ornithologist discriminates among species of the genus. The problem arose from the fact that the gulls are equally discriminating. In some places *Larus* species that seem virtually indistinguishable nest side by side, yet they do not interbreed. How do gulls of one species avoid interbreeding with gulls of another?

The question of how species acquire and maintain their identity has received much attention in the century since the publication of Charles Darwin's *Origin of Species*. It is now well established that geographic isolation between populations is of prime importance in initiating the process by which species arise. Indeed, the gulls of the Northern Hemisphere have been cited as a classic example supporting this concept.

The common ancestor of the *Larus* gulls probably emerged in the Siberian region. As these gulls spread to the east and west, simple geographic distance began to inhibit the flow of genes between the most distant populations. By the time these populations had spread around the hemisphere and overlapped in western Europe, their respective genetic backgrounds were different enough so that hybrids between them were at some disadvantage; thus they did not interbreed. The advance and retreat of the ice during the Pleistocene epoch caused a further fracturing and recombination of these circumpolar gull populations. In some cases the differences evolved were not critical enough to confer a disadvantage on hybrids; thus the rejoined populations interbred.

It seems clear that the mechanisms by which species discriminate among one another evolved gradually during the process of species formation. In the Canadian Arctic, and probably elsewhere in the north, the ice intruded between various gull populations at different times and for different lengths of time. Accordingly the isolating mechanisms were likely to be at different stages of development in different populations. By studying populations in such an area one can uncover what these mechanisms are.

It is one thing to identify differences in the appearance of two closely related species living side by side and infer that the differences function as a barrier to interbreeding. It is quite another to demonstrate that these features are actually utilized in the isolation of species. To explain how such features work is still another step. This article is primarily concerned with the last two problems. It also considers the evolutionary history of the *Larus* gulls, because the elucidation of a feature that is utilized in species isolation can suggest what the species were like in the past and how the isolation mechanisms evolved.

The four species of *Larus* gulls I have been studying comprise the Canadian portion of the complex of gull populations around the North Pole. The fact that the four species do not interbreed has been clearly established by other workers and myself. All four gulls have a white body and a gray back and wings. The largest in body size is the glaucous gull (*Larus hyperboreus*). The tips of its wings are white, the iris of its eye is yellow and the fleshy ring around the eye is an even brighter yellow. Colonies of glaucous gulls are found throughout the polar area; in the eastern part of the Canadian Arctic they usually nest on cliffs. A more familiar species is the herring gull (*L. argentatus*), the only one of the four that breeds in the continental U.S. It is a medium-sized bird with wing tips that are partly black and partly white. Like the glaucous gull, the herring gull has a yellow iris; its eye-ring, however, is orange. In the Arctic this species usually nests on the ground in marshy areas. About the same size and coloration is Thayer's gull (*L. thayeri*), except that in this species the iris of the eye is dark brown and the eye-ring is a reddish purple. Thayer's gull nests almost exclusively on towering cliffs. The smallest of the four species (although not by very much) is Kumlien's gull (*L. glaucoides*), which also nests on cliffs. It is most like Thayer's gull: its eye-ring is reddish purple but the iris varies from clear yellow to dark brown. Its wing tips also vary in their amount of gray.

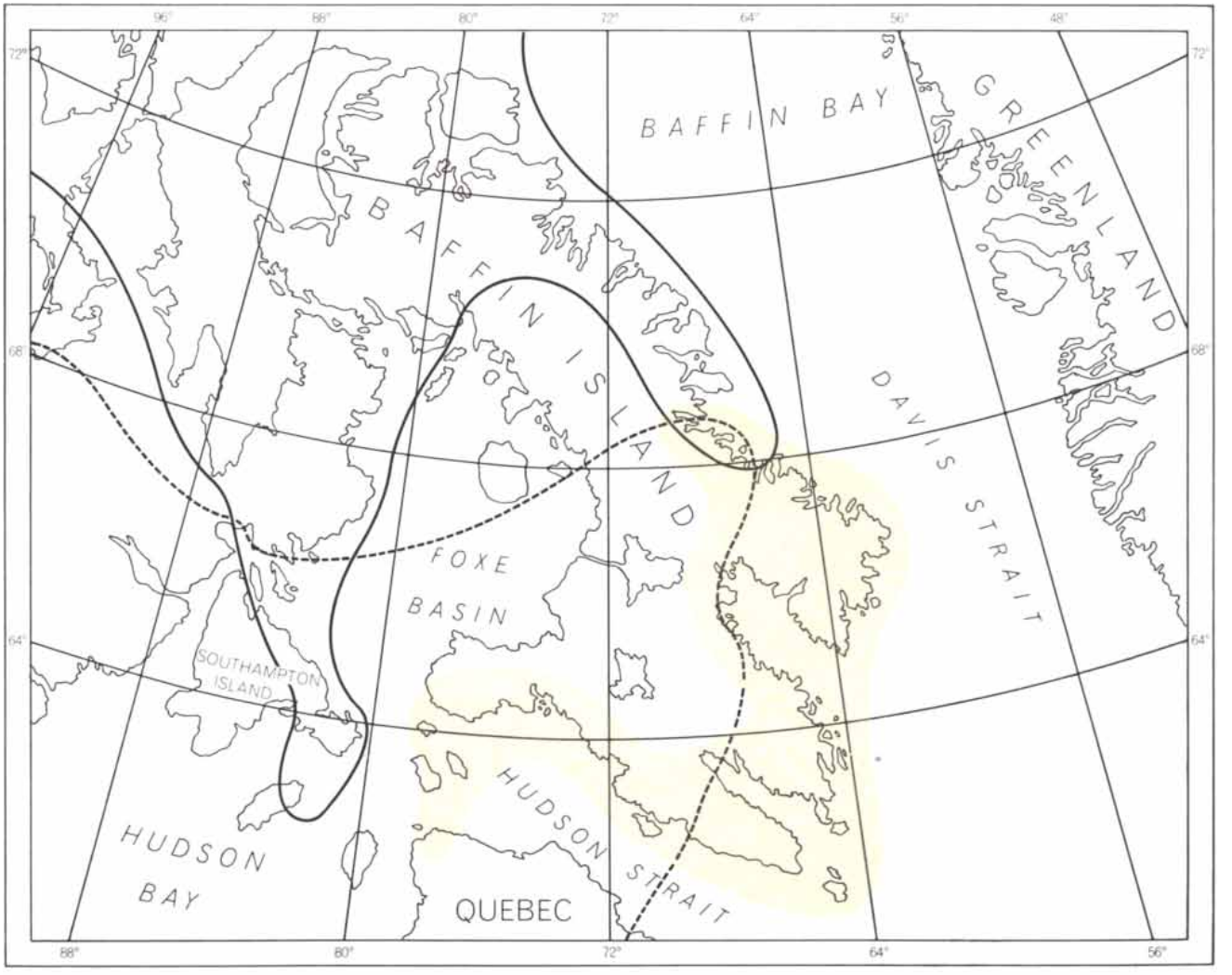
The common breeding grounds of these gulls are difficult to visit, and not

HEADS OF *LARUS* GULLS are almost identical except for the color of the eye and its encircling fleshy ring. At top on the opposite page are two Kumlien's gulls (*Larus glaucoides*), a species in which the iris varies from clear yellow to mottled brown. The eye-ring is reddish purple. Below appear two Thayer's gulls (*L. thayeri*). The eye-ring is the same as it is in Kumlien's gulls but the iris tends to be darker in this species. Next is a herring gull (*L. argentatus*), the only one that nests in the continental U.S. The glaucous gull (*L. hyperboreus*), shown last, has an eye-ring of yellow, which distinguishes it from the herring gull. Largest gull is at top; smallest, at bottom. The painting was made by Guy Tudor.

much has been known about them. When I began my work, the evidence was that no one area was shared by all four species. In the course of trying to find such an area I spent three seasons (April to September) in the Canadian Arctic, during which I covered just under 2,000 miles by dogsled and canoe. During this time I studied three of the gulls (glaucous, Kumlien's and herring) I found nesting together on the south side of Baffin Island and a different trio (glaucous, Thayer's and herring) on nearby Southampton Island. Finally I discovered all four species nesting together on the east side of Baffin Island. It was never easy to find the ground-nesting herring gulls in association with the cliff-nesting species. Nesting on cliffs evolved as an adaptation against predators such as foxes; apparently competition with the other gulls for nesting sites has resulted in the herring gulls' occupying poorer sites. Nevertheless, where the surface allowed it and where the birds were safe from predators in a place such as a rocky islet, all the gulls would nest together.

There were a number of factors, for instance the habitat differences I have mentioned, that tend to reduce the possibility of mixed matings in the areas shared by different populations of gulls; here, however, I shall discuss only differences in external appearance among the species that function as major isolating mechanisms. In 1950 Finn Salomonsen, a Danish ornithologist, suggested that the color of the eye-ring might serve as a signal for differentiation between Kumlien's gull (reddish-purple eye-ring) and the glaucous gull (yellow eye-ring). Although I tested the possible significance of all the differences in the gull's external appearance (with the exception of size), I concentrated on the color of the eye-ring.

In order to study the gulls closely it was necessary to catch them. At first I did so by stretching over a ledge a large fishnet under which food was placed. When the gulls were under the net, an Eskimo assistant and I rushed forward and dropped it, pinning the gulls to the ground. This was obviously an inefficient method, and later I used the drug tribromoethanol. Capsules of the drug were inserted into pieces of meat; after eating the meat the gulls quickly became anesthetized. In this way more than 1,800 gulls were trapped. After the gulls had been drugged they were immobilized with a surgical rubber band that pinned their legs and wings to their bodies, and colored leg bands were put on them to



BREEDING RANGES of large *Larus* gulls lie in the eastern Canadian Arctic. Thayer's gulls (*black line*) and Kumlien's gulls (*colored area*) usually were found nesting in colonies on sea cliffs. The glaucous gull nests throughout this region; it was observed both on cliffs and on level ground. Herring gulls (*broken line*), a ground-nesting species, were found with the others only on rocky islands. Before discovering all four gulls on the east coast of Baffin Island, the author studied some species on Southampton Island.

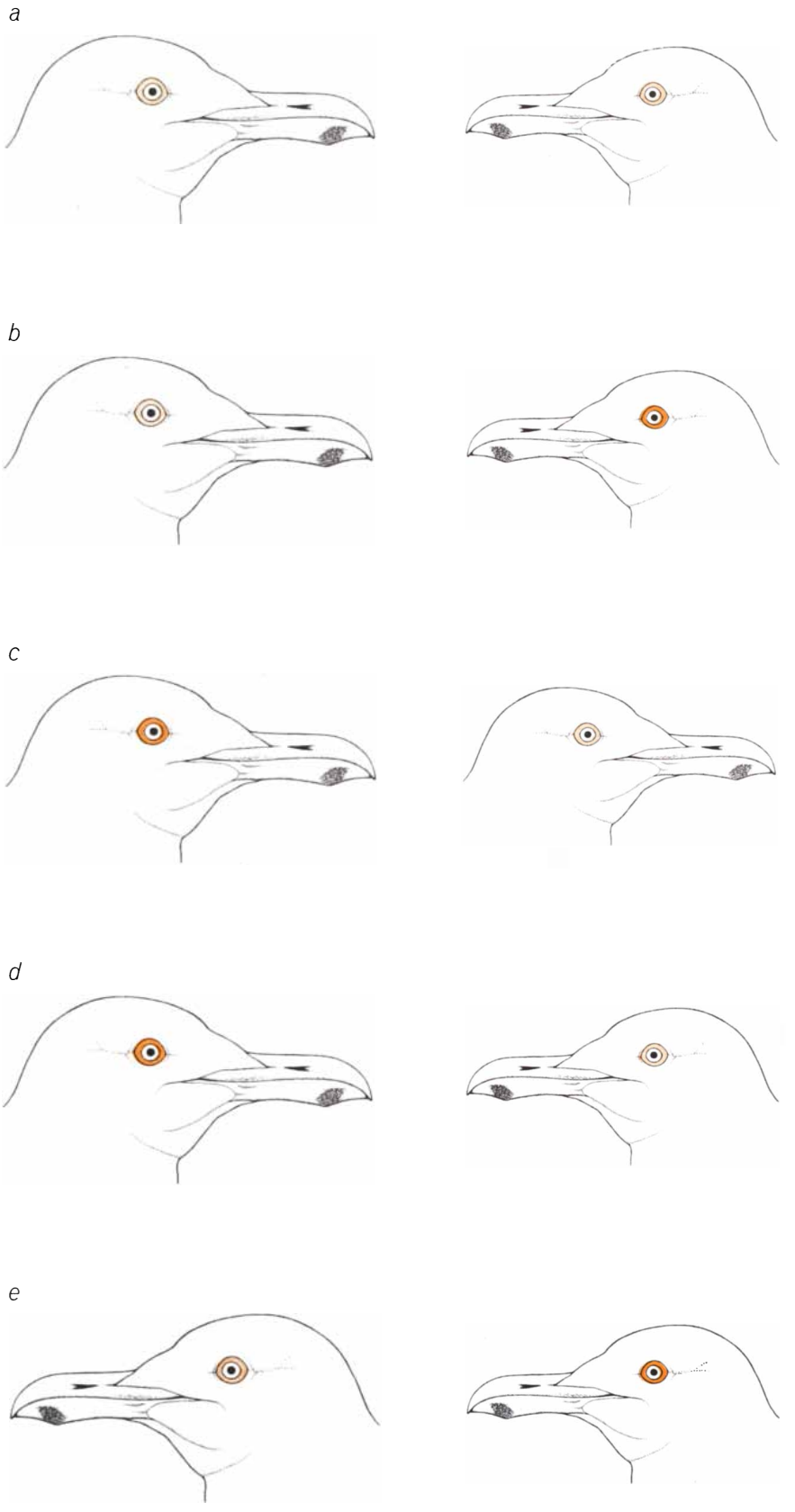
make it possible to recognize individuals. Sex was determined by measuring bill, feet and wings; the males are usually larger. The determinations were confirmed by the subsequent behavior of the gulls.

One of my first thoughts had been that if markings and coloration play a role in the gulls' mating behavior, it should be possible to demonstrate it by changing these features artificially. This I now undertook to do. To change the color of the eye-ring I applied oil paint with a thin brush. The wing-tip pattern was changed with white or black ink after first wiping the feathers with alcohol so that the ink would penetrate. Judging from the behavior of the painted gulls neither of these procedures caused any physical irritation. On the other hand, when I attempted to change the color of a gull's back by spraying it with paint, the feathers stuck together and the gull tried repeatedly to remove the paint.

In my first season, after observing the behavior of individual pairs of glaucous, Kumlien's and herring gulls in a colony in southern Baffin Island, I captured a small group of the gulls. The eye-ring of each one was changed to the color of a different species. Over the yellow ring of the glaucous gull, for example, I painted a ring of reddish purple. All the female birds had copulated with males before the experiment but none had laid eggs. When the females returned to their nests, they were accepted by their mates. In the days that followed, however, the males would no longer mount, in spite of intense solicitation by the females. In all cases where the female's eye-ring color had been changed the pair did not remain together. Five of the males whose mates had been painted formed pairs with nonaltered females in adjacent territories. Copulation ensued, and after two weeks all the new pairs had eggs. The females I had painted left the colony.

In contrast to these findings, changing the eye-ring of a mated male gull appeared not to affect a pair's behavior. The females accepted their altered mates and the males responded to the soliciting behavior of the females. In the one case where both individuals of a mated pair were changed the results were exactly the same as they were when only the female was changed.

The results looked promising. Although the number of individuals involved was small (33 females and 30 males) and some important controls were lacking, I now had a working

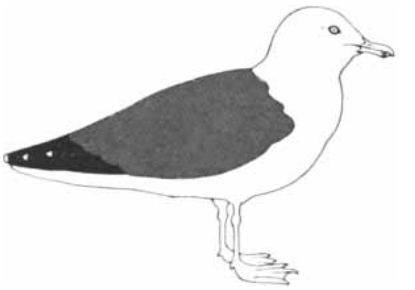


MATING BEHAVIOR OF GULLS changes when their appearance is artificially altered. Even when individuals of like species nest nearby, males and females of the same species normally mate (*a*). Such pairs still form even if an unmated female's eye-rings are painted to look like those of another species (*b*). Painted the same way, an unmated male fails to obtain a mate of his species (*c*). If the male is mated when his eye-rings are altered, his mate remains with him (*d*). When same change is made in the female, they usually separate (*e*).

hypothesis, namely that in some way the eye-ring color of the females functioned as a stimulus for mounting by their mates and that this reaction was keyed to differences among the species.

The program for the next two seasons was to repeat the eye-ring experiments with the necessary controls and to explore the hypothesis in greater detail. Was it the fleshy eye-ring alone or the entire eye that functioned as a stimulus? Was the important factor color or was it contrast? In answering these questions the critical species would be Thayer's gull, with its dark eye-ring and dark iris. It was also of prime importance to test the function of eye-ring color and other physical features with unmated gulls. There was reason to believe that the females choose the males, and it seemed unlikely that a mixed pair would form only to separate later because copulatory behavior was disrupted. There should also be an earlier isolating barrier.

In the experiments of these two seasons there were three major control groups: gulls that were drugged but not painted, gulls that were drugged and painted with their own color or pattern and gulls that were not captured but whose behavior was observed. My earlier findings with mated female gulls were confirmed in experiments that also shed light on the question of color v. contrast. A group of Kumlien's gulls was captured and their reddish-purple eye-ring was painted over either with a light color (yellow, orange or white) or a dark one (red or black). When the female gull had been painted with a light color, copulation usually stopped and the pair separated; in this regard an eye-ring painted white was the most effective. Dark colors had no significant effect. Exactly the reverse was true when the herring gull (orange eye-ring) and the glaucous (yellow) were painted in the same way: dark colors inhibited copulation and light colors had no significant effect. Among the broken pairs were a number of female glaucous gulls whose yellow eye-ring had been changed to orange. This fitted the other results rather nicely, the orange eye-ring of the herring gull being darker than the yellow one of the glaucous gull.



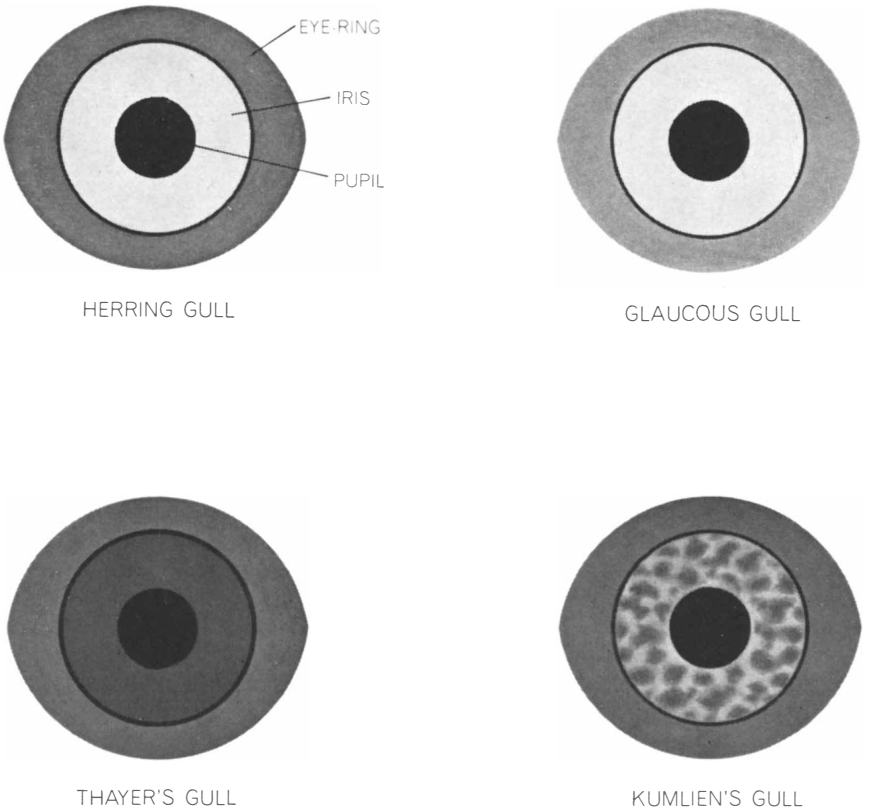
HERRING GULL

EXTERNAL FEATURES vary among species. Each gull shown above differs from the

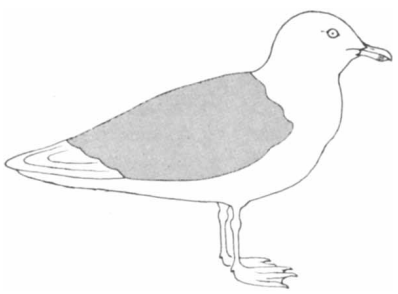
When the same procedures were tried with Thayer's gull, however, there was no significant change in behavior. In this species it is not the eye-ring that stands out against the bird's white head, as it does in the other three species, but the entire orbital region—both the iris and the eye-ring are dark. This suggested that the orbital region as a whole functioned as a stimulus.

One could not paint the eye to change its color, but painting the reddish-purple eye-ring white reduces the contrast of the orbital region against the white head. After thus "erasing" the eye-ring I painted a larger one on the feathers around the eye. In making this "super-eye-ring" I used on various gulls the same assortment of colors as I had in the other experiments. One might think of the painted circle as the "eye-ring," the white feathers between it and the eye as the "iris" and the actual iris as the new "pupil." This may seem a bit farfetched, and I do not mean to imply that this is what the gull sees, but the fact remains that in a significant number of cases where the female had been given a light-colored super-eye-ring copulation was inhibited and pairs separated. Apparently the stimulus to copulation was the contrast pattern of the ringed eye against the white head: dark color against white in Kumlien's and Thayer's gull and light color against white in the herring and glaucous gull.

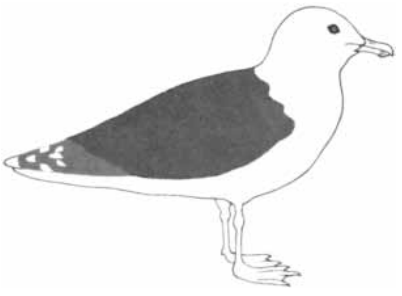
In the course of these experiments I observed that a male occasionally mounted his altered mate but did not attempt copulation even when the female prodded his breast or rubbed her tail against his anal region. Earlier I had observed that copulation was invariably preceded by such tactile stimulation on the part of the females. I concluded that successful copulation probably involves both visual and tactile stimuli.



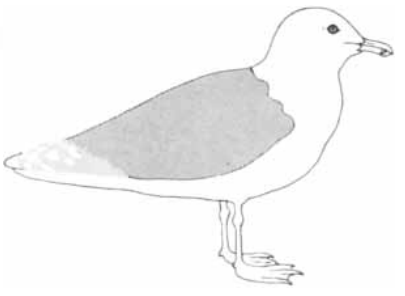
RINGED EYES of various colors, photographed in black and white, exhibit different color values. The orange eye-ring of the herring gull shows darker than the yellow ring of the glaucous gull. Darker still is the reddish-purple ring of Thayer's and Kumlien's gulls. In Thayer's gulls brown irises enforce the contrast of the orbital region against the white head; the iris of Kumlien's is lighter. Eye-head contrast acts as an interspecies barrier among gulls.



GLAUCOUS GULL



THAYER'S GULL



KUMLIEN'S GULL

others in size, in the coloration of the orbital region, back and wings and in the pattern of the wing tips. The author's experiments suggest that the wing-tip pattern serves to supplement the signal of eye-head contrast in preventing the formation of mixed pairs.

(Auditory stimuli may also be involved, but this was not tested.) It appeared that the tactile stimuli were supplemental to other stimuli rather than independent of them; the eye-head contrast of the females played the major role.

Did the eye-head contrast play a role in the formation of pairs as well as in copulatory behavior? The eye-rings of a group of unmated female gulls were changed to determine if this made a significant difference in the species of the males with which they paired. The results showed no difference between this group and control groups. After a week or two, however, pairs in which the females had been given the "wrong" eye-head contrast separated; the males would not copulate. This of course further supported the role of eye-head contrast.

When the same experiment was performed with unmated male gulls, the results were quite different. In one instance 91 percent of the male Thayer's gulls that had been changed by the super-eye-ring technique to the light-eyed condition failed to obtain mates of their own species. An experiment with glaucous and herring gulls also showed that if the eye-head contrast of unmated males was "wrong," they were significantly less successful in obtaining mates of the same species than the controls were.

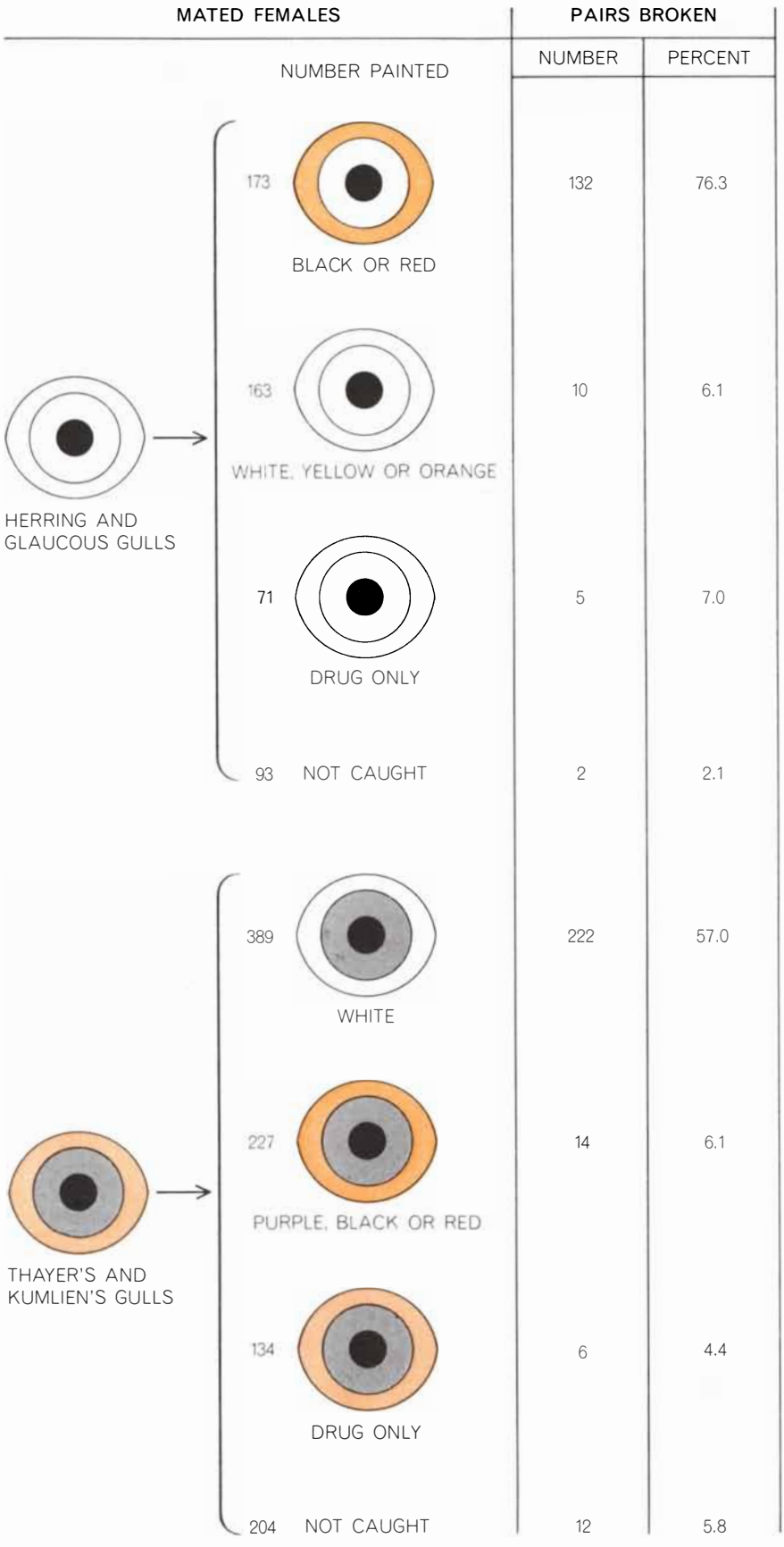
The results suggested that in pair formation it is indeed the females that choose the males, and that they select males with an eye-head contrast like their own. In other words, the same feature works in two ways to isolate the species: in the males it serves the purpose of pair formation and in females the purpose of copulatory behavior. What role is played by other external differences? The color of the mantle (back and wings) of the *Larus* gulls varies from one species to another. Among the four species I studied the differences in mantle coloration were not pronounced; still it seemed worthwhile to attempt an evaluation of mantle color as a possible signal. As I have indicated, however, spraying paint on a gull's back has too great an effect on the gull's behavior to make for a sound experiment, and the role played by this feature remains obscure.

Tests of the wing-tip pattern displayed at rest suggest that this feature does function as a signal in species discrimination during pair formation. There was no significant change in behavior after alteration of the wing tips of female gulls, whether mated or unmated. On the other hand, alteration of the wing tips of unmated males indicated that the wing-tip pattern functions as a stimulus to pair formation in combination with the eye-head contrast. This was shown by the fact that female gulls chose males with both "right" wing-tip pattern and eye-head contrast over males with only the "right" eye-head contrast. The wing-tip pattern alone is apparently not utilized in species discrimination during pair formation.

In several of the experiments male Thayer's gulls painted to appear light-eyed had been chosen by glaucous females. Since the females had the "wrong" eye-head contrast for the males, no copulation resulted and these mixed pairs did not remain together. After 59 Thayer's-glaucous pairs had formed I captured all but three of the glaucous females and altered them to the "right" contrast. Ten days later all 56 male Thayer's gulls had been observed to mount their altered mates, and about two weeks later 55 of the pairs had eggs. (One pair did not remain together.) Heavy ice on the rocks unfortunately forced me to abandon these colonies; I was never able to return to them. Before leaving I did collect several eggs, and they contained well-developed embryos. It may be that the mixed pairs produced hybrid offspring.

From the start of my experiments it had been clear that there was a strong correlation between the behavior that resulted from changing the eye-ring and the gonadal cycle of the gull. Two identical experiments, one performed 16 days before the first eggs were laid and the other 12 days later, yielded strikingly different results. I considered initially as a working hypothesis that the main component of the pair bond was the attachment of the individuals to each other, and that during and after the egg-laying period the main component of the bond became the attachment of the individuals to the nest and the eggs. This hypothesis could account for certain pairs of gulls that had remained together even though the males had failed to respond to the solicitations of their altered mates. It could not, however, explain instances in which males continued to mount their mates after they had been painted and before egg-laying had begun. Moreover, the hypothesis offered no answer to the crucial question of what the physiological basis for the male's behavior is.

The solution to the problem was found in the relation between the internal physiological state of the male (indicated by the weight of the testes) and the number of times a pair had copulated. All but 12 of the 168 pairs of gulls that had remained together after the female had been given a different eye-ring had copulated six or more times before she had been painted. This number of copulations could be correlated with a certain weight of the testes attained in the male's gonadal cycle. I concluded that a gull whose testes had developed to the critical weight or



SUMMARIZED FINDINGS document experiments with mated female gulls. Pairs separated in most cases where the female's eye contrast was changed; this feature appears to be a major stimulus to the male in copulatory behavior. Because a drug was used in capturing gulls, one control group was drugged and not painted. Another group, not captured, was observed. Some gulls were painted with eye-rings of their own color as a further control.

beyond it would respond to a mate whether or not her eye-ring had been changed. The most telling evidence was that if the female's eye-ring was changed at a time before the critical weight was reached, the testes of her mate did not increase in weight—in fact, they diminished!

It is fairly well substantiated that gonadal development in many species is stimulated by changes in the daily cycle of daylight and darkness. On arriving in the Arctic in summer gulls are subjected to periods of daylight lasting almost 24 hours. This factor alone, however, could not cause the gulls' testes to develop beyond the level attained at the end of pair formation. Certain other stimuli must interact with light, and one of them—probably the most important one—is the presence of a mate with the proper eye-head contrast.

Although I have no evidence for it, it seems likely on logical grounds that a similar mechanism functions in females during pair formation. Once a pair bond is formed and a series of hormonal events is activated, inhibition of the female's gonadal development does not occur, even when the original stimulus—the eye-head contrast of the male—is removed. In the female, as in the male, the interaction of stimuli and the hormonal background at different times in the season provides a species-isolating mechanism that appears to be wholly effective.

Thus far we have been considering the two questions raised at the beginning: What are the visual factors involved in species discrimination among the gulls, and how do these factors affect reproductive behavior? At this point I should like to take up the matter of how the mechanisms that isolate species have evolved. In this regard it is instructive to examine the natural variation in iris and wing-tip color that occurs in one species: Kumlien's gull.

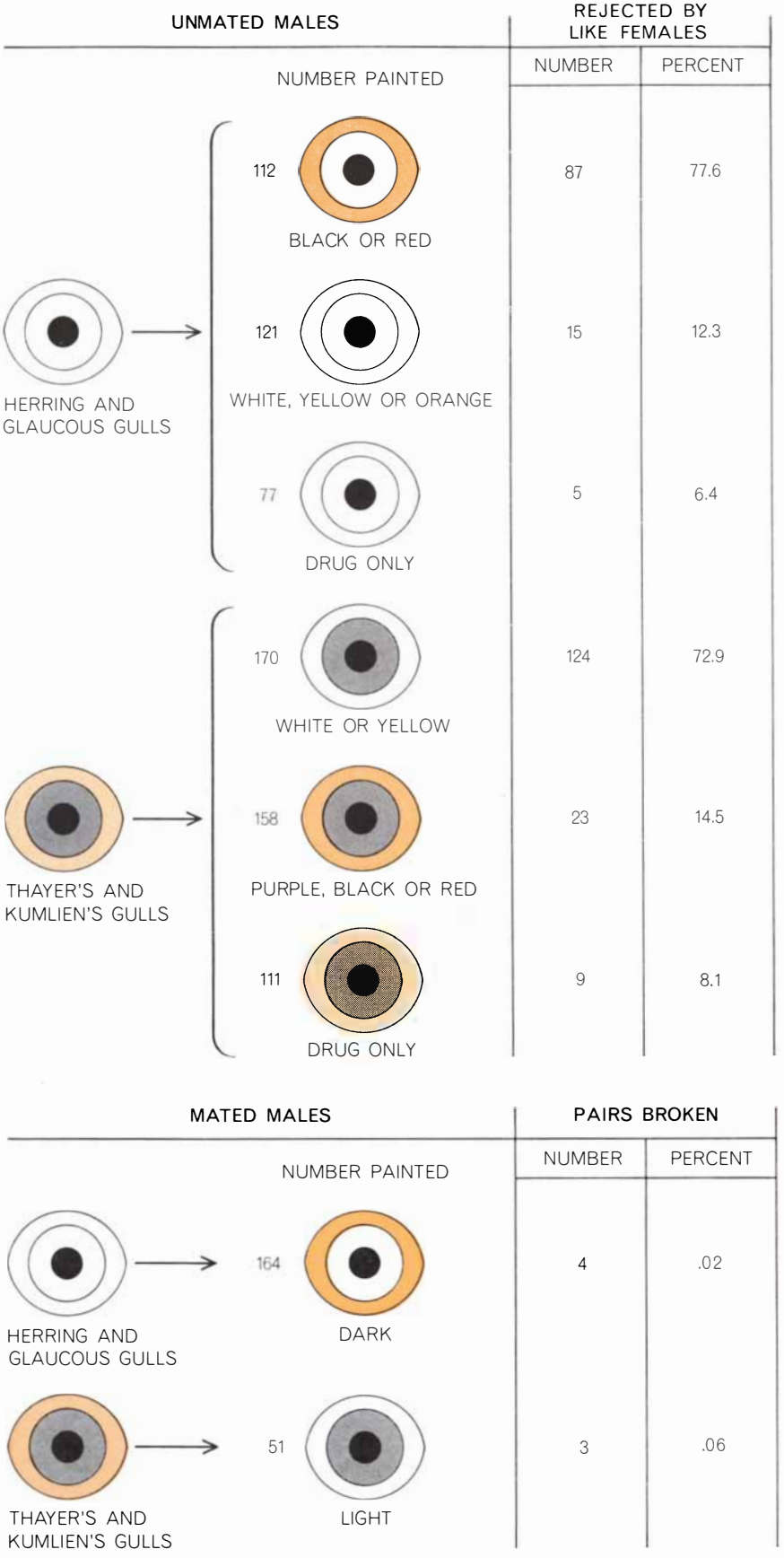
The eye-ring color differs little among Kumlien's gulls and Thayer's gulls but the amount of dark pigment in their irises varies considerably. Kumlien's gull is by far the more variable, ranging from individuals with completely dark irises to those with completely clear eyes of yellow. I divided this variation into six classes, Class 1 being the darkest and Class 6 the clearest. On the south coast of Baffin Island, Kumlien's gulls live together with herring gulls and glaucous gulls. In this locale Kumlien's gulls with clear irises were almost entirely absent; they occupied classes from Class 1 to Class 4 or Class 5.

On the east coast of Baffin Island, where Kumlien's gulls nested with Thayer's gulls and glaucous gulls, the situation was reversed. There almost all the Kumlien's gulls fell into the last three classes, being clear-eyed or nearly so.

This pattern can be explained in terms of the natural selection of the variations that will reduce the possibility of mixed mating. According to my experiments, the contrast of the eye-ring and iris against the white head is the chief factor in species discrimination among gulls. To avoid mixed pairings, then, selection favored dark-eyed individuals where Kumlien's gulls nested with the light-eyed herring gulls and light-eyed individuals where Kumlien's gulls nested with the dark-eyed Thayer's gulls. Apparently the dark eye-ring of Kumlien's gull has been adequate for species recognition between Kumlien's gull and the yellow-eye-ring glaucous gull. The orange eye-ring of the herring gull affords a darker contrast, however, and where herring gulls and Kumlien's gulls nest together the dark iris of the latter reinforces the eye-head contrast. It is interesting to note that in Greenland, Kumlien's gulls have light eyes; there herring gulls are not found and glaucous gulls are.

The amount of dark pigment in the iris of Kumlien's gull is highly correlated with the amount of pigment in the wing tips. Individual Kumlien's gulls with light irises, as found on the east coast of Baffin Island, have white wing tips; those with dark eyes, as found on the south coast of the island, have dark blotches on their wing tips. It has been suggested that this variation in wing-tip pattern is the result of hybridization between Thayer's gulls and Kumlien's gulls, but that is not the case. The two species are most unlike each other where they nest together; they are very much like each other where they do not live together but where each is associated with glaucous gulls and herring gulls. The explanation for the variation of the wing tip is simply that it reflects the correlation between the pigment in the iris and the wing tip and the results of selection for differences in iris color in different populations.

In the course of my earlier work I had come to the conclusion that female gulls chose males that in eye-head contrast and wing-tip pattern were most like themselves. This created a problem, because it implied that the female knows what it looks like. A series of observations and one experiment on the east



RESULTS of experiments in which the eye-ring of male gulls was altered indicate (*top*) that in pair formation the female chooses the male and that eye-head contrast is a factor in the choice. Changing the eye contrast of the male after a pair was formed (*bottom*) did not produce a change in mating behavior: nearly all the pairs of gulls remained together.

coast of Baffin Island provided an escape from this dilemma and also showed how responsive to very slight evolutionary pressures the visual isolating mechanisms are. The experiment was one in which I had hoped to induce mixed matings between Kumlien's gulls and Thayer's gulls by painting the eye-rings of unmated male Kumlien's gulls black to increase the contrast. The males were chosen not by Thayer's gull females, however, but by females of their own species. I concluded that other features, perhaps the wing-tip pattern, were the critical ones in discrimination between the two species.

Then further investigation of Kumlien's gulls in this area where they overlapped with Thayer's gulls revealed a curious phenomenon. Although the majority of Kumlien's gulls in the area had clear yellow irises, there were many individuals (37 percent) with various amounts of iris pigmentation. If the gulls are viewed as two groups, one with iris pigmentation and one without it, a pattern emerges: in each group there is a striking preponderance of matings between individuals that look alike. Outside the overlap area mating is essentially random with respect to the presence or absence of iris pigmentation.

With this information in mind the results of the black-eye-ring experiment can be interpreted very differently. In this area dark-eyed males normally are chosen by dark-eyed females and clear-eyed males by clear-eyed females. Yet in the experiment even though 92 clear-eyed females were available for mating, they chose only four from the group of 41 clear-eyed males that had been painted to have a darker orbital region; 29 of these males were chosen by dark-eyed females. None of the 26 males with dark irises ringed in black were picked by light-eyed females. It can be seen that by increasing the eye-head contrast of unmated male Kumlien's gulls in this area, one can predict the iris coloration of the eventual mate.

Thus there was both observational and experimental evidence that the female Kumlien's gulls of this area were discerning very slight differences in the eye-head contrast of prospective mates. This mating system probably evolved as a result of two primary pressures. The presence of small numbers of herring gulls in the overlap zone probably provided pressure to maintain the delicate balance between clear-eyed and dark-eyed Kumlien's gulls. Secondly, in order to avoid mixed pairings with Thayer's gulls, selection favored individual Kumlien's gulls that perceived slight eye-head contrast differences. The mating system among Kumlien's gulls, in which like mates with like, is a by-product of such selection. This view is supported by the fact that increasing the eye-head contrast of unmated males just outside the overlap zone had no detectable effect, whereas the same alterations within the zone produced major changes in the mating system.

At first, of course, it is difficult to imagine how female gulls manage to choose mates that look like themselves. Presumably they do not actually see themselves. (Mirrors are rare in the Arctic.) The answer may nonetheless be quite simple. It is known that many birds "imprint" on their parents soon after birth, and that they choose mates that look like their parents. Possibly gulls do the same. If eye color in gulls is inherited (as seems likely, although genetic information is lacking), then female gulls choose mates that look like themselves simply because they are looking for mates that look like their parents, and in most cases they themselves look like their parents. This hypothesis suggests that the Kumlien's gull mating system may simply represent an intensification of the normal process, that is, a female chooses a male most like her parents in eye-head contrast and wing tips.

To understand the evolution of these visual signals that function as reproductive isolating mechanisms one can examine the distribution of the large *Larus* gulls throughout the Northern Hemisphere. With the exception of the glaucous gull, all the other *Larus* gulls that overlap with the herring gull and are reproductively isolated from it have the contrast pattern of a dark eye against a white head. The populations that apparently hybridize with herring gulls have dark eye-rings but light irises. As I have indicated, dark eye-rings without dark irises are insufficient as isolating mechanisms against the orange-eye-ring herring gulls. The important point here is that the darkening of the eye region (principally the eye-ring) begins to develop in an isolated population. If the population becomes genetically so different from the one from which it was separated that on coming together again the two populations remain distinct, selection will favor a further increase in the darkening of the eye region, specifically a darkening of the iris. The end result is a sealing off of gene exchange.

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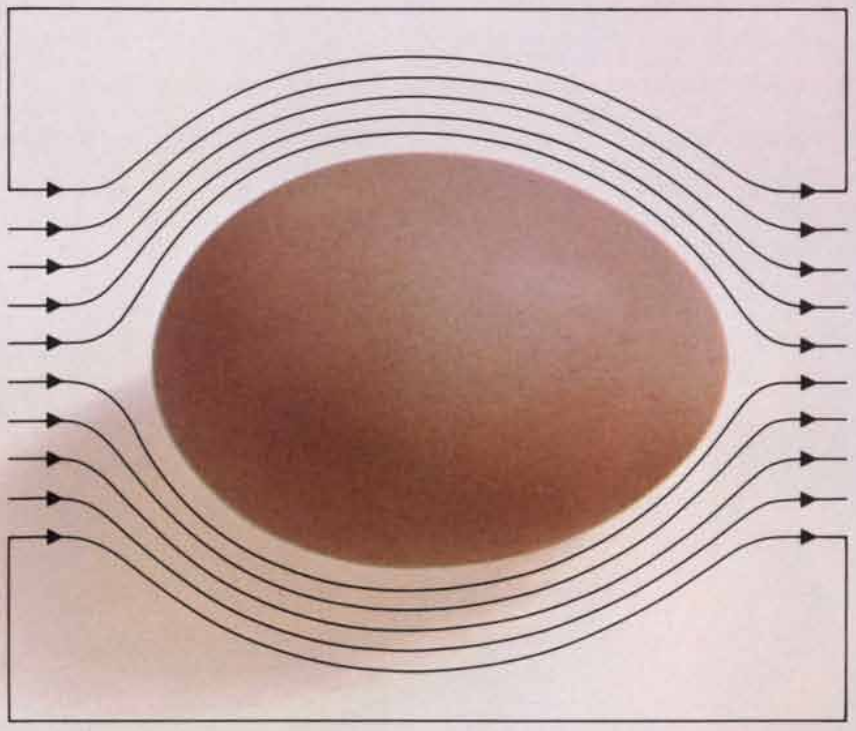
Investigations are providing new knowledge of flow conditions at high speeds • Improved wing design could increase the critical Mach number • Airfoils are being synthesized by computer • Vortex experiments may mean multiplied lift for airfoils • New rotor blade increases lift, speed and maneuverability

Lockheed is looking for the perfect shape

The perfect aerodynamic shape varies according to specific mission requirements. As commercial, defense and space programs expand, vital knowledge in areas ranging from subsonics to hypersonics, from launch to reentry, is being uncovered, ushering in a new era in aerodynamic technology. Lockheed's efforts in a never-ending quest for the perfect shape for each application involve a number of significant projects. Here is a sampling:

Hypervelocity rarefied flow. In the hypervelocity regions of boost and reentry flight, aerodynamic characteristics of lifting vehicles become highly sensitive to viscous drag effects at changing altitudes. Flow conditions encountered in this velocity range are not yet fully understood. To develop aerodynamic shapes meeting specified flight performance requirements for vehicles traveling at Mach 10 and above, more thorough knowledge of high-speed flows is needed. Lockheed researchers presently are using experimental and theoretical prediction techniques to study these phenomena.



Transonics/Supersonics. Inadequate analytical methods for computing the properties of transonic flow fields long have been stumbling blocks in developing high-subsonic-speed aircraft. Current aircraft flying in this speed range have been developed by application of empirical "rules" based on experimental results. Lockheed's intensive efforts toward developing a fundamental understanding of mixed flows will enable a more rational design approach. Increases upwards of 10% in critical Mach number are anticipated as a result of this approach. ¶ Initial fruits of Lockheed's work in this area are exemplified by the wing design for the coming C-5A Galaxy, the world's largest airplane. Incorporating an adaptation of the peaky airfoil in this giant craft has significantly reduced wing drag. ¶ In supersonics, Lockheed is continuing research along a broad front. Included are investigations concerning sonic effects and optimum wing shapes to provide high cruise efficiency

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for future fighters and other vehicles.

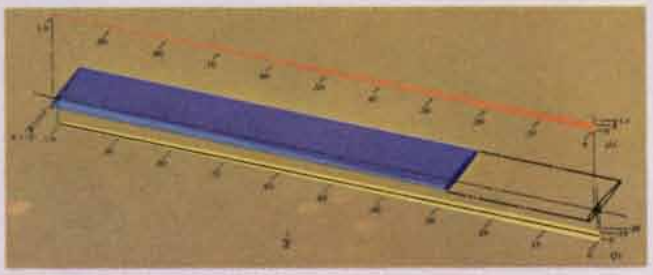
Computer-specified wings. Applying a new programming technique called "airfoil synthesis," Lockheed aerodynamicists now can synthesize airfoil shapes meeting specified performance requirements. ¶ This technique converts a computer into an electronic wind tunnel for formulation and evaluation of aircraft wing designs. The engineer feeds in the aerodynamic requirements for a certain wing, activating the computer with a hand-held light pen. The computer responds by computing and displaying the required airfoil shape. If the engineer deems the design acceptable, the computer proceeds to display data on performance of the wing under various flight conditions. Performance requirements can be changed by the engineer at any stage, resulting in different optimum airfoil designs for different sets of conditions. Once he accepts a basic wing configuration, his "super assistant" computer supplies additional data needed to complete the design for the full flight spectrum. ¶ "Airfoil synthesis" promises to save aerodynamic engineers considerable design time, as well as to produce more efficient and less costly wings for future aircraft.

Viewer displays synthesized wing design plus performance data.

Vortex lift generation. For years, investigators have been attempting to increase the lifting ability of airfoils by employing various passive and active boundary layer control schemes. Lockheed scientists, extending work begun by NASA/Langley, now are experimenting with the locked vortex principle. ¶ Slow-traveling boundary layer air is allowed to enter a cusp formed between the wing and its flap, thus creating a vortex. Suction applied at discrete intervals along the wingspan locks the vortex in place and generates increased lift. For practical operation, application of this principle could multiply lift coefficients as much as two or three times.

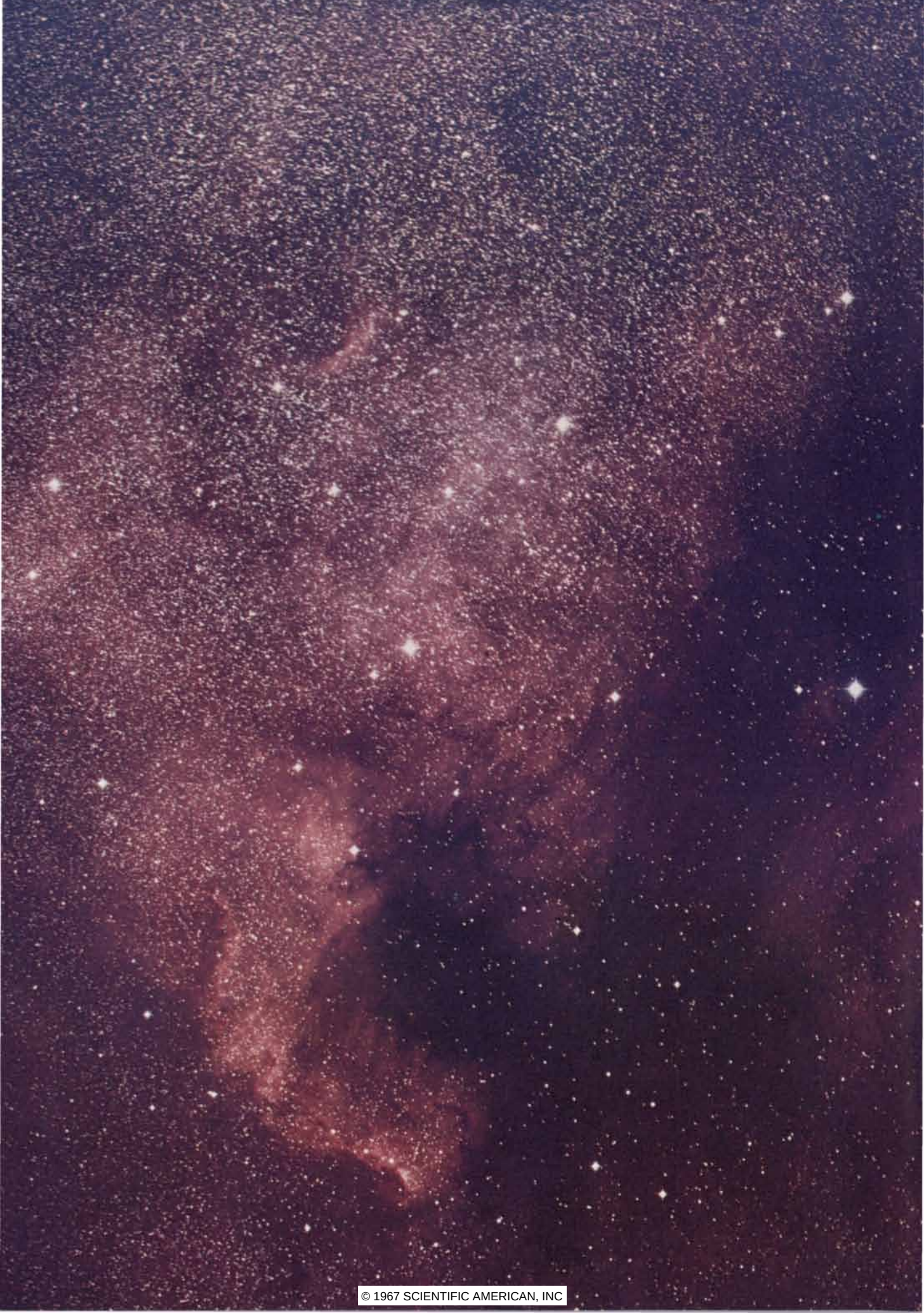
Vortex behavior smoke demonstration. Vortices may generate lift in new wings.

Advanced-geometry rotor blades. Growing helicopter mission requirements are demanding increased performance from rotor blades. A new armed compound aircraft being developed for the U.S. Army, the AH-56A advanced aerial fire support system, provides an important example. Army specifications call for good hover efficiency, high-speed performance and short turning radius capability in forward flight. The design features that these requirements impose are independently feasible, but tend to be mutually conflicting. This is further complicated by the limitations of production techniques. To overcome these difficulties, Lockheed manufacturing engineers have combined improvements of precision fabrication and metal bonding techniques, while design engineers have tailored an advanced-geometry blade that fits within production limitations. ¶ For hover lift efficiency, the blade incorporates linear twist. The twist is moderate to keep down oscillatory stresses during forward flight. High-speed performance is assured by decreasing blade thickness toward the tip sections. This feature delays Mach number effects that would otherwise limit speed. Maneuver lift, or short turning radius capability, is implemented by adding camber. The distribution applies optimum camber between 70% to 90% of the rotor radius, generally increasing inboard and decreasing outboard. Camber, besides providing retreating blade lift coefficients necessary for short turning radius, further aids hovering efficiency at high gross weight conditions.



Advanced-geometry rotor blade features twist, taper and camber.

The activities described here are only a few of Lockheed's current aerodynamic R&D projects. If you are an engineer or scientist interested in this area of work, either in California or Georgia, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California. ¶ An equal opportunity employer.



INTERSTELLAR GRAINS

These dustlike particles, which may be frozen gases, constitute less than one part in 1,000 of all the matter in our galaxy. Yet they successfully hide most of the stars in the galaxy from view

by J. Mayo Greenberg

For the past 40 years astronomy has been trying to learn more about an important constituent of the universe that cannot be seen with the most powerful telescopes or detected by the most sensitive radio techniques. This constituent consists of fine particles, now commonly referred to as grains, that are known to be widely distributed throughout interstellar space. If they are invisible, how was their presence established and how can they be studied? They are like the purloined letter of Edgar Allan Poe's story: their presence seems obvious when one has properly interpreted their effects on the celestial radiation that *can* be seen and recorded.

Sometimes interstellar grains reveal themselves by reflecting the light of particularly luminous objects or glowing masses of gas. More often they dim the light of luminous objects or completely hide them. Fortunately for astronomy interstellar grains subtract light in a preferential manner, so that the radiation reaching the earth is often reddened and polarized. By measuring the amount of polarization and reddening one can infer much about the nature and distribution of this interstellar material. Given such information, the astrophysicist can begin to construct hypotheses about the origin of interstellar grains and the role they have played (and presumably are still playing) in the evolution of the universe.

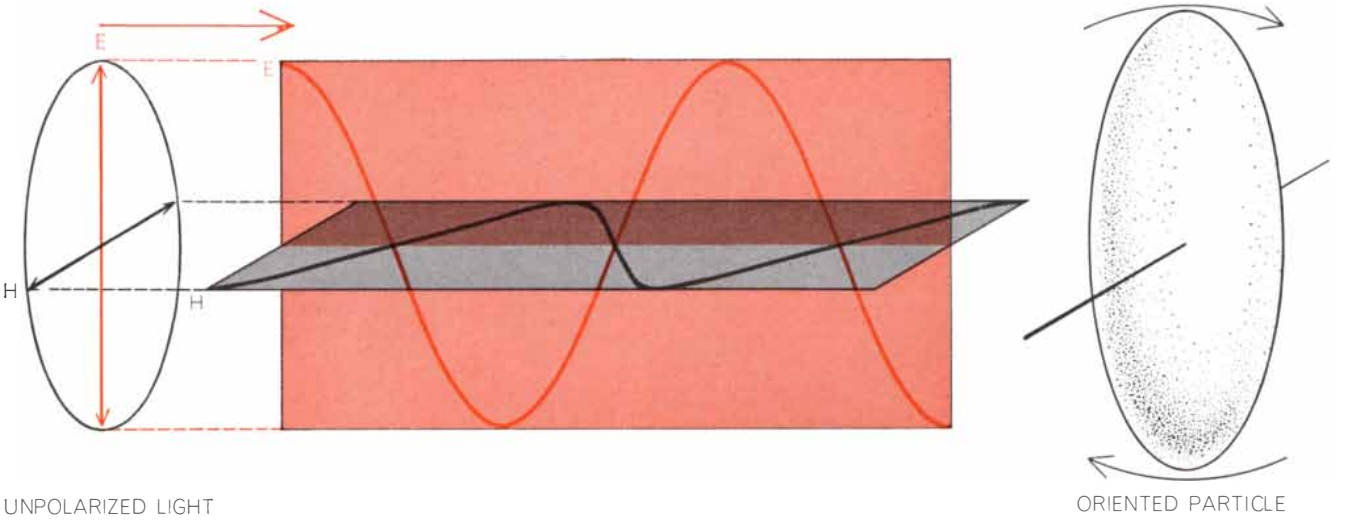
Anyone who has looked at the Milky Way on a clear, dark night knows how patchy and uneven it appears. Even astronomers accepted this irregularity at face value until well into this century; they assumed that the stars were simply distributed in uneven clumps. With the recognition that the Milky Way represented the view along the central plane of the great rotating pinwheel of stars in our galaxy it became increasingly obvious that the uneven distribution of visible stars was actually caused by the uneven distribution of interstellar dust.

Considering how effectively this dust obscures our view of the galaxy, one might assume that it represents a sizable fraction of the galaxy's total mass. It is not so, and for an interesting reason that anyone can demonstrate for himself. Shine the light from a slide projector on a screen in a dark room. Now watch the brightness of the screen when the following are introduced separately into the beam: a piece of chalk, an unlighted cigarette, a cloud of chalk dust from a blackboard eraser and a cloud of cigarette smoke. The smoke will cause the greatest reduction in light, even though its total mass is far less than the mass of the entire cigarette and significantly less than the mass of the chalk dust. The critical factor in the extinction of the light turns out to be the size of the particles in the cloud of smoke or dust; for the highest extinction efficiency the particles should be somewhat smaller than the wavelength of the incident light.

If the galaxy were filled with icelike particles the size of basketballs, and the total mass of the particles equaled the mass of all the stars in the galaxy, the particles could not be detected optically. Indeed, their extinction efficiency would be only 1/300,000th the efficiency of the interstellar grains. By the same token the obscuration of starlight by the interstellar gas (chiefly hydrogen) is negligible even though the mass of the gas represents perhaps 10 percent of the total mass of the galaxy. It is estimated that the interstellar grains represent only about a thousandth of the total galactic mass. Within the spiral arms of the galaxy, however, the concentration of interstellar grains rises to perhaps three parts in 1,000. It can also be estimated that if a tenth of the stars in the galaxy have planetary systems like our own, the mass of the interstellar grains would exceed the total mass of the planets by about 10 to one.

The actual size of the grains is not known with any precision. The reason is that their composition is still uncertain. They might, for example, consist largely of ices, perhaps a mixture of ordinary ice and frozen gases such as methane or ammonia. In that case they would tend to be elongated particles—perhaps tiny needles with a thickness of about half a micron, which corresponds to the average wavelength of light. On the other hand, the grains could conceivably consist largely of carbon or metals. If they are carbon in the form of graphite, they would tend to be tiny plates, and they would be smaller than half a micron by a factor of five or 10. The difference in size estimates follows from the composition and optical properties of the grains. If they are optically dielectric, they will absorb very little of the radia-

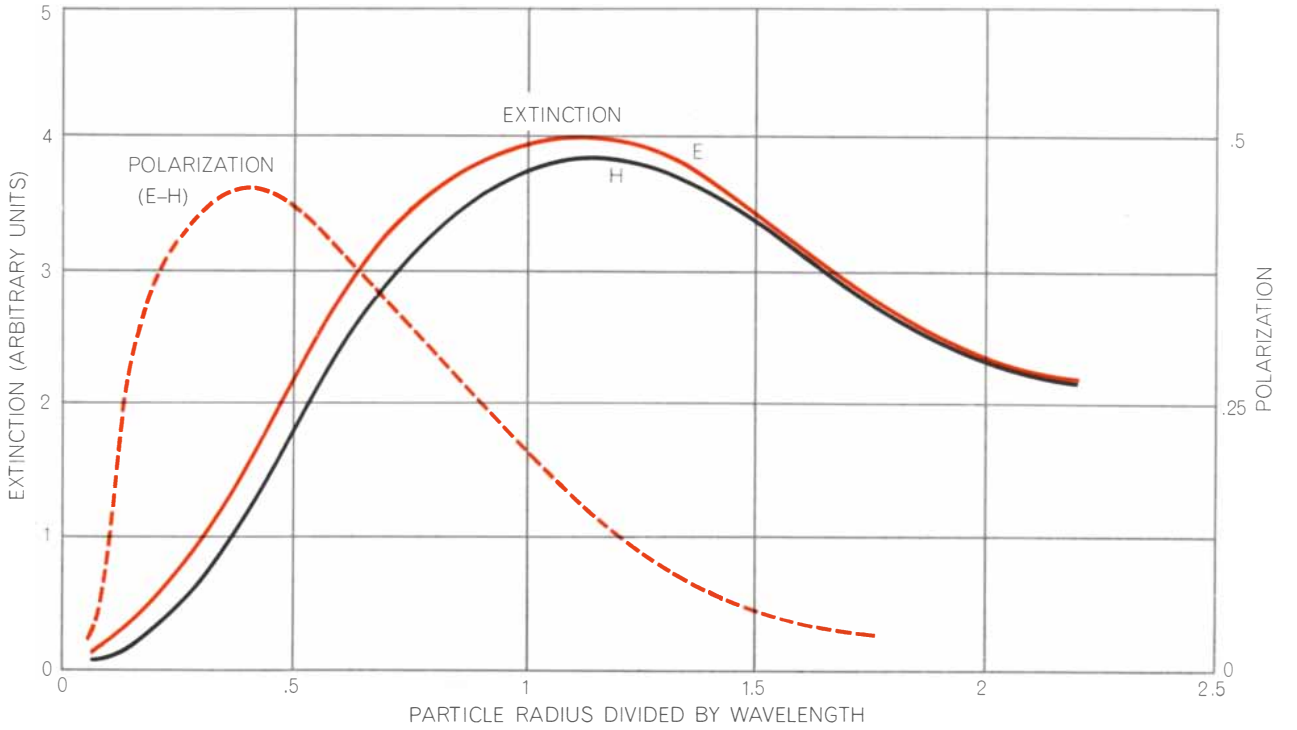
NORTH AMERICAN NEBULA, embedded in the Milky Way, illustrates some striking characteristics of interstellar grains, or dust. The "Gulf of Mexico" and "Atlantic Ocean" are regions of high dust obscuration. The general luminosity of the nebula, however, is evidently not stellar radiation reflected from interstellar grains, as might be thought. It may represent excitation of gas by bright stars hidden by dust, but more likely it results directly from the collision of interstellar dust clouds. This is consistent with the idea that clouds in the spiral arm of the galaxy are moving at high velocities. The photograph was made with the 48-inch Schmidt telescope on Palomar Mountain by William C. Miller.



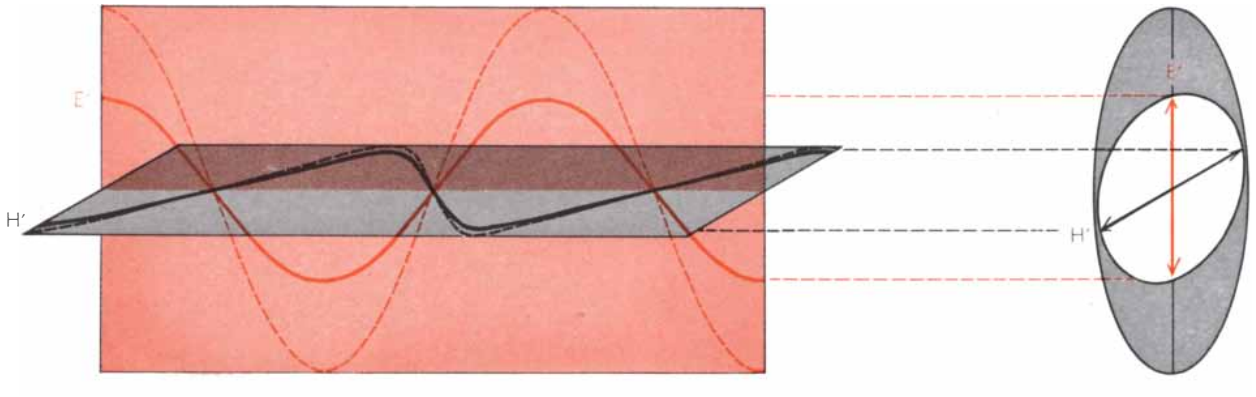
POLARIZATION OF STARLIGHT is believed to occur because interstellar grains are both asymmetric and oriented by weak magnetic fields in space. The ellipsoidal interstellar particle depicted here is viewed as if threaded on a line of magnetic force, around which it twirls. The starlight that reaches the particle from the left is unpolarized, which means it can be resolved into two beams of equal intensity (*E*, *H*) that are polarized into two planes at right angles to each other. Because of the orientation of the particle the

tion, whereas if they are metallic, they will tend to absorb strongly.

Not quite 20 years ago John S. Hall of the U.S. Naval Observatory and W. A. Hiltner of the Yerkes and McDonald observatories were carrying out a search for a predicted polarization effect when they discovered one that had not been predicted. They independently observed that the light from certain stars was linearly polarized. This means that if one were to look at such a star through an ordinary Polaroid filter of the kind used in sunglasses, their light would dim and brighten as the filter was rotated. It was noted at the same time that the stars exhibiting this polarization were invariably the stars whose light had also been reddened and partly extinguished by interstellar dust. Later studies showed that the degree of polarization is strongly



EXTINCTION EFFICIENCIES for long icelike particles, as measured by the author, produce curves of this general type. The particles are oriented as in the illustration at the top of these two pages. Thus the extinction is greater for the *E* beam, polarized vertically, than for the *H* beam, polarized horizontally. Maximum extinction occurs when the wavelength is about equal to the radius of the particle. On the rising portion of the *E* and *H* curves the extinction for a particle of a given small radius is greater the *shorter* the wavelength, which explains why blue light is dimmed more than red. As particles become much larger they reduce the intensity of starlight without altering its color. Maximum polarization (*E*–*H*) occurs when the wavelength is about twice the particle radius.



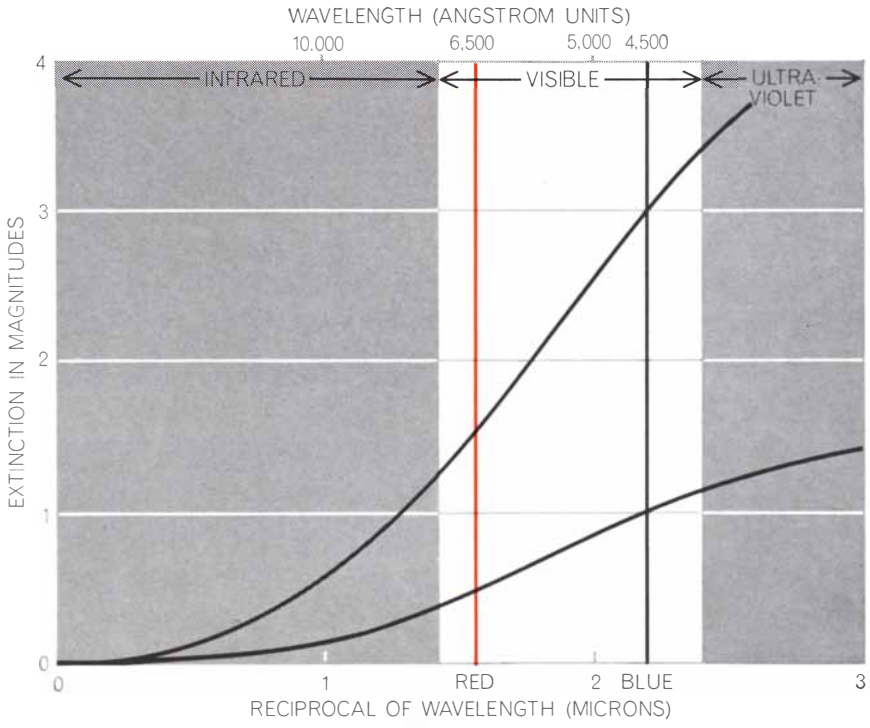
PARTIALLY PLANE-POLARIZED LIGHT

***E*, or vertical, beam suffers a greater reduction in intensity than the *H*, or horizontal, beam. Consequently the residual radiation, when viewed from the earth, will be polarized in a plane perpendicular to the direction of orientation of the particle. Using scaled-up models of grains and radio waves to simulate light, the author has found in his laboratory studies at Rensselaer Polytechnic Institute that for icelike grains of this general shape polarization is greatest when the wavelength is about twice the radius of the particle.**

correlated with the amount of extinction. It soon became obvious that whatever was responsible for reducing the light must also be polarizing it. This could only be interstellar dust. The problem was to discover the mechanism of polarization.

When light that is unpolarized passes through a polarizing filter, it is reduced in intensity by at least half. It is said to be plane-polarized, and if it is now directed into a second polarizing filter, it can be completely extinguished by rotating the second filter until the filter's plane of polarization is at right angles to the plane of the first filter. Compared with an efficiency of 100 percent for a good polarizing filter, the grains in interstellar space show a polarizing efficiency of at most about 6 percent. Although this may seem a modest amount, it has not made the polarization any easier to explain.

The currently accepted hypothesis is that the polarization results from the orientation of interstellar grains by large-scale magnetic fields. In fact, the polarization of starlight provided early evidence that such fields exist. They appear to play an important role in the motions of gas clouds in the galaxy, and until recently it was conjectured that they might also provide the "ribs" that hold the galaxy's spiral arms outstretched [see "The Magnetic Field of the Galaxy," by Glenn L. Berge and George A. Seielstad; SCIENTIFIC AMERICAN, June, 1965]. More recent studies suggest, however, that the arms develop as a dynamic consequence of the galaxy's motion.



EXTINCTION V. WAVELENGTH can be represented by a family of curves of which two are depicted. The bottom curve shows the characteristic extinction for starlight that has passed through about 2,000 light-years of interstellar space containing a typical amount of dust. The top curve shows the extinction expected after starlight has traveled three times as far through typical interstellar space, or about 6,000 light-years. At a distance of 9,000 light-years a star like the sun could not be seen from the earth with the most powerful telescope.

The mechanism by which interstellar grains are oriented by magnetic fields is not the simple one that turns the needle of a compass. The fields in space are much too weak. The strongest interstellar field probably does not exceed a thousandth of the magnetic field at the earth's surface, and the average strength of the galactic magnetic field is only a tenth or a hundredth of the maximum. Such fields would have little effect on the interstellar grains even if they were made of iron, and the fields would almost certainly fail to align particles that were

HORSEHEAD NEBULA is perhaps the most spectacular example of obscuration produced by interstellar grains. Located in the constellation Orion, the Horsehead is about 1,000 light-years distant. In this region there is probably as much matter in the form of interstellar dust as in stars. This photograph was made with the 200-inch telescope on Palomar Mountain.

SPIRAL GALAXY M 51 is probably much like our own, except for its small companion (*left*). Lanes of dust help to delineate the spiral arms, which tend to contain the brightest, bluest and youngest stars. This photograph was also made with the 200-inch Hale telescope.

being steadily bombarded by the atoms of the interstellar gas.

According to a hypothesis proposed by Leverett Davis, Jr., and Jesse L. Greenstein of the California Institute of Technology, the aligning mechanism is paramagnetic relaxation, a force that would make an interstellar grain spin on its short axis, which in turn would be lined up parallel to the lines of force in the magnetic field. Thus the particles would be "threaded" on the field lines much like buttons on a taut string. If the particles are like needles rather than buttons, they would resemble a string of tiny twirling batons.

It is not difficult to visualize how such oriented arrays of button-like or baton-like grains would polarize starlight. If the twirling grains were threaded on magnetic lines of force that ran parallel to our line of sight as we observed a star, they would present a maximum rotationally symmetrical area and therefore would not have any polarizing effect; they would simply reduce the intensity of all the components in the original unpolarized light. But if the lines of force were, say, horizontal and perpendicular to our line of vision, the grains would act as an array of vertical pickets that would reduce the vertical component of the originally unpolarized light and leave an excess of the horizontal component [*see top illustration on preceding two pages*]. If the magnetic lines of force intersected our line of sight at less than 90 degrees, the polarization would be proportionately less. The process is so effective that the direction of optical polarization is extremely uniform over wide ranges of galactic longitude.

Where do interstellar grains come from? It may be that there is more than one source. An early hypothesis was that the grains were similar to the micrometeorites that abound within the solar system. The idea was discarded when it was seen that there would be no way for such particles to be ejected from a solar system—our system or any other—and begin wandering through space.

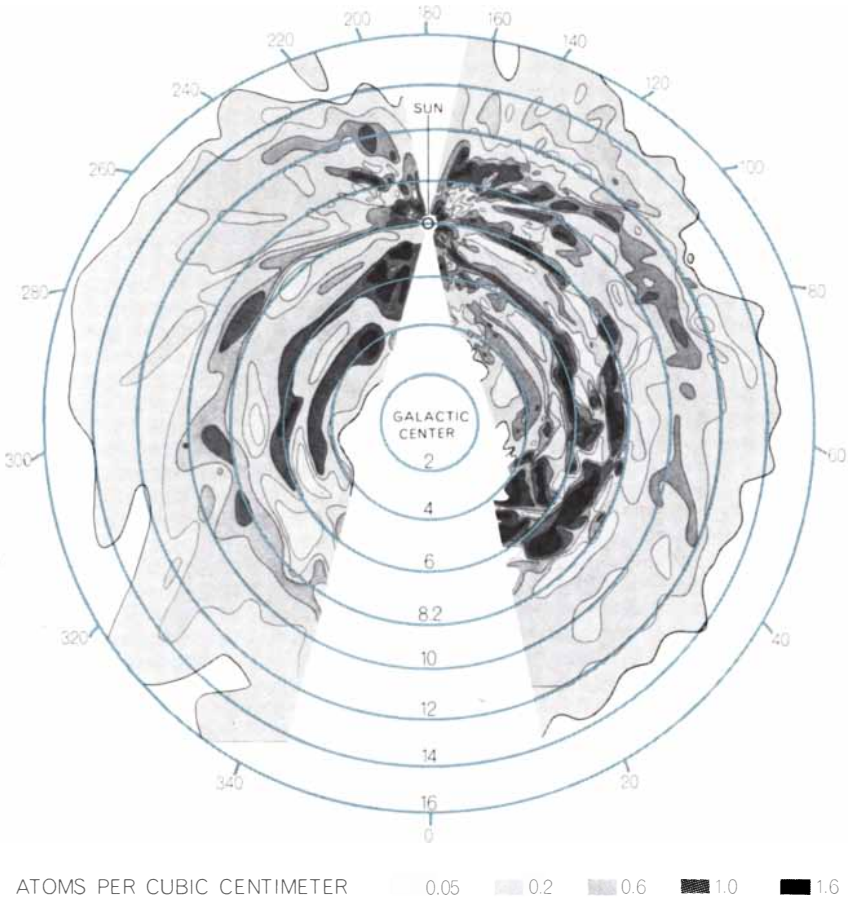
It was then suggested about 30 years ago by the Swedish astronomer Bertil Lindblad that the grains grow by simple accretion out of the already existing gaseous matter in space. The suggestion was appealing and was consistent with the observation that there seems to be a direct correlation between the presence of interstellar grains and the density of the interstellar gas. Difficulties arose, however, when astrophysicists tried to explain exactly how grains could begin

to form in a typical space environment. The proposed mechanisms failed to supply enough grains to satisfy the observations.

Attention was then turned to other hypotheses. It is well known that molecules are formed in the atmospheres of cool stars. Recently it has been shown that it should be possible for small particles of carbon and silica (molecules of silicon and oxygen) to grow under certain stellar conditions and for these particles to be blown out into space by the pressure of stellar radiation. If these small particles should get caught in a reasonably dense cloud of gas, they would serve as nuclei on which atoms could condense. When atoms of hydrogen, nitrogen, carbon and oxygen accidentally collided with such a nucleus, they would tend to stick and ultimately form molecules of various simple compounds: water, methane (CH_4) and ammonia (NH_3). Along the way less abundant atoms present in the gas cloud would also get embedded in the grain; thus one would expect to find, for instance, one atom of iron for every 1,000 atoms of oxygen.

If this process of growth by accretion were allowed to continue undisturbed for several billion years, the interstellar grains would grow to substantial size, perhaps as large as 20 microns, or 40 times the wavelength of light. This is about the size of the ice crystals in the atmosphere that produce the halo sometimes seen around the sun or the moon. Interstellar grains of this size, however, would be much too large to produce the effects we are trying to explain. Accordingly the proposed accretion mechanism is too effective. Might there be some other mechanism at work that limits grain size? There is.

The comparatively dense clouds of gas that are responsible for the growth of the grains could also provide the mechanism for limiting growth. Such gas clouds are in rapid motion in random directions, and about once every million years, on the average, a typical cloud will collide with another one. In the turbulent environment that results the growing grains will be bombarded by high-velocity atoms, will collide with one another and in general will be subjected to attrition. Low-energy cosmic rays and particles traveling with energies of 10 million to 100 million electron volts may also play a part in limiting the size of interstellar grains. Very recently S. B. Pikelner of the Sternberg Astronomical Institute in Moscow has correlated this type of grain attrition with the large numbers of electrons that evidently exist in the cool regions of interstellar space; he believes the electrons are produced when cosmic rays and energetic particles collide with hydrogen gas. The net effect may be to limit the grains to a maximum size of perhaps one micron, which would be about right to satisfy the observations.

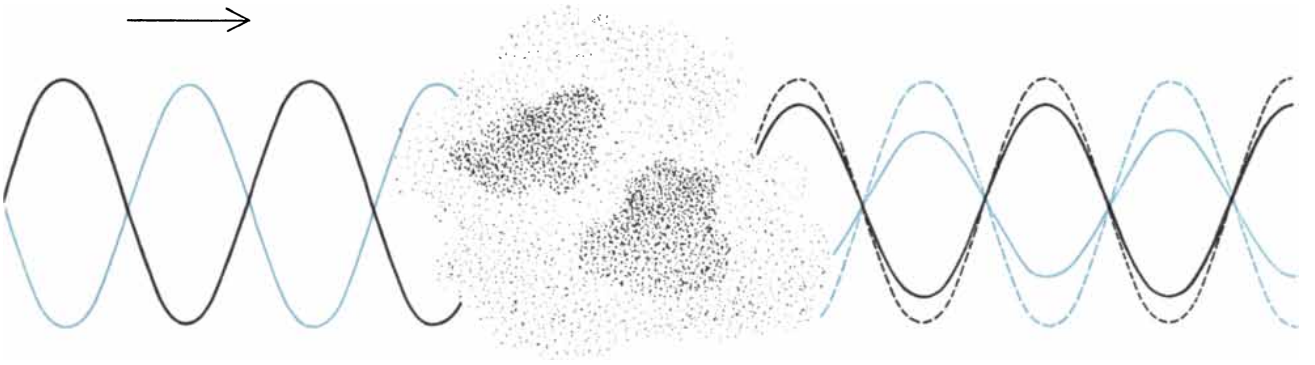


DISTRIBUTION OF HYDROGEN in our galaxy is believed to parallel closely the distribution of interstellar grains as well as young stars. This map of hydrogen distribution is based on measurements of the 21-centimeter radiation emitted by neutral hydrogen, which is not obscured by dust. The map follows one prepared by Jan H. Oort of the University of Leiden. The numbers on the concentric rings indicate kiloparsecs; a kiloparsec is 3,262 light-years. The sun is now thought to be about 10 rather than 8.2 kiloparsecs from the galactic center.

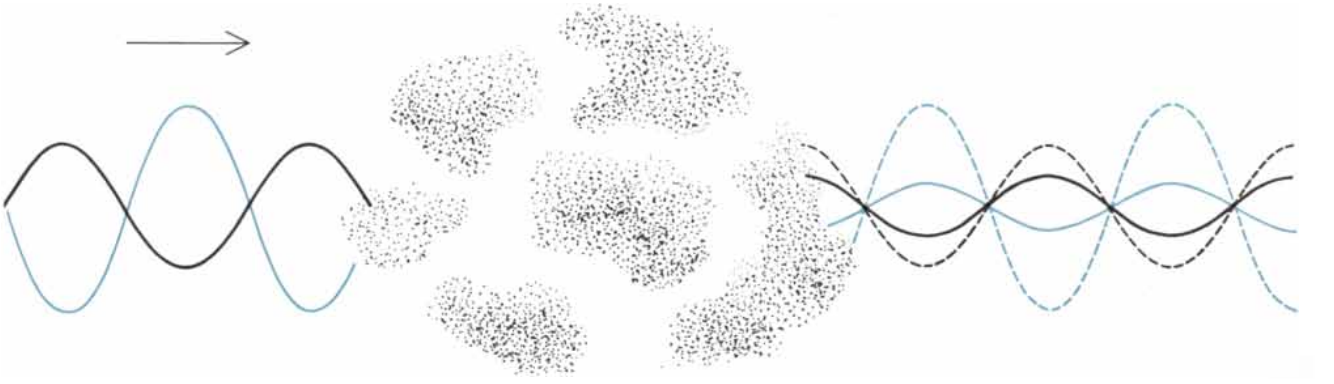
The only growth mechanism that would not satisfy the observations would be one that produced essentially spherical particles. The particles might still twirl around magnetic lines of force and reduce light intensity, but being symmetrical they would have no polarizing effect. The desired asymmetry would result if the grains were platelets of pure carbon in the form of graphite, or if they were produced by accretion on such plates, which would give rise to shapes resembling doorknobs. Alternatively, if molecules such as those of water are heavily involved in the growth of interstellar grains, one would expect the grain to be needle-like or possibly cigar-shaped. One cannot, however, entirely rule out hexagonal plates resembling miniature snow crystals.

In our laboratory at Rensselaer Polytechnic Institute we have developed a technique for measuring quite precisely how grains of various shapes will intercept light. The scattering and absorption of light by particles of wavelength size are not very amenable to calculation, particularly if the particles are not spherical. This is true even for particles of very regular shape, with one exception: infinitely long cylinders of circular cross section. To get at the general problem, including irregular or rough particles, we use an analogue experimental method in which all dimensions are scaled upward by a factor of about 100,000, or 10^5.

Accordingly we replace visible light (wavelength 5×10^{-5} centimeter) with radio waves whose wavelength is about three centimeters. Similarly, we use particle models that are about 10^5 times larger than the assumed interstellar grains and therefore range from about .5



REDDENING OF STARLIGHT depends on both the initial color of the star and the amount of dust its light must traverse to reach the earth. The diagram shows how passage through about 2,000 light-years of interstellar space containing a typical amount of dust will reduce the intensity of red light (*black curve*) from a white star by half a magnitude and the blue light by a whole magnitude.



MORE EXTREME REDDENING would be produced if the starlight had to travel about 6,000 light-years through typical interstellar space. This is about the diameter of a spiral arm of the galaxy. It is assumed in this diagram that the light originates from a hot, young star that emits three times as much blue light as red. The interstellar dust reduces the blue component by three magnitudes and the red component by 1.5 magnitudes. As a result the star will appear to contain about 20 percent more red light than blue.

centimeter across to about 10 centimeters. One's commonsense notion is completely unreliable for predicting how radiation will be obstructed by nonspherical particles whose size is less than or about the same as the wavelength [*see illustration on page 114*]. Of course, one can usually find a completely convincing theoretical argument to show how the observed results are really "obvious." In fact, an approximate theoretical calculation had anticipated, in a qualitative way, the experimental results by several years.

For very small particles the cross section, or effective blocking area, is much smaller than the silhouette of the particle, whereas for very large particles the cross section is about twice the silhouette area. Up to a certain grain size the extinction produced by a particle of given radius is greater the *shorter* the wavelength, which explains why blue light is dimmed more than red [*see bottom illustration on page 108*]. The reddened light then passes with relatively small loss through clouds of particles whose size is less than or comparable to the wavelength. It is for this reason that the sun reddens as it sinks toward the horizon: its light passes through increasing amounts of dust-laden atmosphere. The blue portion of the sun's light that does not pass through the dust is scattered and gives rise to the overall blue color of the sky.

Because the degree of scattering varies with wavelength, each wavelength exhibits its own degree of polarization. For very short and very long wavelengths the polarization drops to zero for a particle of any given size.

On the average the attenuation of starlight in the central plane of our galaxy is so great that we can see the stars only within a small region around us. The distance from the sun to the center of the galaxy is about 10 kiloparsecs, or about 32,000 light-years. Assuming an average extinction of 1.5 stellar magnitudes per kiloparsec, it turns out that stars like the sun would be invisible with the largest telescopes at a distance of less than three kiloparsecs. Even the brightest stars at the center of the galaxy are not visible to us.

The reddening of starlight as it passes through clouds of interstellar dust is generally in direct proportion to the amount of extinction. Passage through 2,000 light-years of average interstellar space will reduce the blue component of "white" starlight by a full magnitude and the red component by only half a magnitude. When the light has traveled through 6,000 light-years, the reduction in the two components is respectively 1.5 magnitudes and three magnitudes. These, of course, are only averages; the actual values vary widely. For example, the attenuation per unit distance through the bright nebula around the star Merope in the Pleiades is about 1,000 times greater than the interstellar average.

What role, if any, do the interstellar grains play in the formation of stars? It may be a coincidence that Merope is so near such a dusty place. In other cases, for example in the Orion nebula, the evidence is clear that regions of high gas and dust density are also rich in newborn stars. It is believed new stars condense out of clouds of dust and gas.

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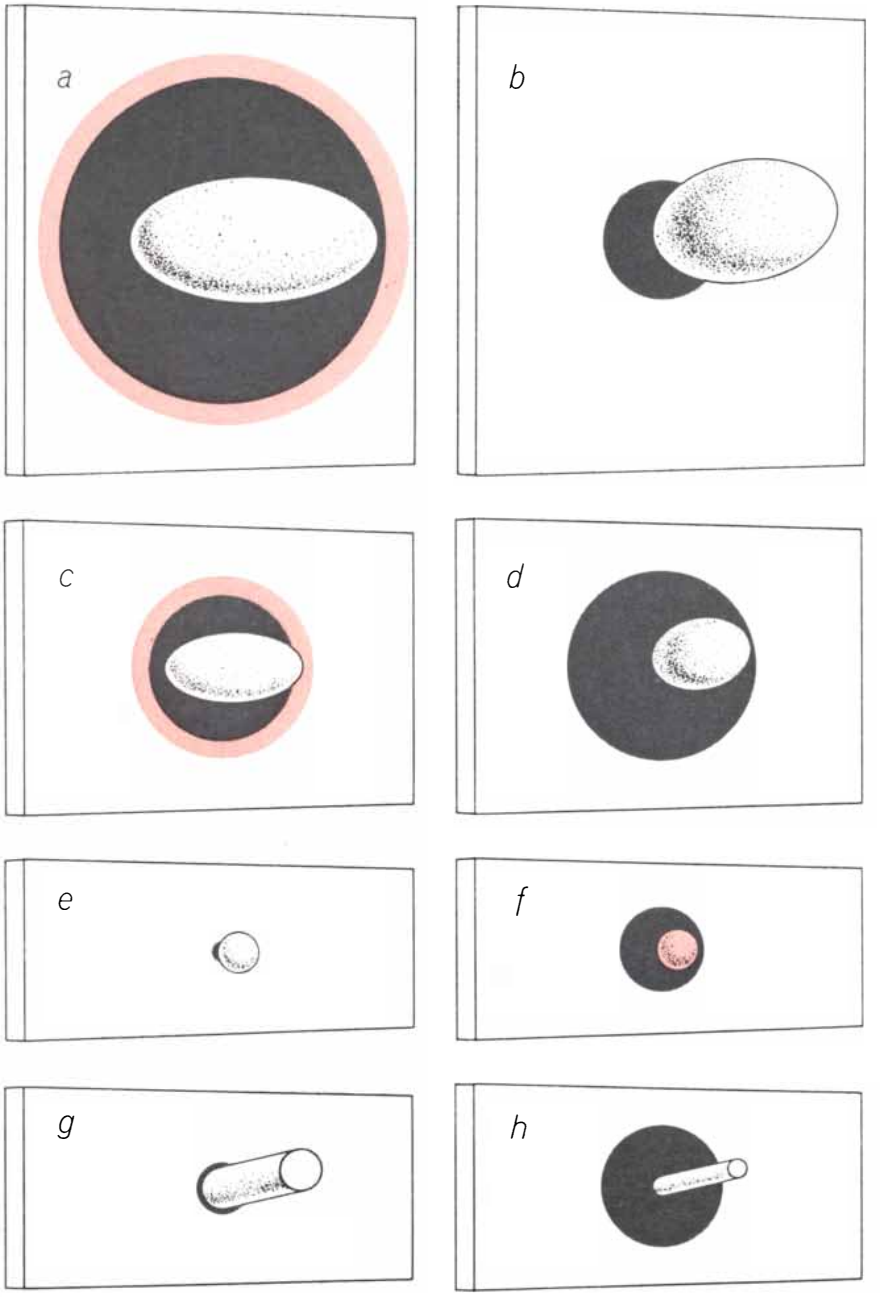
As the condensation proceeds, heat is generated by the release of gravitational energy. Finally the temperature inside the protostar becomes high enough to initiate a thermonuclear reaction. The star bursts forth with radiant energy and what remains of the surrounding dust and gas is vigorously propelled outward. The injection of these high-velocity clouds of gas and dust into the interstellar medium supplies kinetic energy of motion to other gas clouds. Thus are the cycles of interstellar grain growth and attrition continually maintained.



"MODEL" INTERSTELLAR GRAINS, 100,000 times larger in diameter than real ones, have been studied by the author to learn how they interfere with three-centimeter radio waves. As depicted here, the models are a fifth of actual size. The waves strike the models at right angles to the plane on which they are shown mounted. The total cross sections, or blocking areas, of the models are indicated by the various circles behind them. Cross sections depend strongly on the way models are oriented (*a–b, c–d*). Note that model *h* has a much larger cross section than *g*, even though only half the diameter of *g*. The marked difference in cross section of the two small spheres, *e* and *f*, is due to a difference in composition. The effect of polarization shows up only when ellipsoidal grains (*a, c*) are placed with their long axis perpendicular to the radiation. The larger cross section (*gray plus color*) is obtained when the radiation is polarized parallel to the long axis of the particle. The smaller cross section (*gray*) results when the polarization is at right angles to the long axis.

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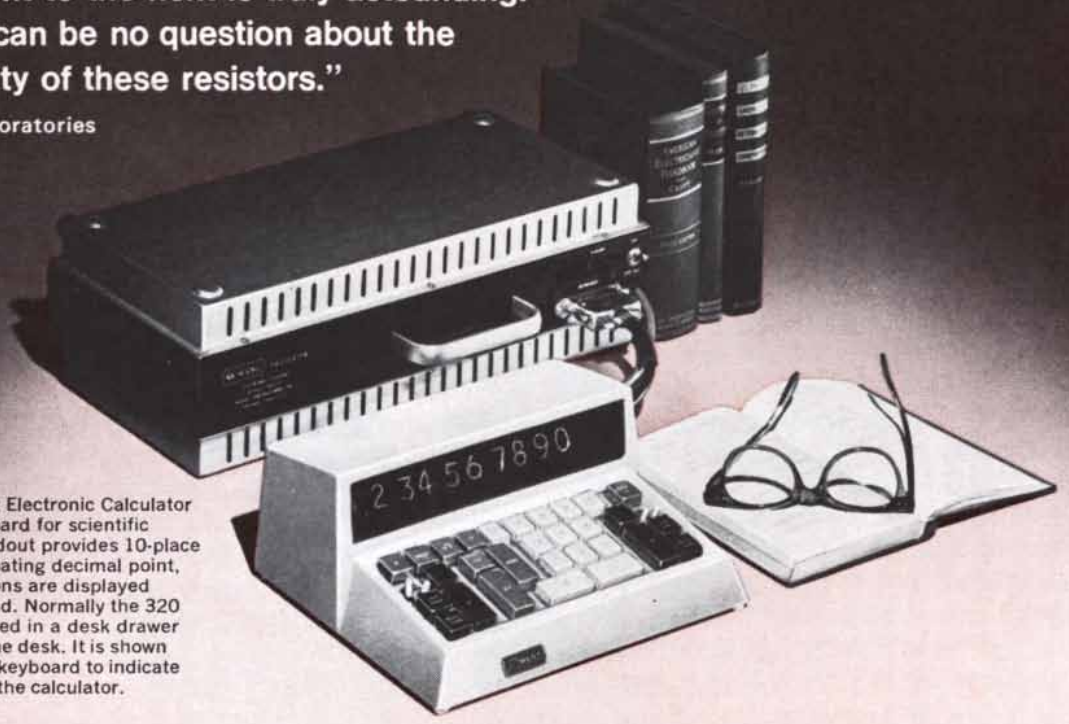
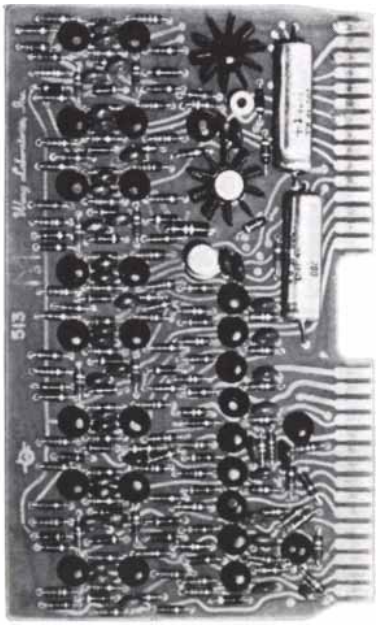


Model 320 Wang Electronic Calculator with 320K keyboard for scientific application. Readout provides 10-place accuracy with floating decimal point, and all calculations are displayed in one millisecond. Normally the 320 calculator is placed in a desk drawer rather than on the desk. It is shown here next to the keyboard to indicate compactness of the calculator.



One of the printed circuit cards from the Model 320 calculator. All resistors on this card are Allen-Bradley Type CB ¼ watt hot molded resistors.

To insure the extremely accurate and high speed operation of the 300 Series Wang Electronic Calculators, all components are selected with utmost care. Thus, it was only natural that Allen-Bradley hot molded resistors were chosen for this most exacting application.

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Many engineers and scientists raise the question "Why does it take so long to get answers to problems that require only a few minutes of computer time?"

The problem involves turnaround time. It's a paradox. Your problems are probably running on a computer that may calculate hundreds of times faster than computers used five or ten years ago. Yet you still wait as long. You wait. And a lot of other people in your organization wait.

Part of the problem is the fact that there are many more people using the computer. Their jobs are more varied. The computer spends more time performing input/output and general "housekeeping" routines.

How can you reduce turnaround time and get results faster? Rocketdyne, a Division of North American Aviation, Inc. cuts turnaround time with a multiprocessor system which operates under the control of an extension to Operating System/360.

Rocketdyne's IBM SYSTEM/360 includes a Model 40 computer coupled to a Model 65. The Model 40 handles system input/output operations, assigns job priorities and automatically schedules jobs into the Model 65. It was the first such system installed. Using the Model 40 in this fashion frees the more powerful central processing unit of the larger computer to process on a practically continuous basis the various mathematical calculations of each job queued into it.

This CPU can take full advantage of its large memory and higher processing speed without allocating time or space to support functions.

The benefits of increased throughput, namely faster turnaround and higher system performance, accrue because of this balanced division of labor between the two computers. The coupled computers are controlled by a multiprocessor operating system called the Attached Support Processor (ASP), which provides a compatible extension to Operating System/360.

The Rocketdyne computer center operates on an open shop basis. Over 400 engineers submit their own FORTRAN programs. The center handles an average of about 500 jobs per day with each job averaging 2½ minutes of computer time.

A large part of Rocketdyne's computing consists of numerous runs in which rocket test data are reduced and analyzed. Calculations average 5-20 minutes for each such job placed into the computer.

Data are transmitted from F-1 engine firings at the Edwards Field Laboratory; from J-2 engines and F-1 components and attitude control engines at the Santa Susana Field Laboratory; from solid rocket operations firings at McGregor, Texas; and from H-1 Thor and Atlas firings at Neosho, Missouri.

Data communications systems carry these data to the computer center at Rocketdyne's facilities at Canoga Park, California.

Results are returned in as little as 30 minutes for action by Rocketdyne's engineers. No waiting hours for the job to reach the front of the queue.

The overall result for Rocketdyne's engineers and scientists is that the computer is now a much more useful tool for them.

Engines may be refired or removed from static test stands at an increased tempo and with greater precision.

The concept of directly coupled systems was first proposed and implemented by IBM in the early 1960's using various combinations of 7000 series computers. For example, the first installation at Rocketdyne used a 7044 as support processor for a 7094 II. This was considered one of the most powerful general purpose computers in the country prior to the installation of third generation computers.

If you would like to find out more about the Attached Support Processor Program which IBM provides for use with SYSTEM/360 and how it might help you speed job turnaround time, contact: Director, Scientific Development, IBM Corporation, Department 805-053, 112 East Post Road, White Plains, New York 10601.

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The Interference Theory of Forgetting

A classical hypothesis about forgetting is that learning some things tends to make one forget others. This mechanism can be demonstrated, and modern experiments have led to a deeper knowledge of how it works

by John Ceraso

An anecdote that has amused many psychologists concerns the professor of ichthyology who complained that each time he learned the name of a new student he forgot the name of a fish. This is not just another joke about an absentminded professor. It aptly illustrates the "interference" theory of forgetting, which attributes loss of memory to the demonstrably adverse effect that learning one group of facts has on the learner's ability to remember other groups of facts. An older theory of forgetting is the "decay" theory, which compares memories to colors that, if not refreshed, fade and disappear from the mind's canvas. The interference theory, however, has grown in popularity since early in this century and is now supported by a massive body of experimental work.

A typical interference experiment requires that two groups of subjects undertake related but quantitatively different learning tasks. One such task is to memorize a list of 20 items in which 10 nonsense syllables are paired with 10 common nouns [*see illustration at right*]. The subjects in a control group are asked to memorize one such list; the subjects in the experimental group, to memorize two lists. The same nonsense syllables appear in both lists, but the accompanying words are different.

The material to be memorized is presented at a brisk pace, and the subjects soon learn to reply to the nonsense syllable with the appropriate noun. After the lists are learned, tests determine how well the subjects recall the material. In a typical experiment [*see top illustration on next page*] one test was given immediately and a second 24 hours later. Inevitably the subjects who had memorized two lists did not recall either List I or List II as well as the control subjects recalled List I. The experimental subjects' poorer performance must be attributed to the only difference between the two groups of subjects: the experimental subjects had to learn two lists instead of one. In some way the increased learning load affected recall.

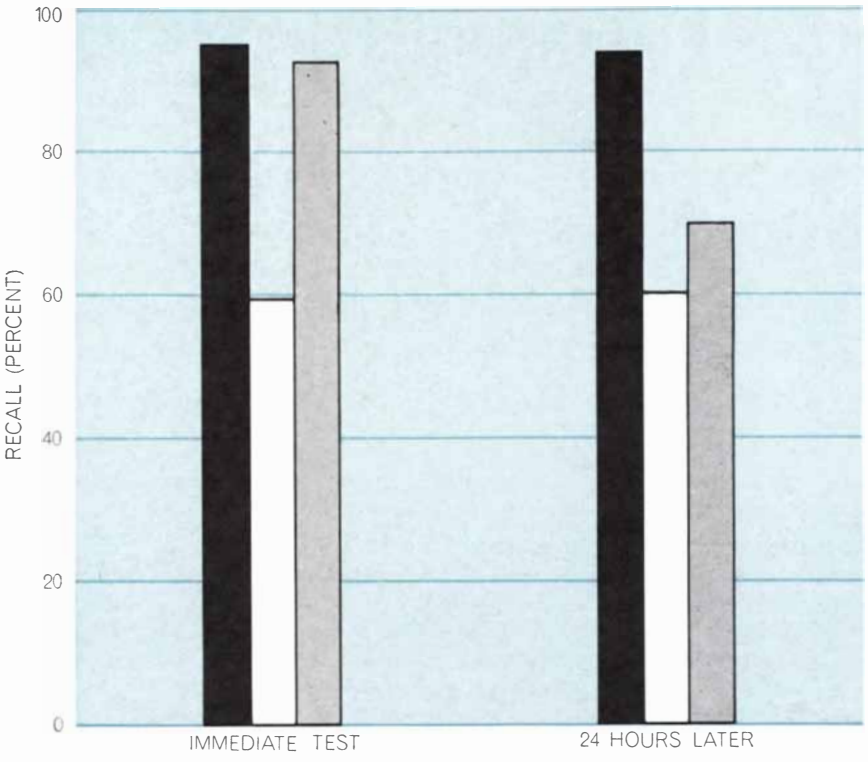
The performance of the experimental subjects was notable in two other respects. First, their immediate recall of List I was significantly poorer than the control subjects' recall and was almost equally poor 24 hours later. The experimental subjects' immediate recall of List II, however, was nearly as good as the control subjects' immediate recall of List I. Evidently learning List II affected the experimental subjects' recall of List I. This effect is called "retroactive inhibition." It was the first form of interference to be demonstrated experimentally and remains the one most widely studied.

Over the years two main theories have emerged in explanation of retroactive inhibition. One, known as the "competition of response" theory, is quite radical from a commonsense point of view. Developed in the 1930's by John McGeoch of the University of Iowa, it essentially states that there is no forgetting process. It supposes instead that, when someone's recollection fails, he has simply remembered the wrong item of information; the remembered item preempts the place of the one he was trying to recall. An analogy is the difficulty encountered by a driver accustomed to the three forward speeds of the standard American gearshift when he tries to shift gears in a foreign car. His hand makes an accustomed but incorrect motion. This motion prevents him from making the correct one since he cannot do both things at the same time. In terms of the word-recall experiment McGeoch's theory suggests that each nonsense syllable has two channels. For example, if the subject remembers *lawn* on hearing the syllable BEM, he has utilized one of the two channels and the other channel, running from BEM to *aisle*, is automatically blocked.

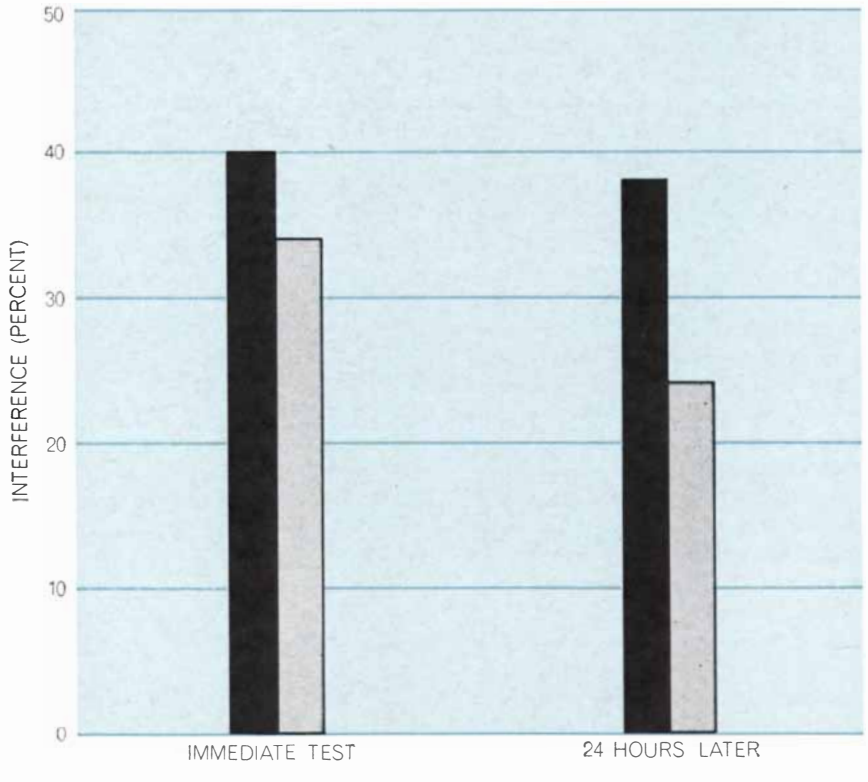
A second explanation of retroactive inhibition is the "unlearning" theory proposed in the 1940's by Arthur W. Melton of the University of Michigan. Imagine an experimental subject's efforts to memorize List II after having successfully learned List I. At first the new learning process will be disrupted as List I words come to mind in response to the nonsense syllables. After a few trials, however, the well-learned List I words will no longer come to mind and the subject can get on with the job of learning List II. Melton's theory reasonably as-

LIST I		LIST II	
BEM	*lawn*	BEM	*aisle*
TAQ	*barge*	TAQ	*cave*
MUZ	*host*	MUZ	*bass*
PEZ	*tube*	PEZ	*vine*
LUF	*weed*	LUF	*dame*
ROH	*mate*	ROH	*file*
VID	*ache*	VID	*gown*
JOP	*cart*	JOP	*whip*
KUG	*quart*	KUG	*budge*
GAV	*zinc*	GAV	*dough*

TWO LISTS used as learning material in the author's experiments contain the same 10 nonsense syllables. Each syllable acts as a memory stimulus but the common word with which it is paired differs in each list.



TWO GROUPS OF SUBJECTS in an "interference" experiment show differing abilities to recall memorized words. Learning one word list, a control group remembers it well. Learning two lists, the test group recalls neither one as well as the control group but remembers the list learned last better than the one learned first.



REDUCTION IN INTERFERENCE results from reduced "crowding," the author's term for the merging of two short word lists into a single long list as time passes. Tested 24 hours after training, the group that was exposed the least to possible crowding was much less affected by interference than the crowded control group was.

sumes that some mechanism has operated at this point to suppress or damp the recollection of List I words. In effect they have been unlearned.

Retroactive inhibition is not the only form in which interference may be encountered. The word-recall experiments also reveal that, 24 hours after having learned List I and List II, a subject's recall of List II words diminishes but his recall of List I words does not. This phenomenon, which demonstrates that interference by List I can affect recall of List II, is termed "proactive inhibition." The observation that proactive inhibition increases as time passes gives this form of interference a striking resemblance to the "gradual decay of ideas" proposed by John Locke in the 17th century as the chief characteristic of forgetting. Benton J. Underwood of Northwestern University was the first to emphasize the importance of proactive inhibition. Although the phenomenon has been little studied, it appears to be the laboratory equivalent of everyday forgetting.

Proactive inhibition cannot be explained by either McGeoch's or Melton's theories. New learning is needed if the old is to be unlearned in accordance with Melton's theory, but no new learning follows a subject's memorizing of List II. (New learning of various kinds may indeed occur during the 24 hours in which the experimental subjects are away from the laboratory, but this is equally true for the control subjects and there is no evidence that its effect is significant.) As for McGeoch's competition-of-response theory, the recall of List I words can be regarded as blocking the channels leading to List II words. This theory, however, offers no explanation of the fact that proactive inhibition increases with the passage of time. Why should there at first be no competition of response and then a growth of such competition?

Underwood proposed an answer to this question that is ingenious in its combination of existing theories. List I unlearning, he suggests, is followed after a period of time by "spontaneous recovery." As the recovery process gradually dissipates the suppression of List I owing to the unlearning process, the list again becomes available for recall. This availability, in turn, increases the degree of List I interference with List II and accounts for the subject's diminished recall of List II after a 24-hour interval. In spite of its ingenuity, Underwood's proposal has a flaw in its applicability to word-list experiments. Spontaneous recovery should cause the recall

of List II to drop, and it does. But it should also cause the recall of List I to rise, and it does not. Instead List I recall is the same at the end of 24 hours as it was initially.

Proactive inhibition has also been studied by R. Koppenaal of New York University. In one of his experiments subjects were given a special "recall" test, first used by Underwood and his co-worker Jean Barnes. The experiment was designed to test the possibility (suggested by several psychologists) that decay in List II recall reflects the subject's mounting confusion about which words belong to which list. Given the syllable BEM and asked for the matching noun from List II, for example, the subject might remember both *lawn* and *aisle* but give the wrong reply because he could not remember which word appeared in List II. Accordingly Koppenaal asked his subjects to give both words associated with each stimulus syllable and scored them simply on the basis of their ability to recall any List II words at all. Tests conducted 24 hours, 72 hours and one week after List II had been learned showed a loss in the ability to recall List II words even when recall was scored in this way. Koppenaal's study thus proved that proactive inhibition cannot be attributed to an increase in confusion as time passes. Rather the increase in interference is characterized by an actual loss of the ability to recall List II nouns.

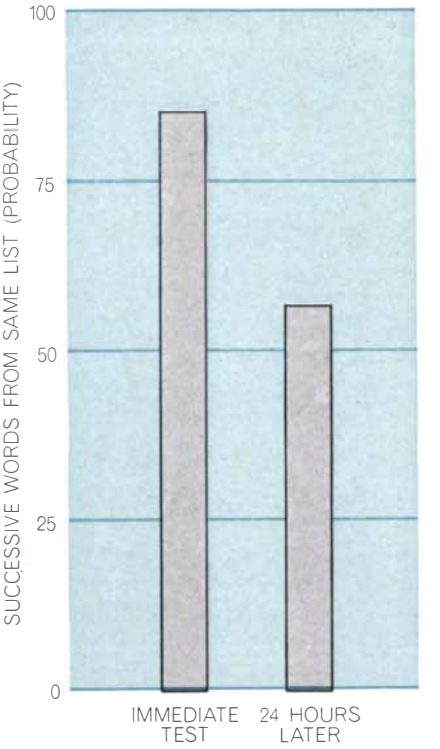
In my opinion proactive inhibition is best explained in terms of the interaction of List I and List II. This interaction does not exist immediately after learning but develops and increases as time passes. At the start of Melton's process of unlearning, List I words interfere with the memorizing of List II words, but the interference disappears after a few trials. One could say that the subject has managed to isolate the two lists and can think of one without thinking of the other. I believe it is this isolation that is lost as time passes. As a result the two lists tend increasingly to merge with each other, a process we can call "crowding."

At first the concept of crowding seems to offer no better explanation of proactive inhibition than the concept of spontaneous recovery does. If the two lists do merge, the decline in recall after 24 hours should affect the words in both lists and not just the words in one. As our initial word-list experiment shows, however, the level of recall for List I remains the same in spite of the passage of time. Some factor is obviously needed that will counteract the effects of crowding and so account for the stability of List I recall.

This counteracting factor is, I believe, none other than the process of spontaneous recovery postulated by Underwood. Reviewing the word-list experiment from this viewpoint, the sequence of events and the operative factors concerned are as follows: (1) On testing immediately after both lists have been learned, List I shows a deficit in recall attributable to the unlearning process. No such deficit is evident for List II because it has not been exposed to unlearning. (2) During the next 24 hours two processes are simultaneously at work. Spontaneous recovery affects List I, whereas crowding affects both lists. (3) On testing after 24 hours, the effect of crowding is evident in the case of List II. Never having been unlearned, List II cannot benefit from spontaneous recovery. As a result List II suffers a decline in percentage of recall. (4) The process of crowding affects List I quite as much as it affects List II, but this influence is masked by the action of the spontaneous-recovery process. In fact, crowding and recovery neatly counterbalance each other, so that the net percentage of List I recall is the same after 24 hours as it was at the start.

Any investigator worth his salt is suspicious of a hypothesis in which two postulated factors work to cancel each other. I realized that in order to give the hypothesis any support I would have to show one or another of the postulated factors at work in isolation. I therefore designed a series of experiments in which the effect of crowding would be minimized. My expectation was that if little or no crowding occurred, Underwood's process of spontaneous recovery would reveal itself.

In my first experiment a control group not only learned List I but also was given the standard 10 trials needed to learn List II. This training made the control group what I considered to be maximally crowded subjects. To obtain minimal crowding, in turn, an experimental group was given a different word list at each of the 10 learning trials that followed their learning of List I. It was thought that, with only a single exposure to each of the 10 "second" lists and thus with no drill, the subjects' List II learning would be weak. Unlearning of List I should nonetheless occur, because in trying to learn new words throughout the 10 trials the subjects would have had to suppress their earlier learning.



PROOF OF CROWDING is provided by an experiment testing subjects' recollection of words memorized as separate lists of 10 words each. When subjects first recalled the words at random, successive pairs were nearly always from one list. After 24 hours this was so in scarcely half of the instances.

The prediction for this experiment was that both groups would show poor recall of List I when tested immediately after learning but that only the group exposed to minimal crowding would display spontaneous recovery from unlearning at the end of 24 hours. Tests immediately after learning showed that recall of List I by both groups had suffered considerably from interference. Twenty-four hours later, however, the least crowded group showed a substantial spontaneous recovery from unlearning; its interference percentage had diminished by nearly a third [*see bottom illustration on opposite page*].

The results of the experiment include two other points of interest. First, clear evidence that spontaneous recovery actually takes place not only indicates that the unlearning process can be overcome but also suggests that it is only an initial and temporary cause of forgetting. Second, the failure of the control group—that is, the most crowded group—to show any significant recovery from unlearning after 24 hours indicates that List I as well as List II suffers from crowding. It is therefore apparent that the recall of both lists, and not just the recall of the second list, encounters

increasing interference as time passes.

Evidence that both lists suffer from interference seemed to me to be strong support for the concept that separate lists gradually merge and hence also support for the crowding theory of forgetting in general. In the hope of finding direct evidence of list-merging I undertook a "recollection" experiment. Its technique was patterned after "clustering" studies first devised by W. A. Bousfield of the University of Connecticut. The experiment did not involve nonsense syllables. Instead the subjects were repeatedly shown a list of 10 common nouns. When they could recite the list by heart, they were shown a second list of nouns and memorized it in the same way. The subjects were then asked to recall words from both sets in whatever order they came to mind. The recollection test was given to some subjects immediately after training and to others 24 hours later.

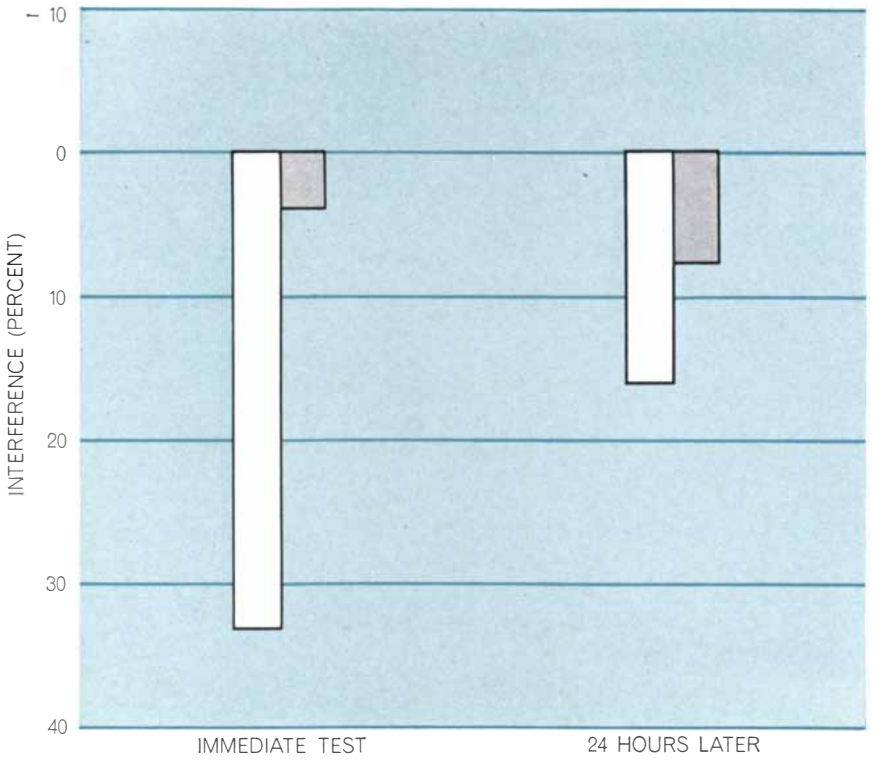
The expectation was that, because the words had been organized into two "categories," the categories would at least in part determine the order of recall of the words. A subject might typically recall a run of words from one list, then a run from the other list and so forth. As time passed, however, and the two lists became increasingly crowded together, the order of recall of any one word should no longer be determined by this consideration. In order to analyze the test results each subject's recitation of words was divided into successive pairs. It was noted whether or not each pair came from the same list and the proportion of all pairs that were from the same list was calculated. The results were expressed in terms of the probability that successive words would come from the same list [*see illustration on preceding page*]. They confirmed expectations: immediately after learning, the subjects apparently recalled words as if from two separate lists of 10 words each. After 24 hours, however, the two lists had evidently merged into a single list 20 words long, and the subjects' order of recall was almost completely independent of which list the words appeared in.

This analysis assumes that it is harder to recall a word when it is embedded with 19 others than when it is embedded with nine. Evidence for this assumption is as old as experimental psychology. Hermann Ebbinghaus, a 19th-century German pioneer in the study of learning in humans, was the first to demonstrate that the more material there is to learn, the more time is needed to master any part of it. For example, 10 trials may suffice to memorize a list containing 10 paired words, but 20 trials will be needed to learn a list twice as long. This is not a simple arithmetical function implying that if the study of 10 items for x amount of time per item takes a period of $10x$, then the study of 20 items will take a period of $20x$. Instead it means that the subject inspects each item on the longer list 20 times, whereas items on the shorter list receive only half that number of inspections.

Why should many more trials be required to master longer lists? There is reason to believe that one factor is the increased difficulty in recalling an item embedded in a long list. If more numerous items are harder to recall, we would expect that a subject who masters a long list would actually have to learn each item *better* than he would the items on a short list, simply to compensate for the increased difficulty of retrieval. This factor would help to account for the greater number of exposures required for long-list learning.

Evidence that a long list is indeed better learned is supplied by a finding that was first made in the 1920's and that I have replicated recently. If subjects are given long and short lists to learn but are not tested for recall until a week later, the subjects who learned the long list greatly outperform those who learned the short list. The superior recall of the long list must mean that it was initially better learned in order to offset the increased difficulty of retrieval from a long list. It is little wonder that when two short lists merge into a single long one, the subject's recall is much impaired. Such is apparently the basis for much of everyday forgetting: what was once a relatively isolated item is crowded in with others as time passes and becomes inaccessible.

What actually happens when lists merge? Kurt Koffka, one of the founders of the Gestalt school of psychology, proposed a physiological answer. Koffka believed that for each memory a "memory trace" exists physically in the brain, and that when one recalls, say, an elephant, it is because the brain's memory trace for "elephant" has somehow been stimulated. It was Koffka's opinion that if too many items of the same kind are learned at the same time, the memory traces will interact and become distorted. On this basis interference diminishes recall by impairing or even destroying the physiological basis of memory.



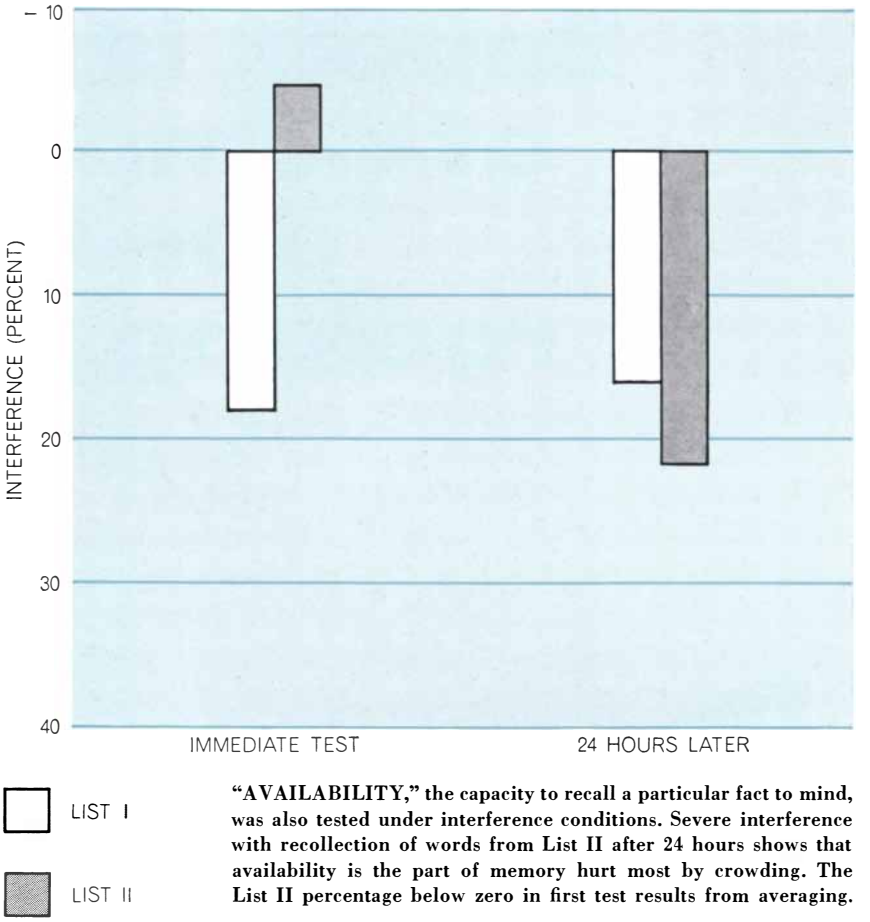
"ASSOCIATION," the capacity to recall how things go together, was tested under conditions of interference by having subjects memorize two word lists. Given scrambled lists later, they tried to restore them to order. Results were good and grew better as time passed, proving association to be almost immune to interference.

A powerful argument against Koffka's position is provided by the existence of one kind of memory—"recognition" memory—that is virtually unaffected by interference experiments. Recognition memory is tested in the laboratory by presenting the subject with a number of objects he has seen previously, as well as with some he has never seen. He is said to have "recognized" if he can pick out the familiar objects and reject the unfamiliar ones. Most people's recognition is superior to their recall. This helps to account for the well-known experience of having difficulty remembering names although never forgetting a face. Remembering a face is a matter of simple recognition; remembering a name, on the other hand, means bringing up from the memory the name with which the face is associated.

If, as Koffka proposed, interference does impair the physical memory trace, it is difficult to explain why recognition is virtually unaffected in interference experiments. How can a subject recognize an item when the physiological basis for memory of the item has been destroyed? It seems likely that problems of recall consist more in the way memories are activated than in their physical annihilation.

A familiar experience of everyday life—the "tip of the tongue" phenomenon—provides an example. One may pride oneself on having a good memory for both faces and names and then meet someone whose face is familiar but whose name seems almost, but not quite, there. If a mutual friend should happen to come along and greet the other person by name, the name would be recognized instantly. This is a typical instance in which "association"—that is, the knowledge that a face and a name go together—has been preserved, even though the desired item of information cannot be brought to mind. The memory is simply not "available." There is also the reverse phenomenon: the memory is available but the association is lost. Stalactites and stalagmites: which one grows from the floor and which from the ceiling? Ordinate and abscissa: which of the coordinates is horizontal and which vertical?

In general, then, forgetting can be attributed either to loss of availability or to loss of association. I conducted further experiments to test the extent to which each of these types of forgetting was affected by interference. The first experiment was designed to measure association. It was a "matching" test, a variation on the earlier list-learning studies. The subject first memorized two lists consisting of identical sets of nonsense syllables paired with different sets of words. He was then presented with the nonsense syllables and the words in a jumble and asked to sort them out. Obviously the subject does not have to bring any of the material to mind; it is all before him. The only requirement is that he correctly match the 10 nonsense syllables with both of their associated words.



"AVAILABILITY," the capacity to recall a particular fact to mind, was also tested under interference conditions. Severe interference with recollection of words from List II after 24 hours shows that availability is the part of memory hurt most by crowding. The List II percentage below zero in first test results from averaging.

The second experiment was designed to measure availability. After the same list-learning preparation the subject was reminded of each of the nonsense syllables and asked to recall both words associated with it. After running through all 10 nonsense syllables with varying success the subject was asked to try to remember any additional words he might not already have given. Availability was scored on the basis of the total number of words the subject recalled, regardless of whether or not the words were correctly associated.

In both experiments the subjects were first tested immediately after learning the two lists and then after a 24-hour delay. The results were expressed as percentages of interference [*see illustrations on these two pages*]. The test immediately after learning showed significant losses in both association and availability performance with respect to List I. The losses with respect to List II, however, were insignificant. This finding supports the suggestion that Melton's process of unlearning is indeed responsible for immediate interference.

A striking contrast between association and availability with respect to List II is apparent in the tests conducted after 24 hours. In the case of association performance there is in effect no loss; the slight difference between immediate and 24-hour scores is statistically insignificant. In the case of availability performance, however, a sharp decline is evident. Hence it appears that interference acting over a period of time chiefly affects availability, leaving association unimpaired.

This being so, the data for List I recall after the passage of time become intelligible. As we have seen, it has been suggested that a spontaneous recovery from the effects of unlearning occurs over a period of time, and that the effects of crowding counteract spontaneous recovery. Evidence that crowding almost exclusively affects availability is provided by the sharp decline of List II availability after 24 hours. Crowding should also block or coun-

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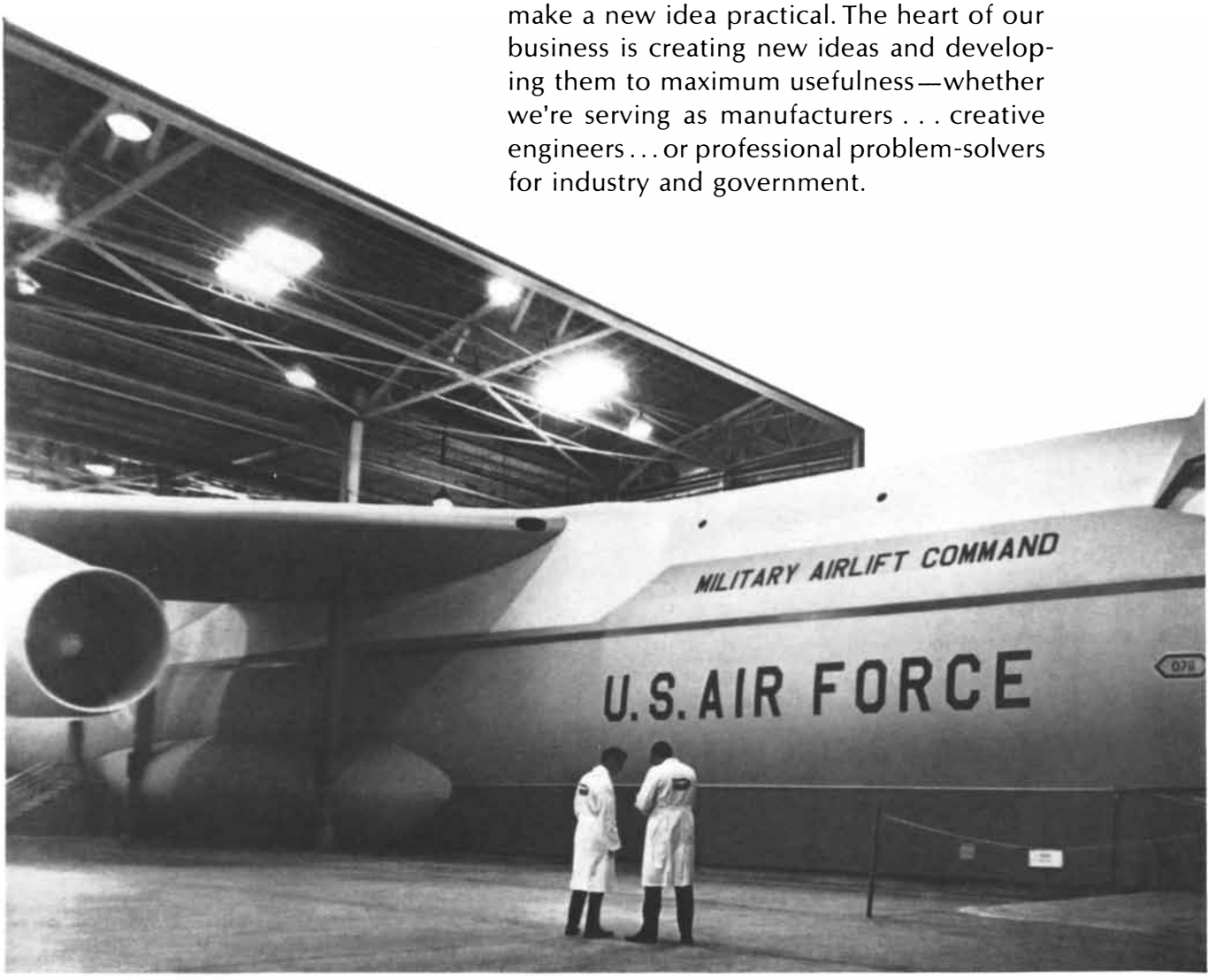

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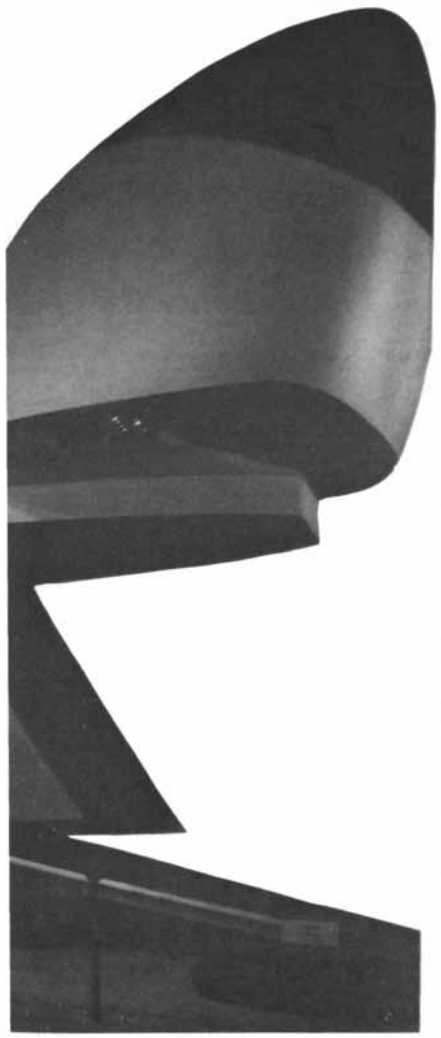

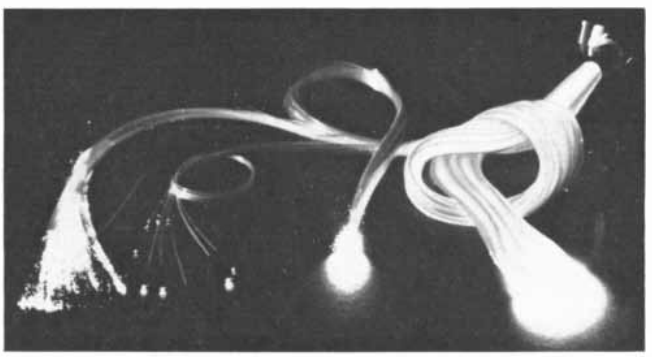

In automotive. Glass fibers that "pipe" light around corners form the heart of a new Bendix system that can tell a driver if each of his car's lights is working. A "pipe of light" visually connects each bulb to the dashboard.

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Where ideas unlock the future

terbalance the spontaneous recovery of List I. That is exactly what happens: the level of interference with the availability of List I at the end of 24 hours is insignificantly different from the level of interference in the first test. The interference with association performance on List I at the end of 24 hours, however, is less than half the interference in the first test. This was to be anticipated; crowding has little or no effect on association and thus the process of spontaneous recovery takes place without interference.

With these results in mind, we may again ask what happens when lists merge. What is the nature of the loss produced by the passage of time? The answer is evidently that the availability of items is lost. The subject's ability to associate items remains generally unimpaired; the difficulty lies rather in bringing items to mind. This finding seems to rule out McGeoch's competition-of-response theory as an explanation of interference. The analogy of one association blocking another collapses in the face of the matching test, in which both associations remain intact. Not only can the subject use the channels from BEM to both *lawn* and *aisle;* he will probably clash the gears of a foreign car only if he is careless or under pressure. Apparently some analogy or model for interference other than McGeoch's is called for.

I should like to suggest an analogy that compares recall to a process of search and likens forgetting neither to a fading canvas nor to McGeoch's blocked channel but to an unsuccessful hunt. As the experiments described here suggest, forgetting increases with the passage of time because things that are learned become crowded and each new search must be conducted over a broader area of memory. From this point of view interference is simply a name for the general difficulty that is experienced when searching for an item embedded among other items in memory storage.

This is not the first time that "search" has been suggested as a synonym for "recall." Recent notions of recall based on information theory, signal-detection theory and computer-memory models all make important use of the search concept. Nonetheless, interference continues to be the phenomenon most studied by psychologists interested in memory. It seems significant that, on the basis of the experiments I have described, interference may now be explained within the framework of a theory of search.

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BRIEFING OUTLINE

I. What is an Integrated Circuit?
- A. What it looks like
- B. What it does
- C. How it compares to other circuits

II. How an Integrated Circuit is made.
- A. Circuit design
- B. Masking
- C. Etching
- D. Diffusion
- E. Metallization
- F. Wafer testing
- G. Scribing
- H. Packaging
- I. Testing the completed circuit

III. Uses of Integrated Circuits.
- A. Functions now available
- B. Applications in industry
- C. Applications in research

CITY	CHANNEL	TIME
Albuquerque	KOB-4	7:00 AM
Baltimore	WMAR-2	7:00 AM
Boston	WNAC-7	6:30 AM
Chicago	WBKB-7	6:30 AM
Cincinnati	WKRC-12	7:00 AM
Cleveland	WEWS-5	7:00 AM
Dallas-Fort Worth	KTVT-11	6:30 AM
Dayton	WHIO-7	7:00 AM
Denver	KLZ-7	7:00 AM
Detroit	WWJ-4	6:30 AM
Fort Wayne	WANE-15	7:00 AM
Houston	KHOU-11	7 00 AM
Huntsville	WAAY-31	7:00 AM
Indianapolis	WISH-8	7:00 AM
Kansas City	KCMO-5	7:00 AM
Los Angeles	KHJ-9	7:00 AM
Miami	WCKT-7	6:30 AM
Milwaukee	WITI-6	7:00 AM
Minneapolis-St. Paul	WCCO-4	7:00 AM
New Orleans	WVUE-12	7:00 AM
New York	WPIX-11	6:30 AM
New York	WPIX-11	7:00 AM
New York	WPIX-11	7:30 AM
Orlando	WDBO-6	6:30 AM
Philadelphia	WFIL-6	7:00 AM
Phoenix	KTAR-12	9:00 AM*
Rochester	WHEC-10	7:00 AM
St. Louis	KPLR-11	7:00 AM
San Diego	KOGO-10	6:30 AM
San Francisco-Oakland	KPIX-5	6:30 AM
Seattle-Tacoma	KING-5	6:30 AM
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MATHEMATICAL GAMES

Problems that are built on the knight's move in chess

by Martin Gardner

He sat leaning on his cane and thinking that with a Knight's move of this lime tree standing on a sunlit slope one could take that telegraph pole over there . . .

—Vladimir Nabokov, in *The Defense*

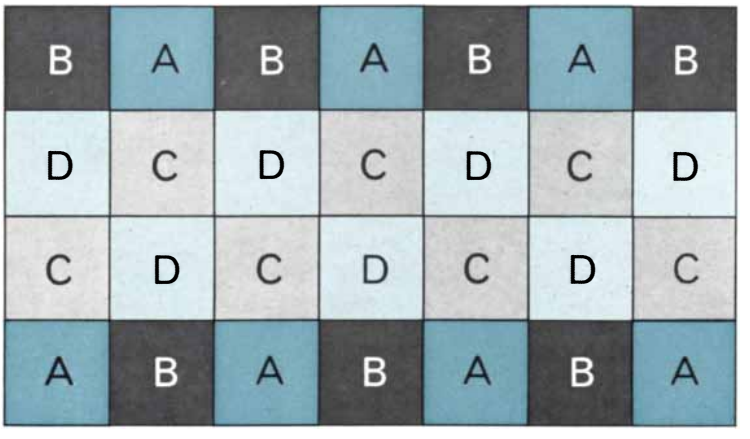
The Defense, a novel about a chess grand master, is not the only novel by Nabokov—himself a good chess player and composer of chess problems—in which characters see knight's moves in patterns around them. Humbert Humbert, the narrator of *Lolita,* observes a latticed window with one red pane and comments: "That raw wound among the unstained rectangles and its asymmetrical position—a knight's move from the top—always strangely disturbed me."

The knight is the only chess piece with a move that covers an asymmetrical pattern of squares; surely it is this lopsidedness that gives the move its disturbing strangeness. *Der Springer,* as the piece is called in German, springs two squares along a row or file and then, like Lewis Carroll's White Knight behind the mirror, topples one square either left or right. Another way of describing this asymmetrical gallop is to say that the knight moves one square diagonally, like a bishop, pivots 45 degrees to the left or right and moves another square like a rook. This is how the move of the *ma* (horse) in Chinese and Korean chess must be explained because, unlike its Western counterpart, a *ma* cannot move if another piece occupies the diagonally adjacent square on which the pivot occurs. The *keima* (honorable horse) of Japanese chess moves like the Western knight, vaulting all pieces in its way, but it can only go forward across the board.

"The knight," said British puzzle expert Henry Ernest Dudeney, "is the irresponsible low comedian of the chessboard." No other chess piece has been the basis for so many unusual and amusing combinatorial problems. This month we shall glance at a few of the classics along with some new discoveries by Solomon W. Golomb, a mathematician at the University of Southern California whose recreations are well known to this department's regular readers.

The oldest of knight puzzles, now the subject of an enormous literature, is the knight's tour. The problem is to find a single path of knight's moves (on boards of various sizes and shapes) that allows the knight to occupy each square once and only once. The tour is closed if the knight returns to its starting cell, open if the ends of the tour cannot be linked by a knight's move. If the board is checkerboard-colored, the colors of the cells will alternate along any tour. On a closed tour, therefore, there must be the same number of black cells as there are white. Since all odd-order square boards contain an odd number of cells, it follows that no closed tours are possible on such boards. Tours of both types are impossible on squares of sides 2 and 4 but exist on all higher squares of even order. The 3-by-4 is the smallest rectangle on which an open tour is possible, and the 5-by-6 and 3-by-10 are the smallest on which closed tours can be made. No tour of either type can be made if one side is less than 3, and no closed tour is possible if one side is 4.

The power of color patterns to provide short, elegant proofs of tour impossibilities is strikingly demonstrated by Golomb's method of showing that a closed tour is impossible on any rectangle of side 4. The 4-by-*n* board is colored with four colors [*see illustration on this page*]. Observe that every *A* cell on a knight's path must be preceded and followed by a *C* cell. There are equal numbers of *A* and *C* cells, and all must lie on any closed tour. But the only way to catch all of them is by avoiding the *B* and *D* cells altogether, because once a leap is made from a *C* to a *D* cell there is no way to get back to an *A* cell without first landing on another *C* cell. If there is a closed tour, therefore, it will contain more *C* cells than *A* cells, and since this cannot be the case we conclude that such a tour is impossible.



Coloring for the 4 × n board to prove the impossibility of a knight's closed tour

No one knows how many different knight's tours exist on the order-8 chessboard; varieties of one type of tour alone run into the millions. The search has usually been for tours that display unusual symmetry or that create a matrix (when cells along it are numbered consecutively) with remarkable arithmetical properties. For example, the closed tour shown in the top illustration on the opposite page, one of many constructed by Leonhard Euler in 1759, first covers the board's lower half, then its upper half, and all symmetrically opposite pairs of numbers (on a straight line through the center) have a difference of 32.

The bottom illustration on the opposite page shows an open tour published by William Beverly in *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* for August, 1848. (Whether this was Wil-

liam Roxby Beverly, a distinguished English landscape painter and stage designer of his time, I have been unable to determine.) Beverly's tour was the first "semimagic" tour to be constructed: the sum of each row and each file is 260. (The fact that the two main diagonals do not have the constant sum prevents the square from being "fully magic." If Beverly's square is quartered as shown by the solid lines, each order-4 square is magic in rows and files, and if these four squares are in turn quartered, each order-2 square contains four numbers that add to 130. Numbering the cells in reverse order along the tour produces the complement of the square: a semimagic square with all the properties of the former one.

Is there a fully magic knight's tour on the chessboard? That is the biggest unanswered question in knight's-tour theory. Scores of semimagic tours have been found, both open and closed, but none with even one main diagonal that has the required sum. It can be proved that fully magic tours are possible only on squares with sides that are multiples of 4. Since no tour is possible on the order-4, the chessboard is the smallest square for which the question is still open. Nor is a fully magic tour known for the order-12 square. Such tours have been constructed, however, for orders 16, 20, 24, 32, 40, 48 and 64. (A closed fully magic tour of order 16 is given on page 88 of Joseph S. Madachy's *Mathematics on Vacation,* 1966.)

What is the largest number of knights that can be placed on a chessboard so that no two attack each other? Intuitively one sees that the answer is 32, achieved by putting knights on all the black squares or on all the white. Proving it is a bit tricky. One way is to divide the board into 2-by-4 rectangles. A knight on any cell of such a rectangle can attack only one other knight, and so the rectangle cannot hold more than four nonattacking knights. Since there are eight such rectangles, no more than 32 nonattacking knights can go on the chessboard.

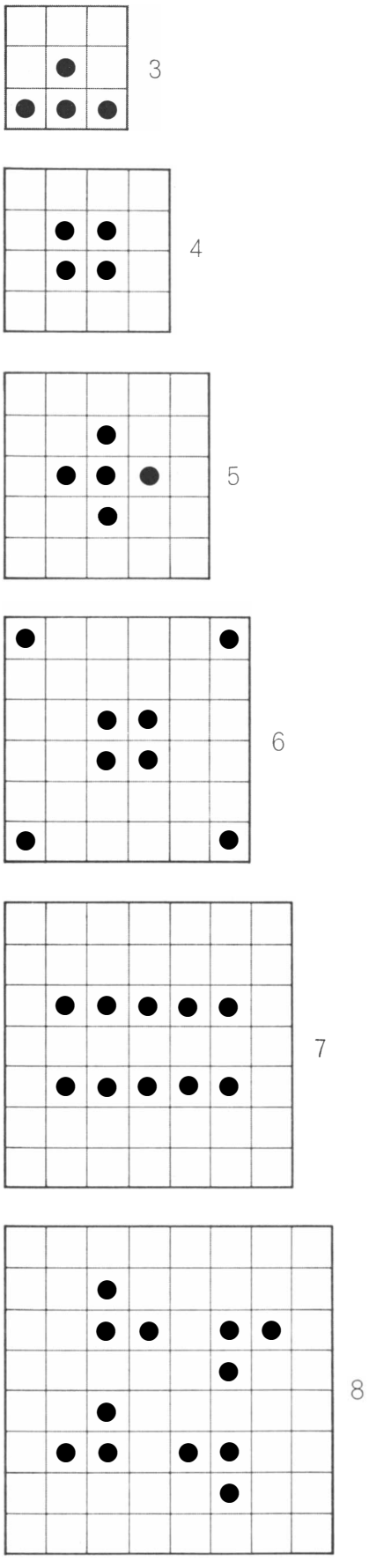
Golomb points out that a cleverer proof (contributed by Ralph Greenberg to *American Mathematical Monthly* for February, 1964, page 210) rests on the existence of a knight's tour of the chessboard. As we have seen, along such a tour the colors of the cells alternate. Clearly we can place no more than 32 nonattacking knights on such a path. Equally obvious is the fact that they must go on alternating cells—that is, on all the white or all the black cells. Put

37	62	43	56	35	60	41	50
44	55	36	61	42	49	34	59
63	38	53	46	57	40	51	48
54	45	64	39	52	47	58	33
1	26	15	20	7	32	13	22
16	19	8	25	14	21	6	31
27	2	17	10	29	4	23	12
18	9	28	3	24	11	30	5

A closed tour by Euler. Symmetrically opposed pairs of numbers have difference of 32

1	30	47	52	5	28	43	54
48	51	2	29	44	53	6	27
31	46	49	4	25	8	55	42
50	3	32	45	56	41	26	7
33	62	15	20	9	24	39	58
16	19	34	61	40	57	10	23
63	14	17	36	21	12	59	38
18	35	64	13	60	37	22	11

The first semimagic knight's tour: an open tour with each row and column adding to 260



Solutions for boards of orders 3 through 8

another way, if we could place 33 nonattacking knights on the chessboard, any knight's tour would then have to include a hop from one cell to another of the same color, which is impossible. The mere existence of the tour not only proves that 32 is the maximum but also adds a surprise bonus: it proves the uniqueness of the two solutions. The proof generalizes to all even-order squares on which a tour is possible. On odd-order squares tours must of course begin and end on the same color. On such squares there is therefore only one solution: placing the knights on all cells that are the same color as the central square.

Turning from maxima to minima, let us ask: What is the smallest number of knights that can be placed on a square board so that all unoccupied cells are under attack by at least one knight? The following table gives the answers for boards of sides 3 to 10, and also gives the number of different solutions for each board (not counting rotations and reflections as being different):

Order	*Pieces*	*Solutions*
3	4	2
4	4	3
5	5	8
6	8	22
7	10	3
8	12	1
9	14	1 (?)
10	16	1 (?)

Examples of solutions for orders 3 to 8 are shown in the illustration at the left. The unique chessboard solution has often been published. Patterns for the two next-highest boards, orders 9 and 10, are not well known; the question marks in the table show that they are thought to be unique. Both have a charming symmetry, with no knight under attack by any other knight. Readers are invited to search for the patterns before they are shown here next month.

Note that in the pattern for order 7 all occupied cells are attacked, and in the order-8 pattern four occupied cells are attacked. If we add the proviso that only unoccupied cells be attacked, more knights are required for each of these boards. The best I have been able to achieve is 13 knights for order 7, 15 for order 8. If we ask that *all* cells, occupied or not, be attacked, the simplest approach is to draw two patterns on transparent paper, one for the minimum number of knights that attack all black cells and the other for the minimum number that attack all white cells. The two patterns can then be superposed in various ways in order to obtain final solutions. On the chessboard—as Dudeney explains in his solution to Problem 319 in *Amusements in Mathematics*—there are only two patterns of seven knights (the minimum) that attack all cells of one color. By combining the two patterns in all possible ways to attack all 64 cells, one can obtain only three 14-knight patterns not counting rotations and reflections as being different.

About 20 years ago Golomb invented a hybrid game combining features of chess and checkers, which he naturally called "cheskers." Like checkers, it is played on the 32 black squares of the order-8 board. Since the knight cannot move on such a board without leaving the black squares, Golomb invented a modified knight that he recently christened the "cook." It moves three instead of two squares along a row or file, then one square at right angles. A centrally placed cook has eight possible moves [*see top illustration on opposite page*].

Golomb has, incidentally, reinvented a piece called the "camel" that was used in 14th-century Persian chess. The rules and board for this complex early version of chess are completely known because of a surviving Persian manuscript, the fullest translation of which is in Duncan Forbes's *History of Chess* (London, 1880). The game is known as Tamerlane's chess because Tamerlane the Great is supposed to have been fond of it. In addition to two camels on each side there are also two "asps" (corresponding to knights) and two powerful pieces called "giraffes" that move one cell diagonally and then continue forward orthogonally for any unblocked distance.

"The invention of the cook," Golomb writes, "immediately suggests two problems: Is there a cook's tour of the checkerboard? And how many cooks spoil the draughts? (That is, what is the maximum number of nonattacking cooks that can be placed on the board?)"

To answer the first question, Golomb uses a transformation of the chessboard suggested by his colleague Lloyd R. Welch [*see bottom illustration on opposite page*]. A jagged-edged board with cells twice the size of the chessboard cells is superposed on the chessboard in such a way that every black cell of the chessboard corresponds to a single cell of the jagged board. Every game playable on the black cells of the chessboard can now be played on the jagged board provided that the moves are suitably redefined. Since the transformation

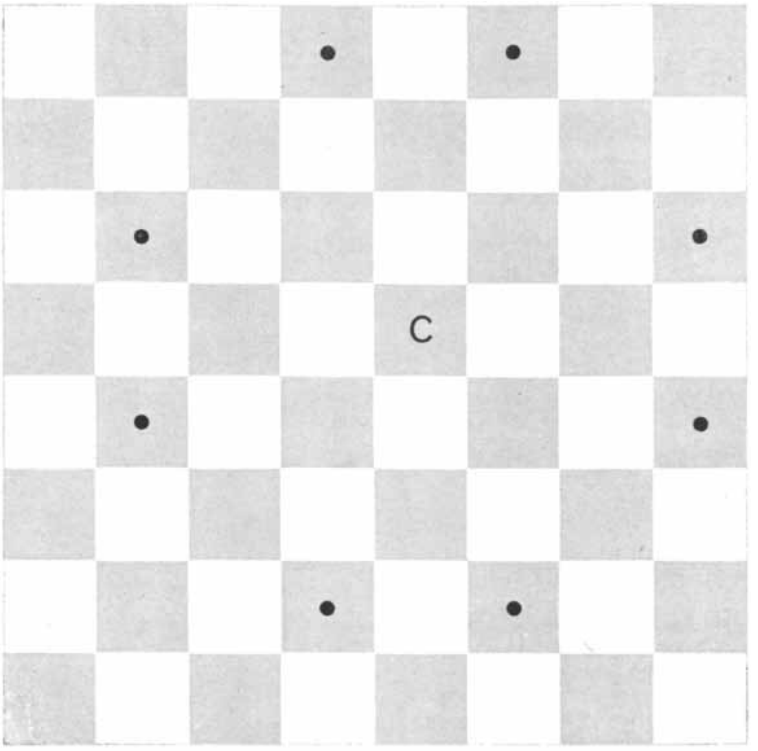
changes rows and files of the chessboard into diagonals on the jagged board, and vice versa, it follows that bishop moves on the chessboard become rook moves on the jagged board, and rook moves become bishop moves. Checkers is played on the jagged board by starting with red checkers on cells 1 through 12, black checkers on cells 21 through 32, and moving orthogonally instead of diagonally. (Has it ever occurred to the reader that, since checkers uses cells of one color only, two simultaneous but completely independent checker games can be played on the same checkerboard by four people seated around the board, each pair of opponents playing on a different color?)

More surprisingly, Golomb points out, cook's moves on the chessboard turn into knight's moves on the jagged board! A cook's tour on the chessboard therefore corresponds to a knight's tour on the jagged board. A sample closed knight's tour on the jagged board is 1–14–2–5–10–23–17–29–26–32–20–8–19–22–9–21–18–30–27–15–3–6–11–24–12–7–4–16–28–31–25–13. Those numbers trace a cook's tour on the black cells of the chessboard.

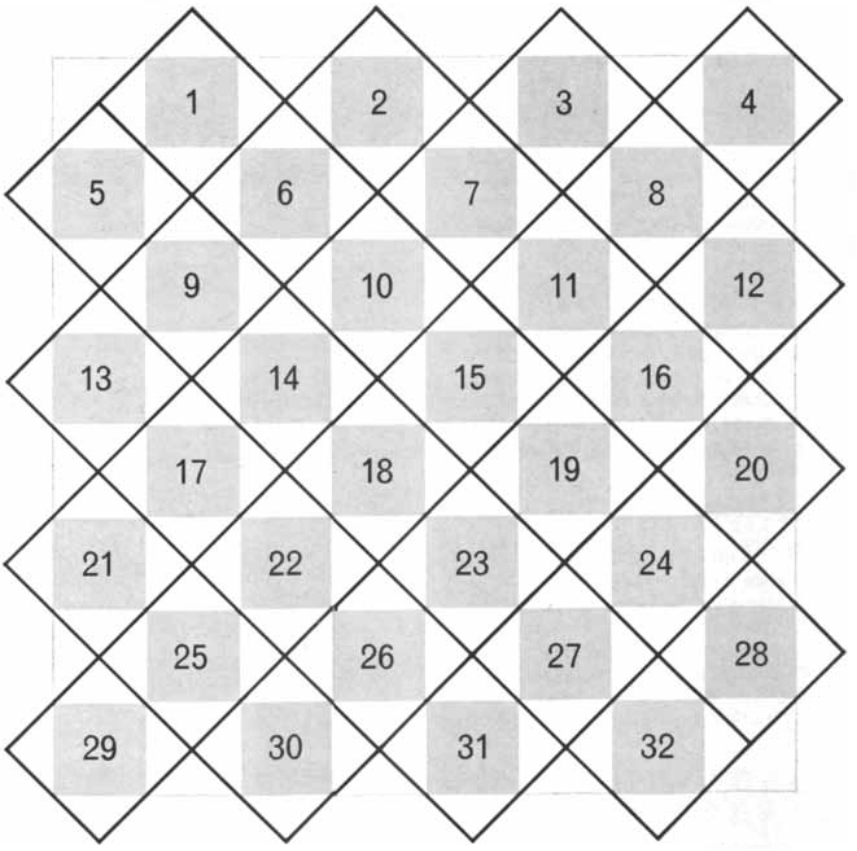
Since every cook's move on the chessboard joins two cells that are separated by two knight's moves, it occurred to Golomb that there might be a knight's tour of the chessboard of such a nature that every alternate cell along it would provide a cook's tour. He soon found, however, that when a knight enters a corner cell of the board, it jumps there from a cell that is diagonally adjacent to the cell to which it will be forced to leap when it leaves the corner. Those two diagonally adjacent cells are not a cook's move apart and consequently, Golomb writes, "the hope that a cook's tour could be extracted easily from a knight's tour is hopelessly cooked."

Golomb's second question is answered in the same way as the analogous problem with knights. Since a cook's tour of the board exists, the maximum number of cooks must occupy 16 alternate cells along such a tour. If the reader will mark the 16 even cells along the given tour (or the 16 odd cells), he will be marking one of the two solution patterns. On the chessboard the marked cells form a square lattice on half of the cells of one color. On the jagged board the marked cells are all those of one color if the board is checkerboard-colored.

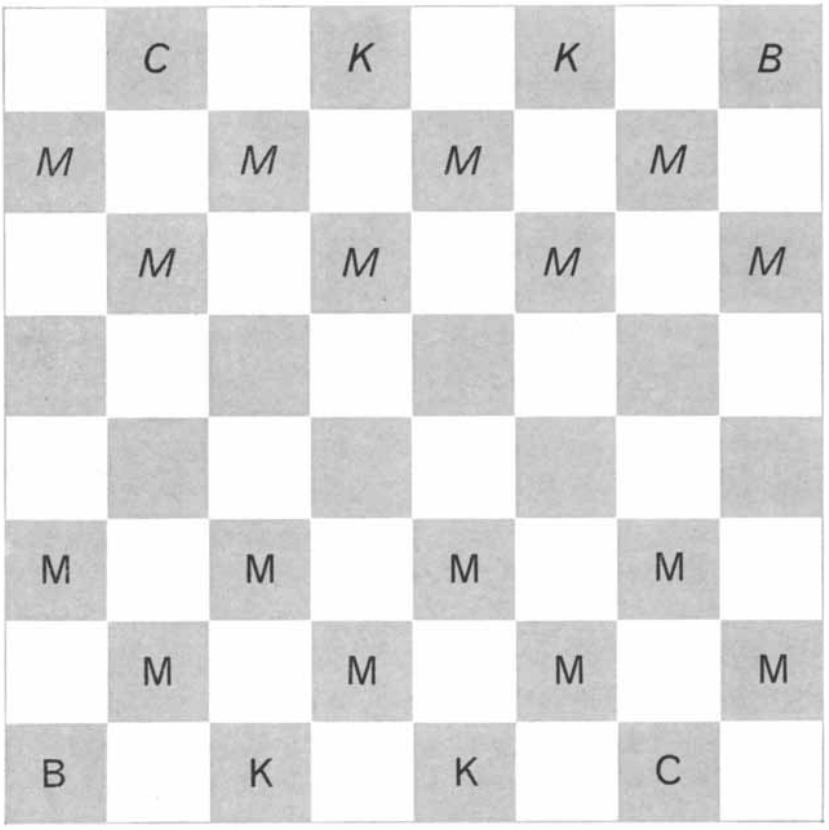
For those who may want to try Golomb's cheskers the illustration on the next page shows how the 12 pieces of each side are placed. The eight "men"



The eight moves of a centrally placed cook



A transformation devised by Lloyd R. Welch



Starting position for Solomon W. Golomb's game of "cheskers"

(*M*) move as checkers. The two kings (*K*) move as checker kings. The bishop (*B*) moves as a chess bishop, and the cook (*C*) moves as previously explained. Like the chess knight, the cook is not obstructed by intervening pieces. The men and kings capture as in checkers, by leaping over the victim. The bishop and cook capture as in chess, by moving onto the square of the victim. If a checker capture exists, it is compulsory to make it, unless a chess capture is also available, in which case the chess capture may be made if one wishes. Chess captures are optional. A man that reaches the last row must be promoted, but the owner of the piece may choose to make it either a king, a bishop or a cook.

Players alternate in moving. The object of the game is to capture all the opponent's kings. The first player with no kings at a given instant is the loser. It is therefore an important strategic decision, Golomb writes, whether to promote a man to a king (for better defense) or to a bishop or cook (for offense). As in checkers, a blocked position is a loss for the player unable to move.

The uprights of Tom Hood's double acrostic, the first of last month's problems, are FROST and SLIDE. The cross-lights are FERNS, REEL, OUI, SINDBAD, TILE.

Lewis Carroll's double acrostic, with the uprights QUASI-INSANITY and COMMEMORATION, was given the following solution in the 1915 *Strand Magazine* article cited last month: 1. QUADRATIC; 2. UNDERGO; 3. ALARM; 4. STREAM; 5. ICE; 6. INTERIM; 7. NO; 8. SUPPER; 9. ARENA; 10. NIGHT; 11. I; 12. TWO; 13. YAWN. The author of the article was uncertain about the ninth, suggesting ARISTA as an alternative, although admitting that neither word was satisfactory. My own guess is AURORA, which sometimes resembles folds of drapery that wave with a "mazy motion." Dmitri A. Borgmann, author of the new book of wordplay *Beyond Language*, focuses on the phrase "tangled talk" in the ninth stanza, for which he suggests ABRACADABRA. As an alternative to the fourth cross-light, Borgmann proposes SCRIM, a coarse cotton fabric that could be "half muslin and half cloth." Does any reader have better suggestions for the fourth and ninth cross-lights?

The horizontal lines of Edmund Wilson's word square are APRON, REEDY, INDEM, A.I.O.A.P. and S.S.N.R.H. The vertical lines are ARIAS, PENIS, REDON, O DEAR! and NYMPH.

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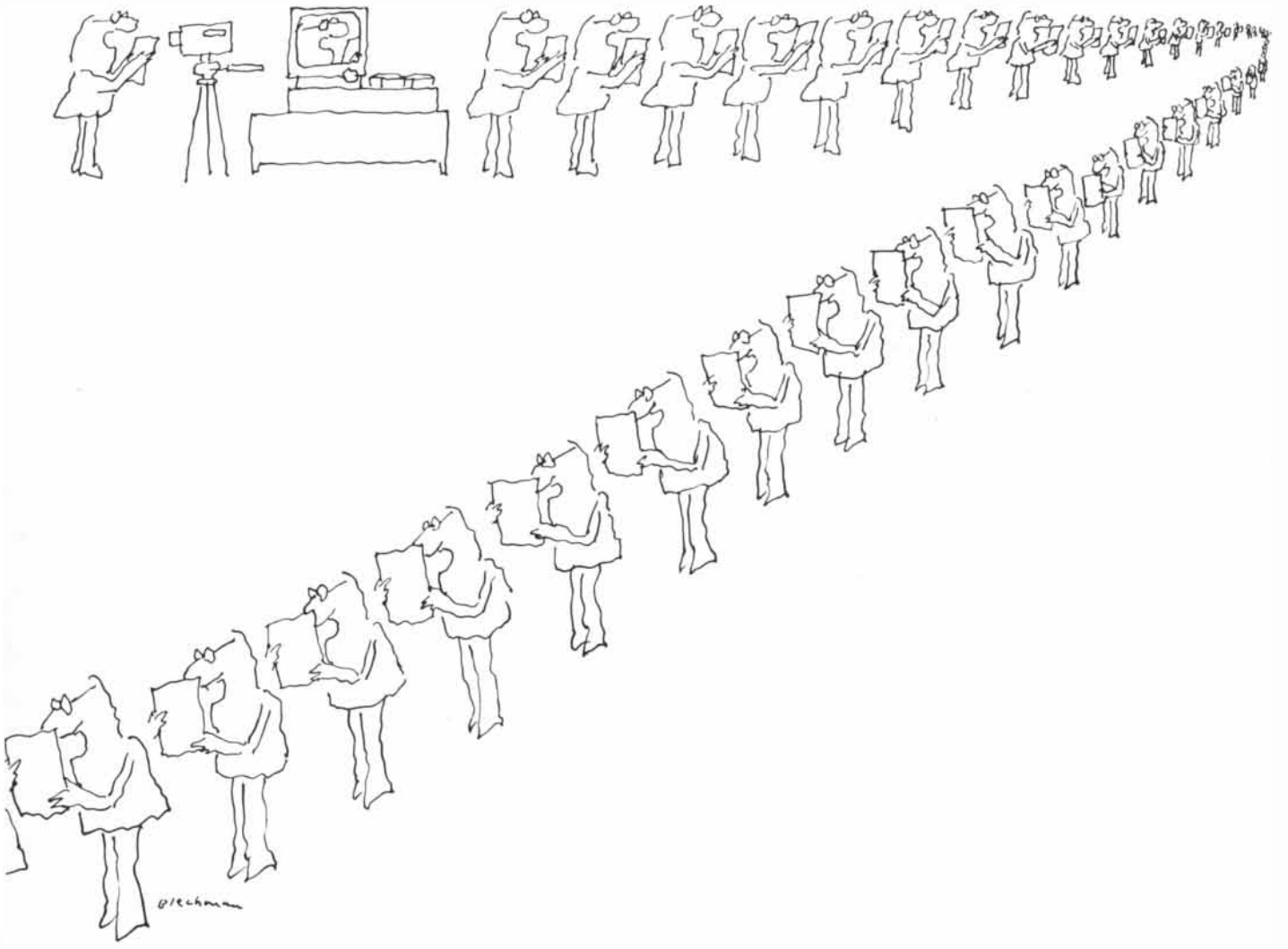

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THE AMATEUR SCIENTIST

How to "sputter" thin films of metal onto glass and experiment with them

Conducted by C. L. Stong

Thin sheets of metal deposited on glass are an essential part of many kinds of apparatus. For example, a film of aluminum or silver is the reflecting surface of the mirror in most reflecting telescopes. The glass part of the mirror gives form to the metal but otherwise functions merely as a mechanical support. Other applications of thin metallic films include beam splitters, which are pieces of glass coated with films so thin that part of the light makes its way through the metal while the rest is reflected.

Fibers of fused quartz made electrically conductive by thin metallic coatings find wide application in torsion balances for measuring small masses and the forces of electric charge. Similar coatings are also used to accumulate charge in electrostatic generators and to shield sensitive parts in instruments from the influence of external electric charges. In recent years multiple films of selected metals and alloys have begun to replace such components of digital computers as transistors, diodes, capacitors and resistors, together with much of the interconnective wiring.

In addition to these useful applications thin metallic films are interesting objects for experimentation. The techniques used for their application are open to improvement; so are methods of altering the properties of films after they have been formed. Four basic procedures have been devised for applying metal to glass. The oldest technique (and until recently the most widely used one) consists in the chemical reduction of metallic salts such as silver nitrate in a bath that also contains the glass. Fine particles of the reduced metal settle onto the glass and adhere as a film. Metal can also be electroplated onto glass. The surface is coated with an electrically conductive substance such as colloidal graphite, and the glass is then immersed in the plating solution.

Most optical parts are now coated by the evaporation technique. Metal to be deposited on the glass is vaporized by heat in a vacuum chamber. The vapor condenses as a film on the glass surface [see "The Amateur Scientist," SCIENTIFIC AMERICAN; March, 1960]. All metals and most alloys can be deposited by evaporation. The apparatus is costly and complex, however, if films of the highest quality are desired. Means must be provided for heating the metal to the temperature at which it vaporizes in gas at a pressure of not more than about 10^{-5} torr. (A column of mercury one millimeter in height exerts a pressure of one torr. Standard atmospheric pressure is equal to 760 torr.)

A simpler technique, known as "sputtering," is made to order for amateur experimentation. The technique is based on the transfer of metal by an electric discharge through gas at a pressure of less than one torr. Glass to be coated is placed between two electrodes in an atmosphere of gas at low pressure. The gas can be air. The cathode is composed of the metal to be deposited on the glass. Voltage sufficiently high to electrify or ionize the gas is connected to the electrodes. The impact of ionized atoms and molecules of gas against the cathode dislodges particles of the metal, which come to rest on the glass as an adhering film.

In its present state of development the sputtering technique is limited in two respects. Some metals transfer more readily than others. Zinc, gold, silver, lead, tin and copper deposit at a relatively high rate compared with nickel, iron, aluminum and magnesium. Silver, for example, deposits 20 times faster than aluminum. Moreover, molecules of gas become embedded in the metal and increase its porosity, an effect that varies with the nature of the atmosphere. These limitations, together with the commercial success of the vaporization technique, explain why sputtering has become largely noncommercial and provides an ideal field of experimentation for the amateur.

Nyle Steiner of Kaysville, Utah, has constructed a number of sputtering systems for silvering telescope mirrors and similar optical parts. He writes: "The apparatus not only is easy to use but also can deposit metal in films of any desired thickness. The films can be thick in the case of objective mirrors for telescopes, thin and semitransparent for such devices as camera lucidas, beam splitters and two-way mirrors.

"The vacuum chamber of my largest sputtering system consists of a bell jar made by cutting off the bottom of a one-gallon glass jug. The chamber will accept pieces up to six inches in diameter. I cut the jug by the hot-wire technique, which involves making a clean scratch around the jug with a glass cutter of the wheel type and pressing a straight length of Nichrome wire, heated to redness by an electric current, against successive parts of the scratch. In each case the glass will crack with an audible click. When the crack extends entirely around the jug, the bottom will drop off.

"The cut edge of the glass must be ground flat. This operation can be done by pressing the edge into a slurry of No. 80 Carborundum grit spread on a slab of plate glass and sliding the jug through a series of small ellipses. If such a grinding compound is not available, the same result can be obtained more slowly by twisting the glass against a sheet of wet No. 1 waterproof sandpaper supported on any firm, flat surface. When the raw edge has been ground free of pits, the roughened surface is finished with No. 00 waterproof sandpaper.

"After the second grinding the edge will be sufficiently smooth to make a gastight seal against a gasket of neoprene or a similar rubbery material. The gasket is sandwiched between the ground edge of the bell jar and a flat baseplate of steel or aluminum about half an inch thick. (Incidentally, sputtering systems can be made in almost any size. I used the gasoline-sediment bulb of

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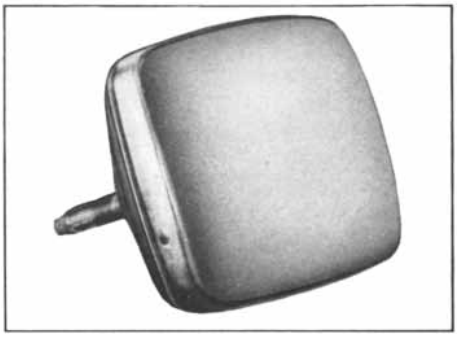

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an automobile for the vacuum chamber of a small system.)

"The baseplate of my apparatus was bought as scrap from a local machine shop. Before use it was cleaned with a wire buffer. The neoprene gasket was cut in the form of a ring about three-quarters of an inch wide. I coat the ring lightly with vacuum grease to ensure a good seal. Suitable grease can be made by melting together four parts by weight of petroleum jelly and one part of paraffin. Heat the mixture smoking hot and stir it slowly as it cools.

"The hose connection to the vacuum pump, and the negative terminal from which the cathode is suspended, enter the bell jar through a rubber stopper [*see illustration on opposite page*]. The negative terminal is a welding rod pushed through a nail hole in the stopper. The size and shape of the cathode and the object to be coated must be similar and the spacing between them should be uniform. For coating a six-inch telescope mirror I use a six-inch disk of sheet silver. The silver is available from manufacturers of jewelry and from some craft shops. Cup-shaped pieces of glass require cup-shaped cathodes. Fibers to be coated are stretched along the axis of a tubular cathode. Conversely, the inner wall of short glass tubes can be coated by supporting a wire cathode along the axis of the tube.

"Cathodes in the form of a flat disk are suspended by a wire spider from a hook at the bottom of the negative electrode. Both metal and electrical energy can be conserved by covering the top of a flat cathode with a disk of window glass. The glass cover confines the electric discharge to the cathode's lower surface, which faces the mirror below. The distance between the cathode and the mirror can be adjusted by sliding the welding rod up or down through the rubber stopper.

"My vacuum pumps consist of two modified compressors from old refrigerators. The compressors are operated in reverse. I bought them for $10 from a dealer in appliances. Details of the modification procedure are determined by the design of the compressor, which varies in minor respects with the product of each manufacturer. In general, however, all compressors include a check valve that must be removed and a by-pass line of copper tubing that runs between the housing and the check valve. The copper tubing must be cut and the ends sealed.

"A wire strainer will also be found somewhere in the inlet tubing. If the strainer is plugged by oil, the compres-

sors, which operate in tandem, will not reduce the air pressure in the bell jar below 10 torr. The oil can be blown from the strainers or the strainers can be removed. In the latter case care must be taken subsequently to prevent dirt or other foreign material from entering the units.

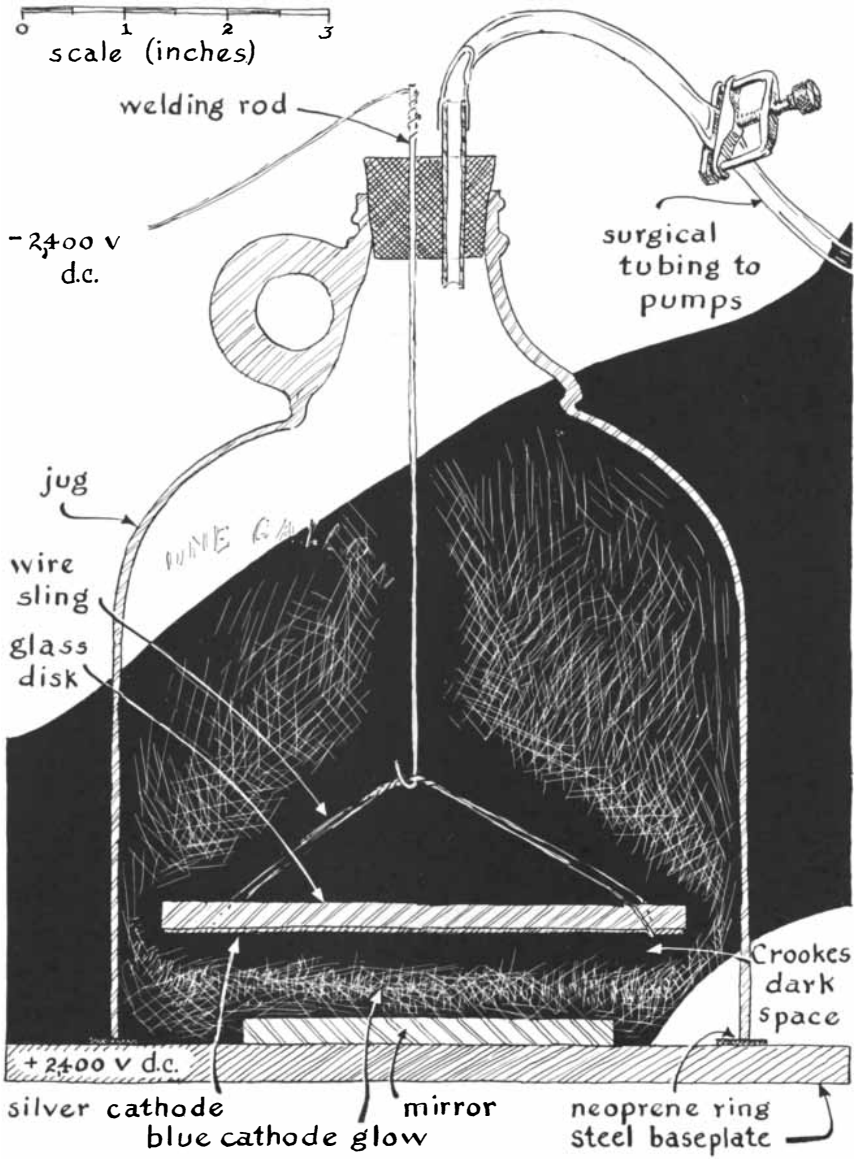
"Most refrigerator compressors are now sealed in a gastight housing. Access to the working parts can be gained only by cutting the housing apart. I do it with a hacksaw.

"Sputtering apparatus can be operated on either alternating current or direct current at potentials ranging from about 1,000 volts to 15,000 volts. Films deposited by direct current appear to be denser and to have higher reflectivity than those deposited by alternating current. The density and reflectivity of the film as well as the rate of deposit also appear to be influenced by the amplitude of the current, which can vary from 10 to several hundred milliamperes depending on the area of the cathode. I deposit most films with a current of from 25 to 60 milliamperes. None of my sputtered films is as dense or as bright as those deposited by the vaporization technique, but they perform adequately and I enjoy trying to make better ones.

"My power supply was improvised from a vacuum tube and three transformers that I bought inexpensively on the surplus market. The primary windings of the transformers were designed to operate from a source of 115 volts and 60 cycles. They were connected in parallel. The secondary windings develop a potential of 800 volts and were connected in series. The combined output is 2,400 volts. The output is converted to direct current by inserting a type-866A vacuum tube in series with one of the output leads [*see illustration on next page*]. The tube is a diode.

"Essentially the apparatus functions as a gas-discharge tube of the Crookes type. When air pressure inside the bell jar is reduced and a potential of 1,000 volts or more is connected to the cathode and to the baseplate that functions as the anode, thin sparklike streamers will ultimately appear between the cathode and the anode. As the pressure continues to drop the streamers will be replaced by a blue glow that covers the cathode.

"At still lower pressure a dark region will appear between the cathode and the anode. This phenomenon is known as Crookes dark space. Simultaneously a bright glowing film will cover part or all of the cathode. The extent of this glow varies with the current. Crookes dark space appears at about .1 torr, expands as the pressure is reduced and becomes relatively thick at a pressure of .01 torr.



General view of Nyle Steiner's apparatus for sputtering

"Metal will deposit on the glass most effectively, at least during my experiments, when the position of the cathode is adjusted to the point at which Crookes dark space almost touches the glass. At comparatively low voltages the glow may fail to appear. In this case the discharge can be started by touching the bell jar with the high-voltage terminal of a Tesla coil, an Oudin coil or even a spark coil of the type used in the ignition system of automobiles.

"Current in the bell jar varies inversely with the resistance, hence a variable resistor can be used for adjusting the current and, as a consequence, for adjusting the rate at which metal is deposited. The resistance of the diode varies with the temperature of its cathode and can be controlled by adjusting the current applied to the filament of the tube.

"Glass must be well cleaned before coating. The cleaning need not be as thorough as is required for chemical coating or for films applied by the evaporation technique. I merely wash the glass with household detergent, rinse it with water and put it aside to dry. Smudges left by dried water droplets are wiped off with a tuft of absorbent cotton. The thin film of vegetable fat that is deposited on the glass by the cotton vanishes during the subsequent ionic bombardment.

"The apparatus is simple to operate. The cleaned glass is placed on the baseplate along with the greased neoprene ring. The perforations of the stopper are also greased, as is the tapered portion of the stopper. All vacuum connections are similarly greased.

"The bell jar, to which the cathode

has been assembled, is inverted over the base and the ground edge is pressed firmly against the neoprene ring to ensure a gastight seal. The cathode is then tentatively adjusted to a height of about three-quarters of an inch above the glass. The pumps are started. After about two minutes I apply the high voltage. Pressure inside the bell jar need not be measured. The proper operating pressure can be judged by the character of the glowing gas. No discharge appears at atmospheric pressure.

"When the pumps have been operating for a minute or so, depending on their speed, the characteristic blue glow will form close to the cathode and subsequently float away, forming Crookes dark space. When the dark space just touches the glass, I apply a pinch clamp to the vacuum hose. The position of the dark space then remains fixed. If the pumps cannot reduce the pressure sufficiently, the dark space may fail to expand into contact with the glass. In that case I turn off the high voltage and lower the cathode toward the glass as required.

"When the system is operating properly, a dense film of silver will be deposited within five to 25 minutes. Its growth can be followed easily by eye. When the deposit has reached the desired thickness, the power is shut off and air is admitted either by pulling off the hose connection or, preferably, by opening a valve installed in a *T* fitting that can be included in the hose. The bell jar can now be lifted from the base so that the coating can be examined. Some films may appear a bit dull, indicating that some variable is not under control. Such films can usually be salvaged by burnishing the metal lightly with a tuft of absorbent cotton.

"When constructing and operating the equipment, the experimenter must be aware of two potential hazards: the high voltages are lethal and the glass may implode. Leads from the power supply to the vacuum chamber should be well insulated. Wire of the type used in automobile ignition systems is satisfactory. Do not touch the wiring when the system is energized. Enclose the vacuum chamber in a cage of heavy wire screening, such as hardware cloth, and wear safety goggles.

"The sputtering rate and the quality of the deposit are influenced by a number of variables. They include the current, the voltage, the nature of the metal and of the surface to which it is applied, the character of the glow discharge and the kind of gas in the chamber. It is in the manipulation of these variables that I have found the fascination of the sputtering technique."

The attractions of seismology as an avocation are described in the July issue of *Earthquake Information Bulletin,* an official publication of the National Earthquake Information Center, which is operated by the Environmental Science Services Administration of the U.S. Department of Commerce. The center keeps a register of seismograph stations that operate on a full-time basis and invites amateurs who own stations fitted with accurate timing equipment to send in observations. The data should include the time, date and frequency of recorded earthquakes. The center also would like information on the amateur's instruments.

"If the instrument is calibrated," the *Bulletin* notes, "the amateur seismologist, as well as the professional, can determine the magnitude and distance to the epicenter of earthquakes even before the news is reported over the radio. The problems facing the amateur seismologist are formidable, however. The pickup unit, which should amplify the ground motion 1,000 times or more, recorders and timing present problems that must be solved separately. The station requires daily attention, yet many months may elapse between large earthquakes.

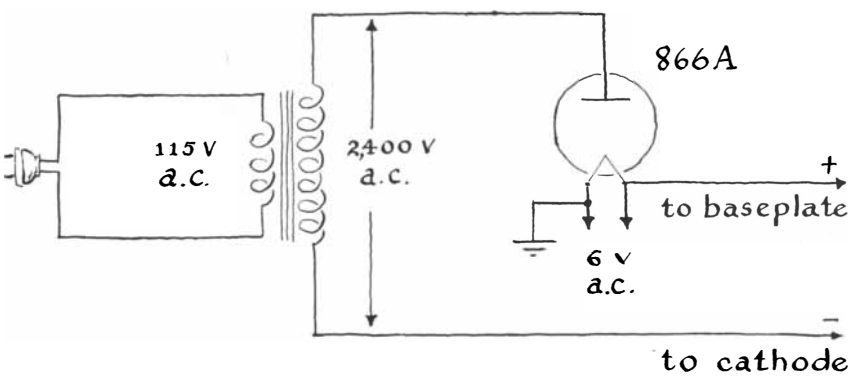
"Very few amateur seismologists have solved the problem of accurate timing, which is essential if the data are to be used by professional groups such as the National Earthquake Information Center. The time of the arrival of phases (basic types of earthquake waves) must be known to the nearest second, for example, for locating earthquakes. This requires (1) a good chronometer; (2) a device for automatically marking minutes on the recording; (3) daily time checks of correct time as broadcast by radio station WWV, and (4) a chart speed of at least 30 millimeters per minute."

The *Bulletin* calls the attention of amateurs to the formation in 1966 of the World Amateur Seismological Society through the efforts of Meredith Lamb of 322 South Raritan Street, Denver, Colo. 80223. This organization promises to fill a basic need of amateur seismologists for affiliation with fellow enthusiasts. The *Bulletin* concludes with an appeal to those who for one reason or another do not find it convenient or possible to operate a station: "To make a significant contribution to the field of seismology, a hobbyist need not operate a seismograph. The written earthquake history of most of this country is limited. To develop an accurate estimate of earthquake risk, records for hundreds of years are needed. The search of historical-society files and old newspapers may uncover additional facts concerning the effects of earthquakes in various regions and thus increase the knowledge of earthquake risk.

"Another aid to professional organizations would be the collection of local newspaper accounts or other reports of recent earthquakes. Many of these details are not available to the seismologist when isoseismal maps are drawn to delineate the felt area of various earthquakes and the intensity distribution.

"Amateur seismology has proved a rewarding hobby for those who have actively pursued it. Its relevance to school studies in earth sciences has provided additional interest in the subject, as have science fairs, where several seismology projects have been recognized with top honors."

The Coast and Geodetic Survey branch of the Environmental Science Services Administration issues a number of publications of interest to citizens who make a hobby of seismology. A list of those that are currently available can be obtained from Jerry L. Coffman, Editor, *Earthquake Information Bulletin,* National Earthquake Information Center, Rockville, Md. 20850.



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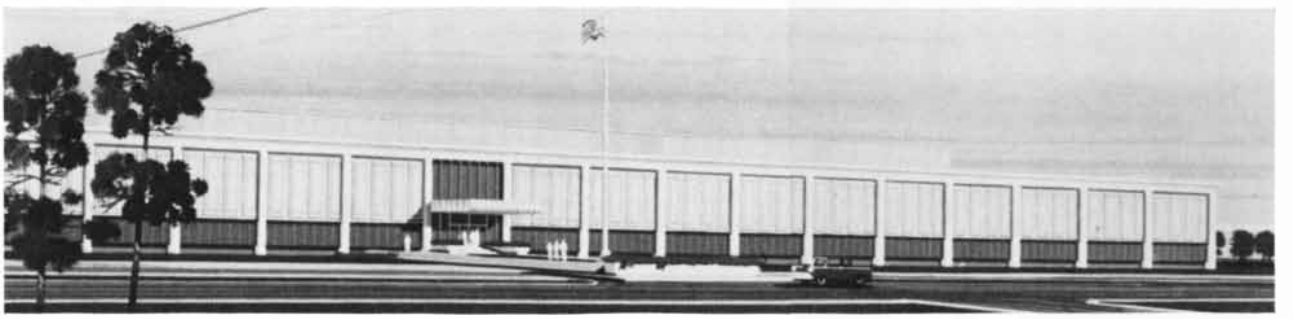

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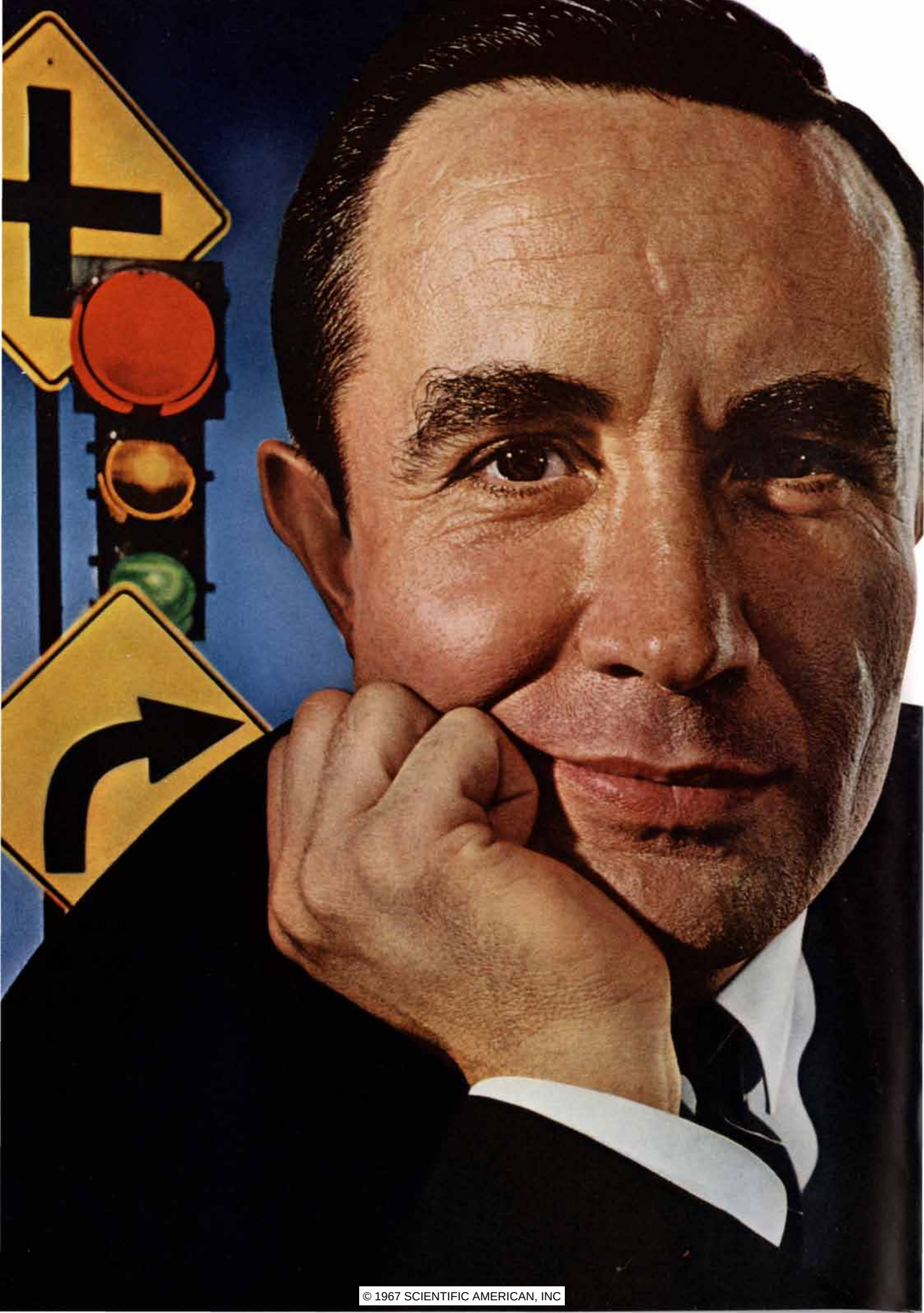

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BOOKS

The rise and decline of Sir Humphry Davy

by L. Pearce Williams

HUMPHRY DAVY, by Sir Harold Hartley. Thomas Nelson and Sons, Ltd. (42 shillings).

The life of Humphry Davy has all the elements of a novel by Charles Dickens. The Davys came from solid Cornish yeoman stock that by the end of the 18th century was struggling to make the adjustment to the new industrial world. Humphry's father was an earnest but ineffectual man who showed a modest talent for woodcarving (one of his carved mantelpieces is in the Victoria and Albert Museum in London) and an immoderate penchant for somewhat shaky financial ventures. When he died in 1794, he left a widow, five children (of whom Humphry was the eldest) and debts of 1,300 pounds. In 1800 a man could live well for a year on 100 pounds, so that this sum must have appeared astronomical to the bereft family. The widow Davy and her eldest son were to pay off every penny of it. Dickens would have expected no less.

From his father Davy appears to have acquired only his passion for angling and bird shooting. From his mother came his ambition and, one suspects, the mercurial temperament that ultimately brought him to both triumph and disaster. In 1794, however, angling, shooting and ambition were not enough; Humphry, in his 16th year, had to leave school and find a position. In 1795 he was bound apprentice to a local apothecary and surgeon. No one could have foretold that within 10 years the young Cornishman would be the lion of London society and a chemist of international reputation.

One of the myths of 19th-century England was that any young man who had the will could, by sheer dint of hard work, rise to whatever eminence he desired. History mercifully does not record the wrecks of those who foundered in the attempt. It saved the spotlight for the rare few, such as Davy and his protégé Faraday, who were successful. In 1795 Davy set out his own course of study in a notebook. It included, as Sir Harold Hartley reproduces it:

1. Theology
2. Geography
3. My Profession
   (i) Botany
   (ii) Pharmacology
   (iii) Nosology
   (iv) Anatomy
   (v) Surgery
   (vi) Chemistry
4. Logic
5. Language
   (i) English
   (ii) French
   (iii) Latin
   (iv) Greek
   (v) Italian
   (vi) Spanish
   (vii) Hebrew
6. Physics
7. Mechanics
8. Rhetoric and Oratory
9. History and Chronology
10. Mathematics

How far he advanced in this program before he began his education in chemistry is not known, but he retained his interest in many of these subjects throughout his life and mastered more than one. The list is worth pausing over. It may not be completely accidental that theology should stand at the head and mathematics at the foot. Davy took his religion very seriously, so seriously that it affected his science. In mathematics he, like Faraday, remained an illiterate, although he continually made public his hope that chemistry would someday become a mathematical science. Hartley makes it clear, however, that Davy's primary weakness as a chemist was as a quantitative analyst.

Davy's interest in language, rhetoric and oratory was to serve him well. It was as a lecturer in London that he was first to achieve fame. His lectures were works of art. He labored over them to get every detail, both of the science and of the art, exactly right. An early love for poetry had sensitized him to the power of language, and this power he wielded with confidence. When Samuel Taylor Coleridge was asked why he attended Davy's lectures on chemistry, he replied, "To renew my stock of metaphors."

Davy's popularity as a lecturer contributed to the renaissance of English science by making science a subject above the commonplace. Chemistry in particular appeared to be a dismal science concerned only with evil smells and the concoction of medical or cosmetic preparations. It was Davy who, more than any other man in the England of his time, saw chemistry as the key to the secrets of matter. The chemical papers in the *Philosophical Transactions of the Royal Society* in the last decade of the 18th century reflect the state of chemistry before Davy: "Experiments and Observations to investigate the Composition of James's Powder" (1791), "An analysis of the earthy Substance from New South Wales" (1798), "On the Decomposition of the Acid of Borax or Sedative Salt" (1799). No chemical subject was considered worthy of the Royal Society's Bakerian lecture during those years. Davy was to deliver no fewer than six, and their subjects were of fundamental importance. The title of his first Bakerian lecture in 1806 was "On some Chemical Agencies of Electricity"; it was here that he first suggested that electricity was the basic agent of chemical reactivity.

These triumphs lay in the future when Davy made out his list of subjects for study. The list seems naïve, yet in a sense he remained true to it. Through theology he could contemplate the universe as a whole, as a single work of the Creator. The peculiar flavor of Davy's theoretical scientific writings comes from his constant striving for a unity that would transcend the particular reaction under study.

The decisive intellectual event in Davy's youth occurred in 1797, when his plan of study brought him to chemistry. Lavoisier's great *Traité élémentaire de*

chimie was available, and Davy plunged into it. Up to that point he had been a more or less passive absorber of knowledge; now he began to experiment. He could not agree with Lavoisier's theory of heat and light. Lavoisier had suggested that light was a modification of heat, being caloric in projectile motion. Davy countered with some ingenious experiments, among them the famous one of rubbing two blocks of ice together in a vacuum, with which he proved that light was *not* a modification of heat. Heat must be a motion, not a substance. Then, seduced by his own ideas, Davy went on to suggest a thoroughgoing reform of all chemical nomenclature. His speculations carried him far beyond his evidence, and he was later to regret his youthful exuberance. Nevertheless, the incident is a revealing one for the historian. It clearly shows how Davy's mind worked. First there was the flash of genius by which he saw the essential elements of the problem; then the almost feverish experimental activity in which brilliance of conception was united with ability in execution, and finally the generalizing of the results to a universal law. This was the pattern of Davy's mature work. All he added later was a certain theoretical caution to prevent his own enthusiasm from running away with him again.

It was this juvenile work that led to Davy's first step up the ladder of success. Again the story line is Dickensian: Davy's mother took in boarders, among whom was Gregory Watt, the tubercular son of James Watt. Gregory and Davy became close friends. Watt, recognizing Davy's talent, put him in touch with Dr. Thomas Beddoes of Bristol. It was Beddoes who published Davy's essay on light and heat and who freed Davy from his apprenticeship by making him his assistant in the new Pneumatic Institution of Bristol. Here Davy was to achieve his first fame. It was only extreme luck that prevented it from being posthumous.

Dr. Beddoes' Pneumatic Institution was devoted to the investigation of the medical effects of various gases, particularly nitrous oxide, which an American physician had said was the cause of most major diseases. Davy's researches on nitrous oxide are now classic; they mark, among other things, the beginnings of anesthesiology. Davy's experimental method was simplicity itself: he prepared various gaseous mixtures and tested their physiological effects by inhaling them. Hartley manages to keep the suspense high in his description of these experiments. At first they seem funny, but then one becomes alarmed as Davy begins his researches on water gas (carbon monoxide and hydrogen) and nitric oxide (which turned to nitric acid in his lungs and trachea). Davy somehow survived and, as a consequence of the fame these researches brought him, was spared further temptations to martyr himself. Benjamin Thompson, Count Rumford, was looking for a young man to serve in the newly created Royal Institution of Great Britain, and Davy seemed the perfect choice. In February, 1801, Davy left the Pneumatic Institution for London. In the years from 1801 to 1812 he was to conduct the series of chemical investigations that were to gain him immortality. This period ended with his marriage, which removed him from the steady pursuit of science, and his discovery of Michael Faraday, who was to carry on the tradition Davy had created at the Royal Institution.

Although Davy made important excursions into agricultural chemistry during his decade at the Royal Institution, the most important of his researches were those concerned with electrochemistry. His early refutation of some of the bizarre theories of electrochemical composition was followed by the great paper on the chemical agencies of electricity, in which a whole new system of chemistry was laid out. Then, in applying his theories to specific bodies, Davy announced the dramatic discovery of the decomposition of soda and potash into sodium and potassium. Equally dramatic was the failure to decompose the basis of muriatic acid and Davy's insistence that the green gas produced in the attempt was an element to which he gave the name chlorine. These labors were summed up, on the eve of his marriage, in his *Elements of Chemical Philosophy*. One wonders about the title. John Dalton's *A New System of Chemical Philosophy*, in two parts, had been published in 1808 and 1810 and had served to spread his atomic doctrine. Davy never accepted Dalton's atoms, and his *Elements* (perhaps the pun was intended) were not those of Dalton. The point is of some importance, and I shall return to it.

The *Elements of Chemical Philosophy* was really Davy's valedictory. He never entirely left chemistry, but his chemical work from 1812 on was sporadic, although still marked by flashes of genius. The invention of the safety lamp and his later researches on electricity in a vacuum were such. By and large, however, Davy withdrew from scientific pursuits, captured by the society into which he had entered when he married Jane Apreece. Mrs. Apreece brought him money; the Prince Regent knighted him. Later he was to become a baronet. His new social and financial position gave him complete freedom to do what he wanted. It is a curious fact, on which Hartley does not remark, that what Davy obviously wanted to do was to escape completely from the life that had brought him such good fortune. It seems a bit surprising that the man who set the standard for popular scientific lecturing in pre-Victorian England, and who was sometimes criticized for his desire to make these lectures as enjoyable and as perfect as possible, should abandon his art at the first opportunity. Would this have been the case, one wonders, if, instead of having been a lecturer to the *haut monde*, Davy had been a teacher in a university, where his auditors would have been disciples as well as admirers? Might he not have founded an English school of chemists who could have rivaled the students whom Berzelius, and later Liebig, turned out?

Davy's departure from chemistry was not as total as his abandonment of lecturing, yet even here it seemed as though his early ardor had cooled. Was it because he enjoyed angling and shooting that much, or did he find science incompatible with his new social status? Was it simply that, at age 34, he felt his intellectual powers slipping? Earlier biographers have suggested that Davy was seduced by the society that had so eagerly accepted him and supported his efforts to bring financial stability to the Royal Institution. Hartley prefers to focus his attention on Davy's sporadic scientific forays, but something of Davy thereby escapes him. Perhaps it would need a Dickens to show the transformation of the young Davy, taking all knowledge as his province, into Sir Humphry Davy, Bart., to whom salmon, trout, grayling and double snipe were the boundaries of passion.

The last role Davy played was as president of the Royal Society. This was a position he had actively sought, and there can be little doubt that he had some ideas of what the society should be. It is equally clear that the majority of the Fellows of the society did not agree with Davy on these views. As Davy's anniversary addresses show, he was concerned with the failure of most of the Fellows to publish anything about science. By the 1820's, in fact, the Royal Society consisted primarily of amateurs in science who felt that F.R.S. added a certain luster to their names but who rarely put anything in writing. The situation appeared quite serious to some of Davy's

scientific contemporaries. Not all of them followed Davy's lead in trying to stimulate their colleagues by subtle hints; there were pamphlets that bluntly demanded reform. The situation, in short, was a potentially explosive one, and Davy was in a rather awkward position. As a "great" chemist he could lecture the amateurs on their responsibilities. But since his "greatness" lay in past efforts, not present ones, he could not serve as the rallying point for the professionals. Davy was doing what he was exhorting the fellowship not to do, namely neglecting science for other pursuits. His exhortations only served to convince the amateurs of the inadvisability of having an ardent scientist for president again. In this they were successful, staving off the inevitable for a generation. Davy seems to have realized his failure and took refuge in his usual fashion by setting out on an extended fishing trip. His health had also begun to fail. He died in Geneva on May 29, 1829, in his 51st year. Hartley ends his book with the phrase Berzelius wrote on the bundle of letters that had passed between him and Davy: *Sitt tidehvarfs störste chemist* (The greatest chemist of his time).

Hartley is to be complimented on the success with which he has illustrated Davy's brilliance and personal complexity. The series of which this volume is a part consists of brief works, and in only 149 pages of text Sir Harold has been able to project both the image of Davy the man and of Davy the chemist. The discussions of Davy's scientific work are particularly clear; Hartley is a kindly but impartial guide in pointing out both insights and blunders.

There is one major point of disagreement between Sir Harold and me that is of such importance to the development of the history of science that it seems worthy of discussion here. What Hartley has done superbly is to *describe* Davy's scientific work. What he has not done, except insofar as accurate description of experiments can serve to imply a logical development, is to *explain* it. The reason for this seems both simple and adequate. After his youthful speculative fling Davy was very cautious in his public pronouncements on the fundamental nature of physical reality. Hartley points out that Davy did not believe in Dalton's atoms, but he does not do much with what Davy did believe the nature of matter to be. He cites Davy's references to Roger Boscovich's point atoms, but nowhere does he use these atoms to explain the course of Davy's thought. Similarly, he points out that Davy was fascinated by metaphysics, and that a mutual interest in metaphysics as well as poetry was part of the bond between Davy and Coleridge. Again, however, there is no indication that Davy's metaphysics had any influence on his science. There is implicit in Hartley's account the thesis that Davy's science was purely and exclusively formed from experiments and flashes of insight.

Now, there is little evidence to challenge Hartley's view. But there is some evidence, and its existence is what creates the problem for the historian. For example, as I have argued elsewhere, one of the important intellectual influences on some of Davy's contemporaries (particularly Hans Christian Oersted and Coleridge) was the philosophy of Immanuel Kant. John Davy, in his biography of his brother, mentions that Humphry had read Kant as a young man. Dr. Beddoes was an early commentator on the Kantian philosophy, publishing several totally undistinguished short pieces on Kant in *Gentleman's Magazine* in exactly those years when Davy was constantly in his company. One of the conclusions some of Kant's readers drew from his writings was the nonexistence of the imponderable fluids with which the late-18th-century universe was filled. Forces were to be substituted in their place. In 1799 Davy wrote: "The supposition of active powers common to all matter, from the different modifications of which all the phenomena of its changes result, appear to me more reasonable than the assumption of certain imaginary fluids alone endowed with active powers, and bearing the same relation to common matter, as the vulgar philosophy supposes spirit to bear to matter." The doctrine of powers, be it noted, left a place for the Divine as the doctrine of fluids did not.

Hartley does not cite this passage, nor does he note that Davy was unique among his English contemporaries in refusing to speak of electrical, caloric or magnetic fluids. He insisted instead on the terms "energies" or "powers." Davy was too careful with his words not to mean something by this, but exactly what it was he does not tell us. The only clue we have is his statements on Boscovich's atoms. These atoms, consisting of mathematical points surrounded by alternating concentric zones of attractive and repulsive force, meet all the requirements of the antifluidist. They can be combined to create the chemical elements and, as Davy noted in his journal, they will explain all the phenomena of chemistry. But did Davy take them seriously? In his last work, *Consolations in Travel,* published posthumously, he certainly seemed to. Hartley reports what amounts to Davy's last scientific will and testament, in which Davy states his adherence to a belief in Boscovichean atoms. This book, Davy wrote to his friend Thomas Poole, "contains the essence of my philosophical opinions," a statement it is difficult not to accept. Still, there is a very important link missing. If Davy did place his faith in the ultimate reality of forces and point atoms, how did he use these ideas in his scientific work? We do not know. There are no documents, as far as I am aware, that provide this essential information.

What, then, should the historian of science do? Should he rest content with a description of scientific work based solidly on documented facts? If history were a science, the answer would undoubtedly be yes. History, however, is also an art. Part of this art is the re-creation of the past, not merely its description. We need to know more, say, about Napoleon's invasion of Russia than the roads he took and the number of men he led. We want to know why he went. This we must deduce from all kinds of conflicting evidence, including Napoleon's later testimony. What the political historian does is to create a Napoleon whose values and motives are made credible. The task of the historian of science, it seems to me, is also to re-create the minds of his subjects. It is made difficult by the fact that the great scientist may never reveal how his mind was working; indeed, he may actually try to conceal the course of his thoughts. This would appear to be the case with Davy. His metaphysics was unpopular, and the point atoms in which he believed had been generally rejected by chemists. He must have known that he would only weaken his scientific arguments by bringing in either of these things, and so he left them out. The historian cannot. Given Davy's hints, the attempt should be made at least to reconstruct Davy's experiments within his own theoretical framework. This I think we must do for all creative scientists. What we would lose in certainty we would gain in our understanding of this greatest of all human inventions: modern science.

Short Reviews

THE WORLD CITIES, by Peter Hall. McGraw-Hill Book Company ($4.95). "There are certain great cities, in which a quite disproportionate part of the world's most important business is con-

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ducted." Seven of these complexes are here described and appraised, with an eye quick to see what trends appear in the posing and the solution of the problems every metropolis knows all too well. London's thousand suburbs stop short at a green belt, but beyond the belt the New Towns rise, huge successes in all respects save one: they begin to inherit the London problems. The green belt is a solution for a static city. Paris, already a center of extraordinary weight, continues to expand. The planners hope to hold it not within a ring but 50 miles downstream along the spine of the Seine, with new towns in profusion.

The least known of these seven regions is the ring city of Holland grouped around Rotterdam, Amsterdam, Utrecht and The Hague. Here the planners hope to let the city grow outward from its unique agricultural core, largely into new polders. The ideas of green wedges instead of constricting belts and of growth along transport lines, in addition to the strength of having many nuclear cities, are viewed by the author as leaving "little doubt that ... the Dutch solution is the right model." Rhine-Ruhr holds a special mix of coal and steel industry, now more than a little ailing, inside a true metropolis; here again the many city centers and the lack of acuteness of all the problems of congestion hold hope. Moscow, the center of a country still rich in space and the heart of a planned society, attracts interest by the degree to which it shares some of the problems of the capitalist West. Here too one can see ahead a central city, a green belt, a system of satellite towns. The Russian investment in first-rate public transport is one genuine note of novelty; the automobile flood has only begun to rise in Moscow.

Now we come to New York. Its core an island scarred by the rusty blade of slavery, New York has heavy problems. The transport outlook is bleak, and the fragmentation of responsibility in government and in transport policy is unequaled elsewhere. The low suburban density and the long rides it implies are at the root of the problem for the outer reaches of the city. It is Tokyo, however, that suffers from "the most acute problem of metropolitan overgrowth in the world." The city has a structure of public services entirely inadequate to its size. There is a 10-year plan to meet this need, which arises from the swift industrialization of Japan since the 1950's. The official plan is sober and London-like, but there is a "wealth of original ... expert ideas for its future development." These "reflect the extraordinary technical ingenuity that is typically Japanese, ... a passionate interest in ... metropolitan growth." We might see a city on rafts, or a high-rise metropolis (memories of earthquakes have set a 10-story limit since 1923), or a Japanese Brasilia at the foot of Fujiyama. The book ends with a chapter of theory. It is work, and not housing, that controls, and the work of the modern city is informational. The ideas industries will continue to grow in the centers. Beyond such a sensible prediction there is not much guidance here. A dispersed Los Angeles or a polycentric Dutch ring city holds some hopes, but can the great congested centers move toward those directions? There are brave people who build models, models for a new time, based not on the simple geometry of rings and cores but on the intricate tapestry of social and economic life.

World Cities is a handsome little book, with absorbing, cosmopolitan maps and diagrams. It is high strategy, campaigns and aims, and barely alludes to the agony of the man in the front line. But for a cool look at our heated struggles it is hard to fault.

COMPUTATION: FINITE AND INFINITE MACHINES, by Marvin L. Minsky. Prentice-Hall, Inc. ($12). The machines of this book are abstract, made out of reason and definitions, not out of germanium and relay racks. Only a few (quite knowing) sentences about real machines appear. But the mathematics is so clear, so fresh, is presented in such a winning style (with many helpful diagrams) and with so attractive a sense of mingling long outlooks over the woods with the analysis of individual trees, that one feels this is how mathematicians ought to write but don't. These machines are digital machines, which read and write digits, slide back and forth, assume one of a few internal states. The key ideas stem from Alan Turing, who first saw how to convert a finite machine, which is unable to do our deepest mathematics, into a machine of universal powers by adding to a rather simple ideal machine of the finite sort one infinite component: a tape of arbitrary length. A Turing machine becomes a concrete way of describing just about any mathematical function. This branch of learning faces most of the issues of mathematics—issues of what axioms are, of what a proof is, of what solving problems and deciding propositions can mean. Its marvel is that formalisms that appear childishly simpleminded can be extended by ingenious (although in the end also simple) means to encompass more or less all the subtlety of mathematics and perhaps of all thought. A universal Turing machine can simulate the behavior of any Turing machine whatever; it is able to compute any computable function. It can be made out of a structure that uses only four symbols and takes on seven internal states. There is, of course, a price to pay: the use of a tape of profligate length. Here is the nub of the philosophical unity of this altogether wise and engaging book: All thought can be reduced to elementary atoms, if only their quantity is sufficient. But the finiteness of time demands in the real world an ever more complex hierarchy of ideas as harder and harder problems are faced. Therefore human thought is not simple, only reducible.

This is a work one can master armed with high school algebra and an interest in mathematical ideas. It sets many problems of wit and value, and gives most of them instructive solutions. One misses only a chapter on machine biology, in the vein of John von Neumann's self-reproducing mechanism, with its genetic tape and universal tool machine. Professor Minsky spends his days designing real machines, machines that can build painfully with blocks, that even suffer some well-known optical illusions. His mechanical text on the theory underlying the mechanization of reason turns out to be the most humane and vivid book of mathematical weight to be seen in a good many years.

JOHN HARRISON: THE MAN WHO FOUND LONGITUDE, by Humphrey Quill. Humanities Press Inc. ($10). The skeptical Board of Longitude hated to give out the government's money, and before they would award the fortune of 20,000 pounds for the first successful marine chronometer they insisted on still another test, by sea voyage to Barbados. This test was triumphant: the big silver watch was about 40 seconds fast in a six-week voyage, three times better than the error allowed by the Act of Queen Anne. But the board saw a loophole. No prize would be granted "until he shall have made full and clear discovery of the said Principles and method." Harrison, then past 70, after more than 40 years of work toward the prize, was still to be balked. (It was George III who finally had justice done.) The French ambassador knew of Harrison's work, and two years earlier a French expert mission had come to look at his timepiece. Then Harrison would show them nothing. By December, 1765,

A handful of people like Mary Carnwath are trying to keep our promise to the Indians. But they won't make it without you.

The Hopi Indians' village of Shipaulovi in Arizona sits on land so poor, infertile and inhospitable that so far nobody has tried to take it away from them.

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Grace will have a chance to continue schooling. The family has been able to make its home a little more livable. And with the money left over, together with funds from other sponsors, the village has been able to renovate a dilapidated building for use as a village center. The center now has two manual sewing machines that are the beginnings of a small income-producing business. It's only a small beginning. More money and more people like Mary Carnwath are needed. With your help, perhaps this village program will produce enough money to end the Hopi's need for help. That is what Save the Children is all about.

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six months after the Barbados voyage, Harrison had made it clear to the French that he would tell all for 4,000 pounds sterling. Meanwhile a member of the board itself, the great watchmaker Thomas Mudge, had offered the French his own information. The French sent their man to London with an offer of 500 pounds for Harrison. He declined this disappointing price, but Mudge accepted, and thus security was broken a little early.

Harrison's competitors in both France and England never drew on his designs, which were too complicated for the age of workaday chronometers that followed. His contribution was to prove that the job could be done. Larcum Kendall's replica of Harrison's final entry was taken on Captain Cook's second voyage of 1772–1775, and Cook wrote in his log: "It would not be doing justice to Mr Harrison and Mr Kendall if I did not own that we have received very great assistance from this useful and valuable timepiece,... our never-failing guide, the Watch."

This readable and engaging book by an amateur historian (a retired Colonel of Royal Marines) centers on the personal story of the self-taught, persistent, puritanical Harrison, who with his brother before 1730 made the finest clocks in the world, while they still earned their living as country carpenters. It is this narrative of 18th-century enterprise, engineering and government that makes the book. The book is not much concerned with the details of Harrison's mechanisms—there are standard references for that—and other short accounts of Harrison's career are well known. This, however, is the first substantial study of this remarkable and enigmatic life.

STRONG SOLIDS, by A. Kelly. Oxford University Press ($6.75). The one-hoss shay failed all at once, and nowhere first. That is the way a theorist's wire pulls apart, along one lattice plane. By the use of the details of atomic forces and the known arrangement of atoms in a lattice the theoretical breaking stress for crystals can be calculated. Diamond turns out, of course, to be very strong, with a calculated shear strength in one particular direction of some 18 million pounds per square inch, nearly 20 times that of iron. But to realize that ultimate value the sample must be free of flaws, without internal cracks, inclusions or dislocations, and with surfaces smooth down to atomic dimensions. This severe condition has been met for a few crystals, the tiny fibrous forms called whiskers. Iron whiskers come up to two-thirds of theoretical strength. On such a tested basis we can now predict what kinds of crystal will be the strongest. They turn out to be those with strong, short, directional chemical bonds. They must have a three-dimensional network of bonds. This implies small (hence light) atoms and structures that are not highly symmetrical; their densities will be low, and the engineers of the future will be happy with new materials that are light and very strong, made of carbon or boron or beryllium compounds!

Real crystals first fail by the motion of atomic dislocations, unless they are locked into the stiff crystal. If the dislocations cannot move easily, then surface flaws bring failure. Dislocations in metals can be locked to order by causing tiny hard particles of alloying compounds to precipitate within the material. Duralumin was the first strong metal made that way; in the past few years a very strong, tough stainless nickel steel called maraged steel, not easily weakened by surface flaws, has been developed. It is about the strongest machinable stuff we have. It fails at stresses about a sixth of the ultimate for its iron bonds; the best steel wires are twice as good as that. Cold-drawing still makes the strongest metals, although they are specialized for strength in one direction.

Glass and silica can be surprisingly strong too. Surface-protected glass rods, free from all abrasions, free from contact even with dust, are about 100 times stronger than glass rods from stock on the shelf.

A rope is strong because "cracks must either be very short, across a fibre, or... parallel to the fibres, and hence harmless." For organic fibers joining the fibers is easily done by coiling. They can be bent sharply without harm, and they are not very sensitive to surface abrasion. None of this is true for glass, silica or the tiny whiskers. They cannot be spun into ropes. They can, however, be bound in a matrix that protects the surfaces and holds the small fibers together, uniting their strengths. Exotic composites are being tried, a kind of generalized fiber glass. There are now graphite-plastic composites four times stiffer than fiber glass and just as strong, and filaments of boron carbide and beryllium oxide and many others are being produced for such uses. Alumina whiskers bound in silver showed a high and calculable strength if the whiskers were hand-selected. Some ingenious efforts have been made to grow fibrous composites directly from a melt, using an alloy that separated out into distinct phases in freezing. The picture of such a microstructure looks like some strange metallic biology—parallel chromium microrods aligned in a copper matrix.

This small volume is an admirable mix of insightful theory and knowing practice aimed at a target, the rational design of materials. That direction is filled with promise; realization is not quite yet at hand, and new engineering materials still arise more by art than by reason.

THE ELECTRONIC INVASION, by Robert M. Brown. John F. Rider Publisher, Inc. ($3.95). Here is a *Consumer's Union* guide to bugs, all but the crisp "best buy" ratings. The bugs are of course not leggy or winged at all but are telephone bugs, eavesdroppers that report by radio, beepers to fix on the underside of a car's gas tank for easy tailing, voice-operated unattended briefcase tape recorders. One of these records on plastic belts that are admissible as courtroom evidence (this one even has a filter against noise, so that it is said to record the speaking voice from a distance of 60 feet). There are debugging hints and circuits, and a directory of suppliers. It is rather rueful reading. The line tracer is "used primarily by professional eavesdroppers serving racketeer clientele and the FBI." The gear described here, however, is mostly intended for gaining evidence in divorce cases or picking up a business competitor's intentions. Prices and appraisals are clearly given. The high-cost devices used by expert government agencies with big budgets are marketed more discreetly. Mosler Research of Danbury and the Kel Corporation of Belmont, Mass., are two companies that restrict their sales to Federal and other agencies. The FM bands between 88 and 108 megacycles (89 megacycles is common) seem to carry most of the bug traffic. Some insight into the big time is given us, less by television fiction writers, who have brought a kind of false understanding of the realities of 1984 minus 17, than by U.S. revelations of the bugging practices of the Eastern bloc. In 1965 a Czechoslovakian radio bug that could be turned on and off from a distance was planted in the Department of Commerce. Such a room bug has no counterpart on the open market here. The Great Seal bug given to our Moscow embassy sometime before 1960 had a microwave resonant chamber with an acoustic diaphragm that responded to voice, monitored by a microwave beam sent from a truck out in the street. It had no wires

and no batteries. That was nearly a decade back.

CHINESE ECONOMIC STATISTICS: A HANDBOOK FOR MAINLAND CHINA, edited by Nai-Ruenn Chen. Aldine Publishing Company ($15). This volume of data, all taken from Chinese publications, deals with the most important economic subject known: the well-being of the largest unit of all mankind. It is one decade—the most important decade—behind the times. "Unfortunately, everything statistical in China stops after 1959, . . . a statistical blackout unprecedented in modern history." This book can hope only to set a bench mark for comparison with an eventual flow of data. In 1959 China generated electric power at a mean rate of five million kilowatts, about the same as Italy. That rate was growing by 50 percent per year.

ENERGY CHANGES IN BIOCHEMICAL REACTIONS, by I. M. Klotz. Academic Press, Inc. ($5.95). This little book is aimed at starting students of biochemistry off on the right thermodynamic foot. It is a genuine success; there is no more clear and sensible account of that Gibbsian interplay of energy and entropy that allows the world to pay for order by the expenditure of energy. There is also an excellent final chapter on the statistical way of thinking. The mathematics employed is minimal, and the nonsense implied by all too many biochemical writers on this key subject is wholly absent. The main examples are biochemical, but electrode potentials and melting ice get due attention.

SYMMETRIES AND REFLECTIONS: SCIENTIFIC ESSAYS, by Eugene P. Wigner. Indiana University Press ($7.50). Two dozen essays and speeches published over 30 years are collected under this charming title. The high theme of invariance is here remarkably well discussed in a half-dozen not very technical pieces. Nuclear energy and its growth is another key theme. The more metaphysical papers, on deep issues such as the conflict seen between molecular biology and quantum mechanics, are always modestly and candidly put, gaining in their personal quality while they lose in persuasiveness.

PREHISTORIC EUROPE: THE ECONOMIC BASE, by J. G. D. Clark. Stanford University Press ($15). A handsome reissue of this out-of-print work, a definitive and thoughtful review of the whole fascinating subject.

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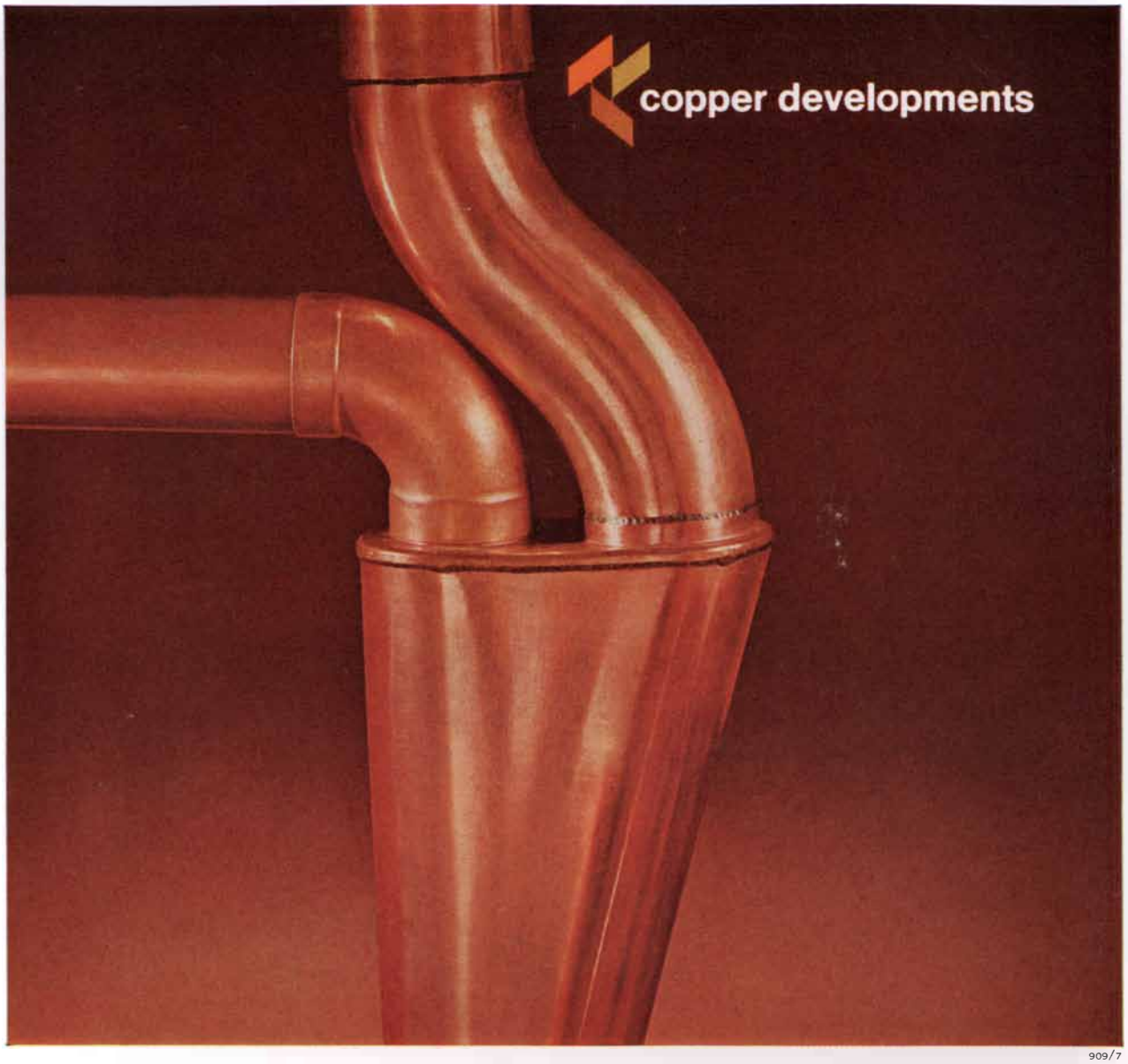

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