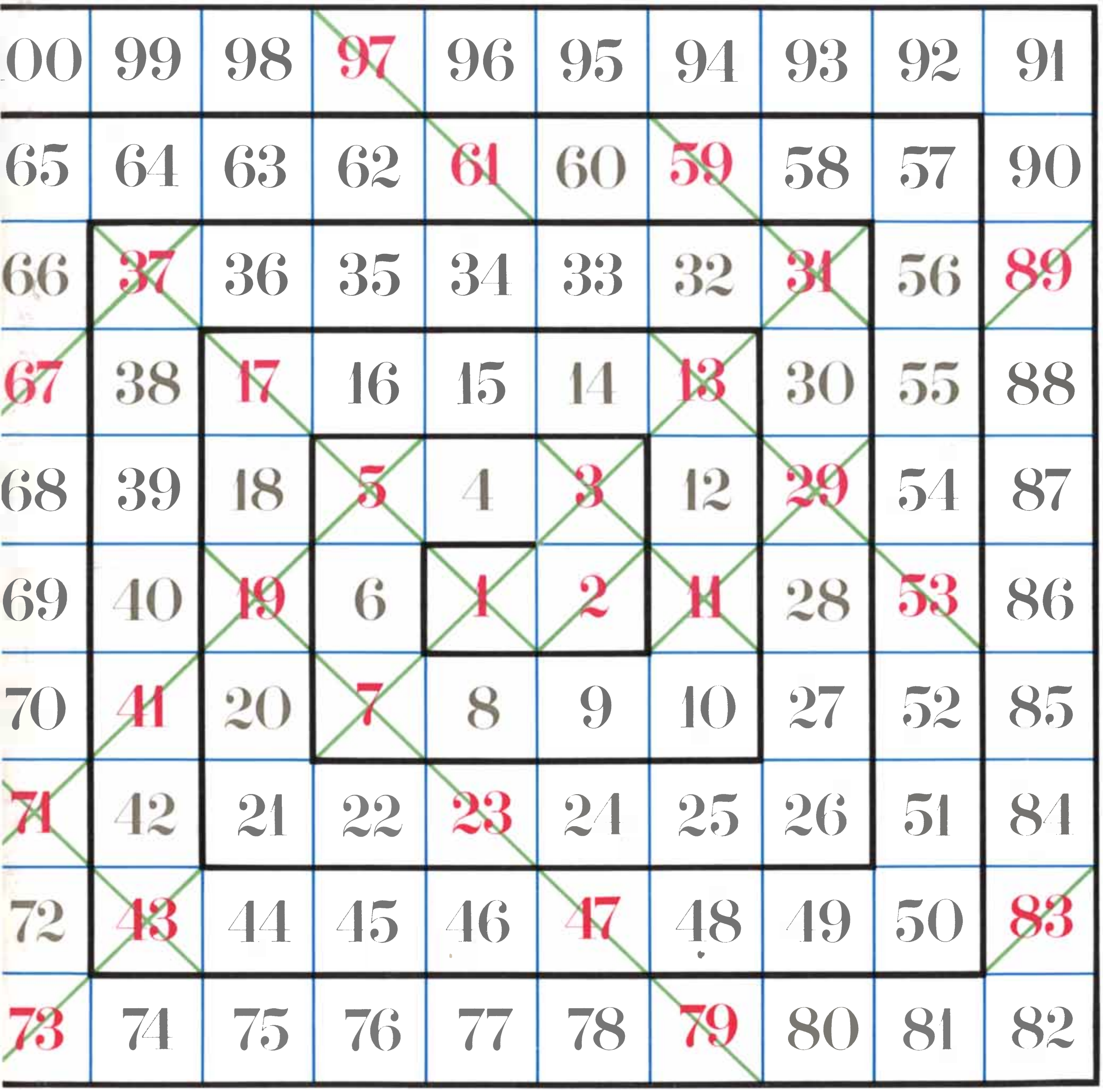
SCIENTIFIC AMERICAN



PRIME-NUMBER PATTERN

SIXTY CENTS

March 1964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YOU PUT
MORE TIME
IN A TUBE?

Unique 3M Invention produces complete microfilm record in just 54 seconds!

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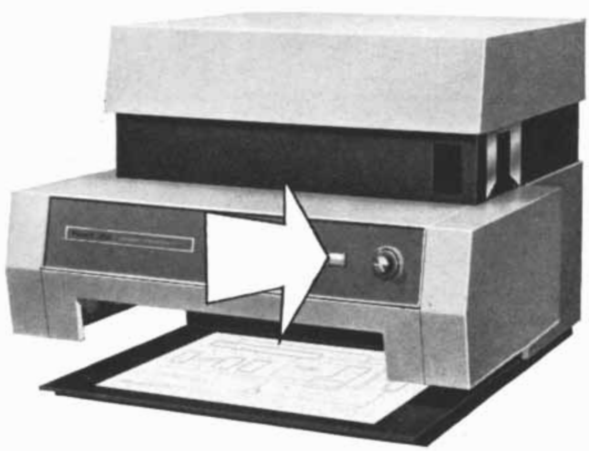
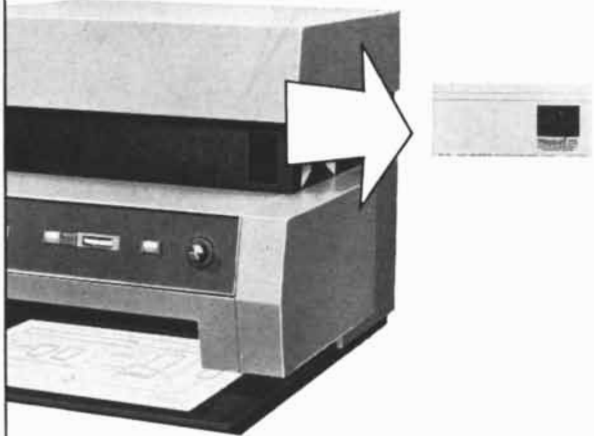
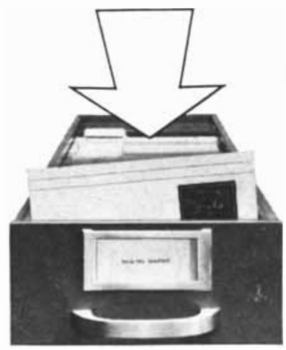


Push a button.



Complete in 54 seconds.



Ready to file—easy to find.

New "Filmsort 1000d" Processor-Camera makes microfilm record-keeping practical for just about any organization. One compact desk-top unit photographs any document up to 18″x 24″ and delivers a microfilm record mounted on an Aperture Card in 54 seconds. Find out now how 3M "Filmsort 1000d" can cut filing and retrieval time in half—reduce filing space 96%.

For a free sample Microfilm Aperture Card and the booklet, "How Business Is Winning The Paperwork Battle," write 3M Company. No obligation!

3M Microfilm Products Division
MINNESOTA MINING & MANUFACTURING CO.
St. Paul, Minn. 55119

THERE'S A NEW WAY TO LOOK AT MULTI-FUNCTION

To do several jobs simultaneously, seven hands are handy, but coordination can be erratic. On the other hand, Litton 'Superpots' perform multiple functions with perfect synchronization because all functions share the same shaft. Like the Superpot above: Three switches with different on-off cycles, each phased to individual taps in a tandem potentiometer section. For certain applications we've compacted custom-tailored combinations into one-half-inch diameter on a single shaft, with ultra precise outputs. We can gang wirewound pots and infinite resolution filmpots on the same shaft. Working out uncommon solutions to difficult functions and extreme parameters is our daily job. Throw us a mean curve and expect optimum results.

Free "Handbook of Precision Potentiometers" will be sent at your request.

LITTON PRECISION PRODUCTS INC. POTENTIOMETER DIVISION MOUNT VERNON, NEW YORK

2-gang conductive film design performs a continuous sine-cosine function with high slope ratios and conformity to 0.1% peak-to-peak.

This multi-tap, ten-turn wire-wound model provides infinite resolution with an ultra-precise 0.0075% linearity.

Litton servo-winding techniques combine non-linear functions with extreme accuracies in ½" diameter, 0.15% terminal conformity and 0.05% resolution.

ACTUAL SIZE

Established 1845 **SCIENTIFIC AMERICAN** March 1964 Volume 210 Number 3

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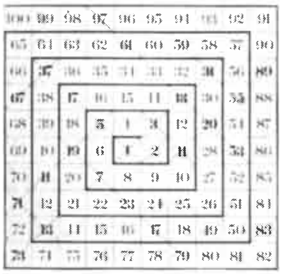

THE COVER

The design on the cover represents a recent discovery concerning the behavior of prime numbers: integers that are divisible only by themselves and 1. Stanislaw M. Ulam of the Los Alamos Scientific Laboratory found that if numbers are written on graph paper in a spiral, the prime numbers tend to form straight diagonal lines (see "Mathematical Games," page 120). On the cover the spiral is indicated by the heavy black line, the primes are in red and the diagonal lines are in green. The diagonal lines are even more apparent in the illustration on page 122, which shows the pattern as it was presented by a computer that worked out the spiral from 1 to about 65,000.

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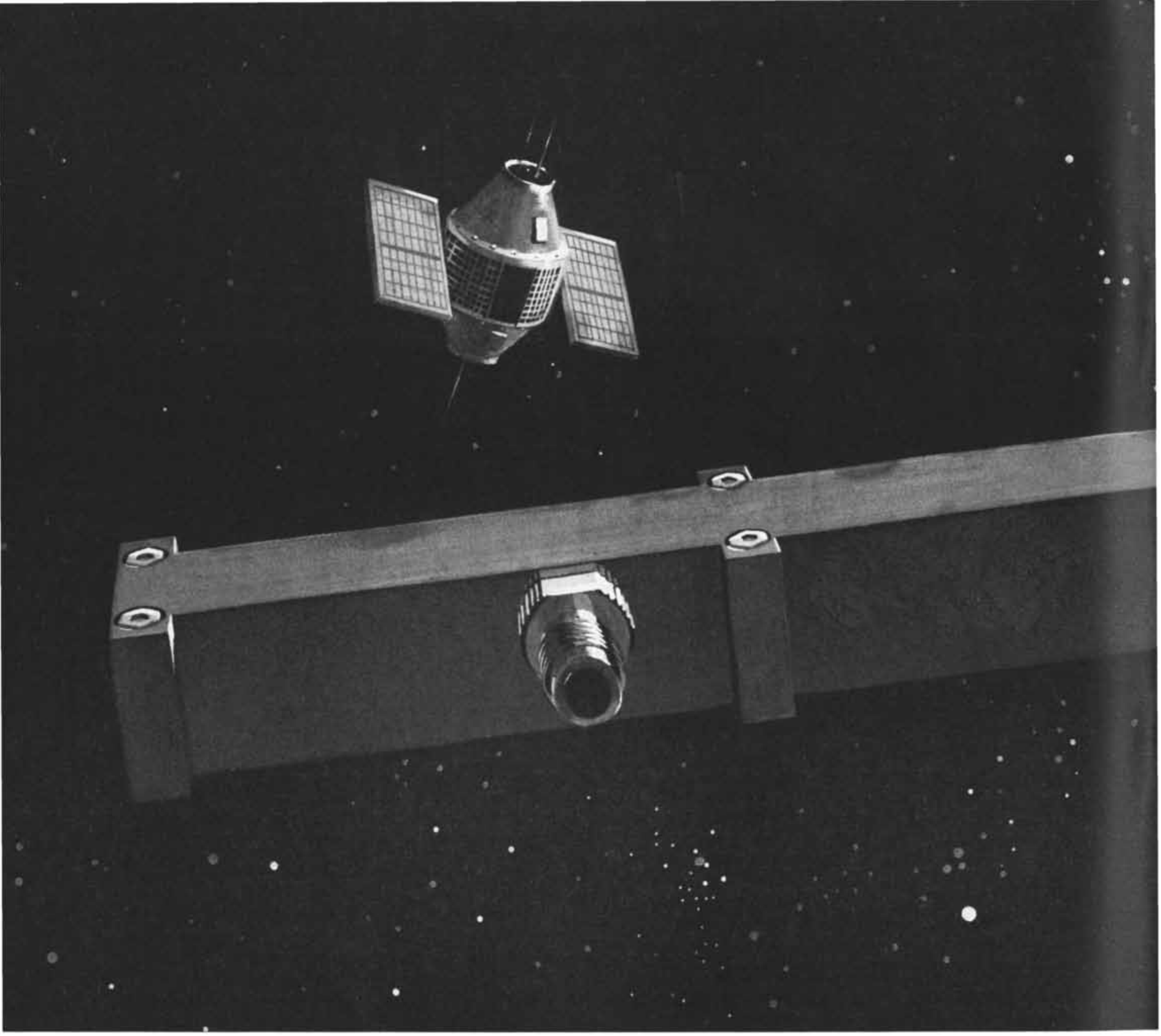


Where no metal but Platinum

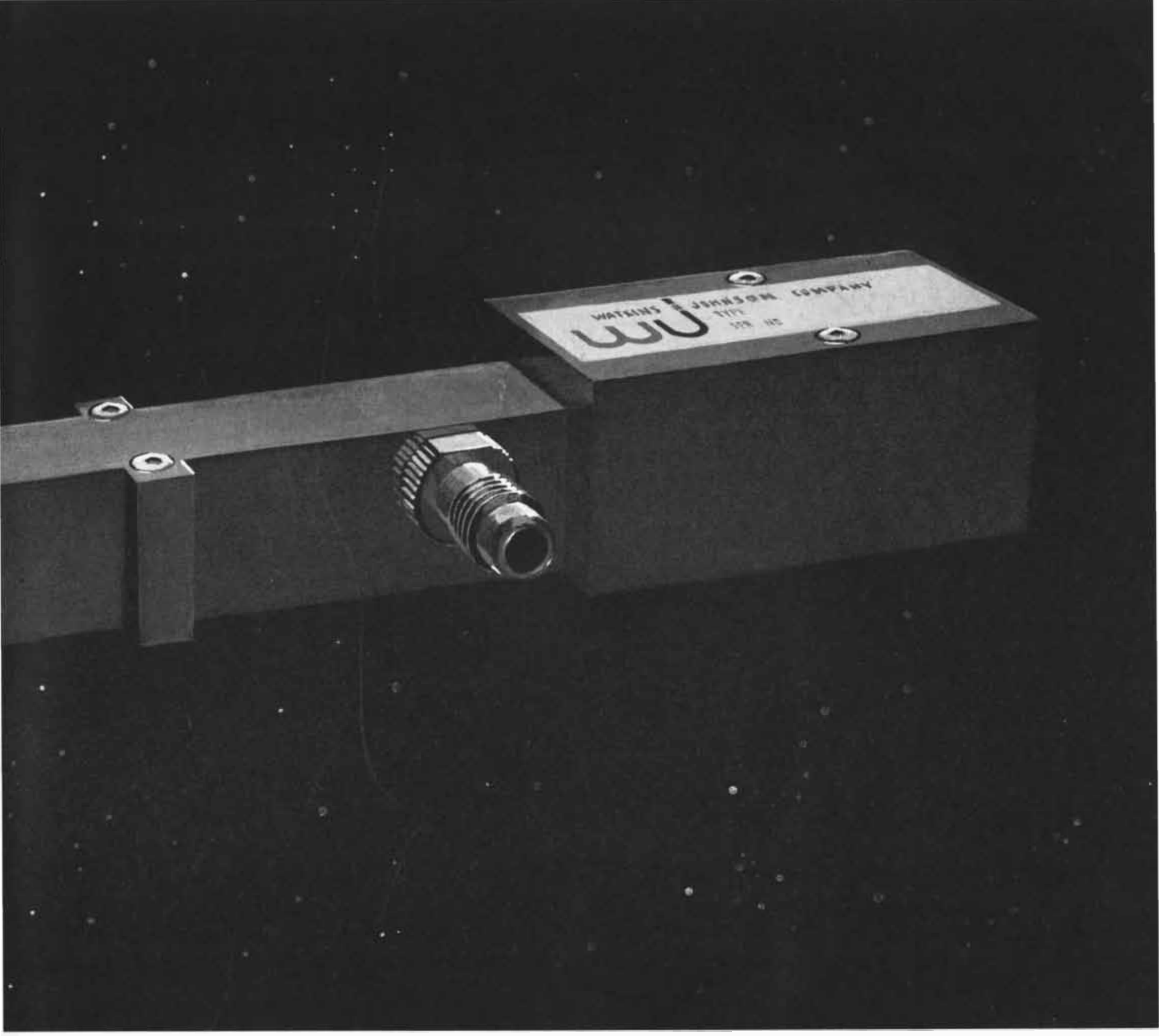
Platinum-Cobalt permanent magnet is credited with providing satellite amplifier with maximum reliability, small size and optimum over-all efficiency.

Space communications specialists now have available a lightweight, highly efficient amplifier for use in earth-orbiting relay satellites. The Watkins-Johnson Company, Palo Alto, California, has developed a traveling-wave tube amplifier which delivers 12 watts of power with an efficiency of 27%—yet weighs only 32 ounces. Watkins-Johnson engineers credit this effective design to a tiny, 7⁄16-inch diameter magnet made of Platinum-Cobalt, an alloy which provides a more powerful permanent magnet than any known material.

Platinum-Cobalt, after appropriate heat treatment, develops a coercive force approximating 4800 oersteds and an energy product in the order of 10 million gauss-oersteds—advantageous properties where strong fields must be produced with a small mass of material.

It could pay you to use a Platinum Metal

Your problem might be readily and economically solved with a Platinum Group Metal—where superior magnetic properties are required...where superior electrical characteristics are required, such as in grid wires...where high temperature corrosion and spark erosion are involved, such as in aircraft sparkplugs... where wear-resisting, non-tarnishing surfaces are required, such as for printed electrical circuits...where a combination of severe corrosion and erosion must be met, as in the case of spinnerettes for rayon production...where peak catalytic efficiency is required, as in the refining of high octane gasoline...or where product purity must be retained despite high temperatures, as in the case of lens glasses...the Platinum Group Metals have proved to be the most economical for certain critical equipment.



will do the job as well...

Industry is going to higher temperatures and higher pressures. Perhaps your own progress has been blocked by the limitations of materials to withstand such severe conditions. The Platinum Metals family have removed many barriers. Have you considered them for your problems?

Platinum, palladium, rhodium, ruthenium and iridium have unique potentials, well worth your attention. Specialists are prepared to work closely with you in evaluating these metals for new commercial and scientific uses.

As the first step, write for the 20-page book, *"The Platinum Metals in Industry,"* describing outstanding characteristics and successful applications of the six Platinum Metals and their alloys—indicating how we might be of assistance to you.

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LETTERS

Sirs:

The article "Vehicular Traffic Flow" by Robert Herman and Keith Gardels, appearing in your December issue, points out the statistical and physical nature of traffic and how "platooning" can defeat the shock-wave effect of heavy traffic on single and multilane arteries. It also makes the observation that drivers tend to maintain speed rather than distance relations, which is the obvious cause of the shock-wave effect.

What the article does not relate are the causes of the valuation of speed, regardless of safe-distance practices. The obvious fallacies of the man-machine system called the automobile are the human error and the human temperament. In semiautomated production lines experience shows that man-machine combinations are inefficient and dangerous; better quality and safety are achieved by either a fully automated system or a fully manual system.

Human beings, although sheeplike at times, are not content to follow the leader, particularly when they have something else on their minds or want to get home for dinner. Heavy traffic is an agent of frustration: it makes tempers grow short and chances grow long. There is always someone, either because

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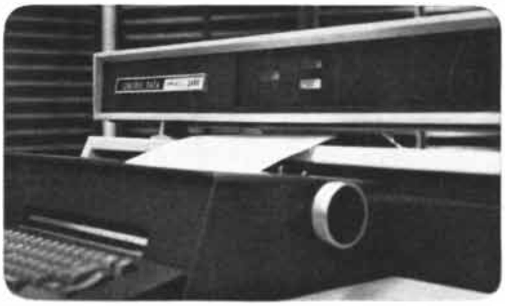

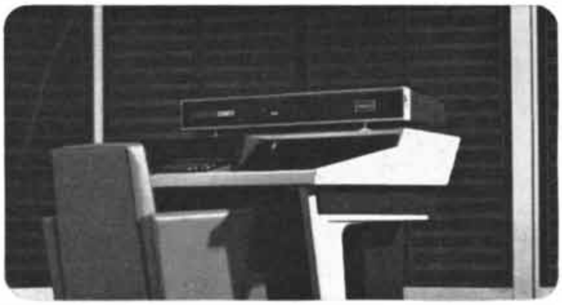

THE **CONTROL DATA® 3400** LETS YOU START WITH LARGE-SCALE COMPUTING AT MEDIUM-SCALE COST

The **CONTROL DATA 3400** is the newest in a family of large-scale computers. It allows the user to benefit from large-scale computer performance—speed, precision and scope.

Yet, the 3400 is as much as 50 per cent lower in cost than equivalent systems.

The 3400 uses the same field-proven logic and circuitry developed for the 3600—Control Data's unprecedented large-scale computer system. Further extending this compatibility with the 3600, peripheral systems are interchangeable.

The 3400 Software (FORTRAN, COBOL, complex monitor systems, assembly routines and simulators) parallels the 3600.

This system compatibility with the 3600 at medium-scale price is significant in two valuable respects: 3400 price allows users an earlier start in large-scale performance, while the 3400's true upwards compatibility to the 3600 significantly extends the user's system life.

Detailed information is now available on the **CONTROL DATA 3400** through the Control Data Corporation representative who calls on your organization.

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What Dr. Herman and Mr. Gardels might consider is a totally automated system in which the road not only controls the vehicle but also powers it—a system in which the vehicle is a programed bit of information, the driver the programmer, and the road system the memory and logic of a computer. The vehicle would be of necessity a new concept. It would have its own power supply, but usable only on minor avenues, not on major arterials. To enter a freeway the driver would pick his destination and feed it to the vehicle's control console, which carries a coded diagram of the arterial system; the vehicle relays information to the computer-road on the on-ramp and the vehicle is transported to the destination without the possibility of human error in control.

Our driver, once off the freeway, resumes control of his vehicle, which now operates on its own power (enough for a speed of no more than 40 miles per hour). If the driver fails to program or to take control, the vehicle could be shunted to a holding area apart from the on- and off-ramps.

Science fiction? I don't think so.

MELVIN RUDIN

Mountain View, Calif.

Sirs:

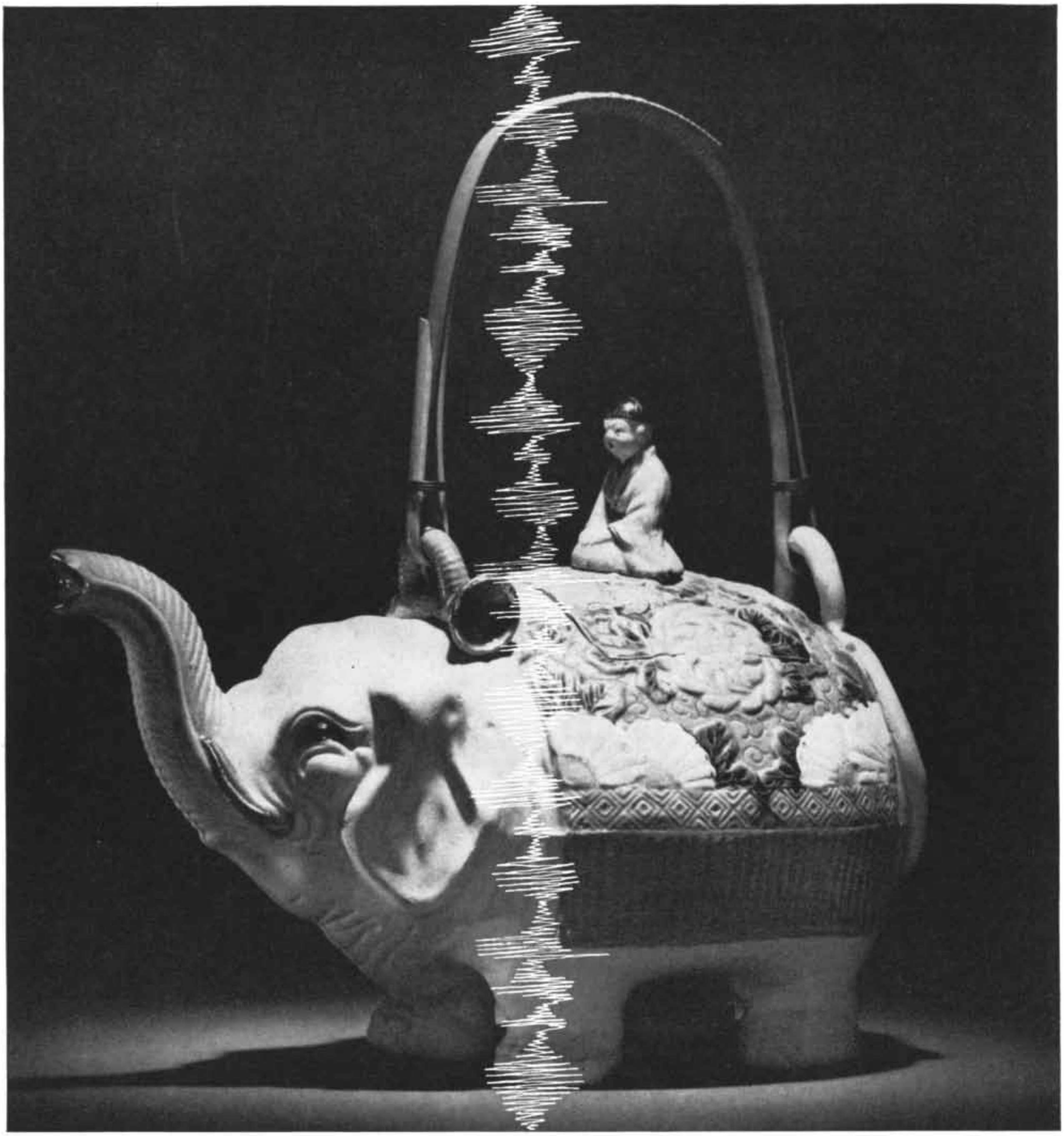
We read with interest the article by Leonard V. Gallagher and Bruce S. Old titled "The Continuous Casting of Steel" in your December issue.

As major suppliers of graphite electrodes to the nation's electric arc furnace industry, however, we were surprised to find no mention of the electric furnace as a source of molten steel, whereas both the open hearth and the oxygen converter were discussed.

In point of fact, of the 71 steel mills that are presently continuously casting steel throughout the world, 50 are equipped with electric furnaces, six with open-hearth furnaces, six with LD (oxygen) converters and six with a combination of electric furnaces and open hearths. No information is readily available on the other three.

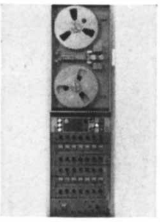
M. M. RAND

National Carbon Company
Division of Union Carbide
Corporation
New York, N.Y.



Will your next instrumentation recorder turn out to be one of these?

Not if it's an Ampex. We've made more instrumentation recorders than anybody else in the world. And none of our customers has ever found himself with a white elephant on his hands. The first recorder we ever made —the recorder that pioneered the industry—is still in service. And right from the start we've held to the idea that no matter how good a recorder is, it's only as good as the backup service of the company that made it. We've built up the largest staff of Service Engineers in the industry, and stationed them in practically every major city in the world. We have Contract Engineers who work full-time in customer installations. And these people are backed up by a corps of Technical Service Engineers. We have a Training Division, a full-time staff of instructors who'll give your people a thorough course in operation and maintenance of our equipment —either at one of our plants or on-the-job. Our Parts and Service Division stocks parts for every recorder we ever made and has depots all over the world. Our Engineering Division provides modernization kits which make it possible to incorporate new advances into older machines. And no matter how old a recorder is, our Service Laboratory can give it a new lease on life. Backup services like these don't get mentioned on spec sheets (they can't be specified). But they're the invaluable extra that can mean the difference between a wise investment and a white elephant. How many companies offer you this kind of service? You can count them on one finger of one hand: Ampex Corporation, Redwood City, California. Term financing and leasing available.



AMPEX

What is it that can travel over water, land, mud and ice and may make the wheel obsolete?

It's been called a "GEM" (for Ground Effect Machine). It's been called a "Hovercraft." It's been called an "Air Cushion Vehicle." And it's a little hard to say whether it flies low or rides high.

But Republic Aviation has just concluded a licensing agreement to develop, produce and sell these revolutionary machines that travel on a cushion of air over any kind of surface, wet or dry.

Gas turbine engines provide air cushion

One of the most publicized GEM's already built has done commuter service on a test basis, carrying 24 passengers across Dee Estuary on Britain's North Wales coast, over sandbars and shoals where no boat could operate. Called the VA-3, it's a 4-engine 12-ton version that can handle about 2 tons of cargo. It hovers 12 inches over the surface on a cushion of air provided by two of its gas turbine engines, while the other two provide propulsion.

A variety of high-speed go-anywhere craft for industry and the military

Similar but more advanced versions of the GEM are expected to operate easily at speeds over 150 mph. Republic's prototype model will be equipped to ride three feet off the surface to clear waves or obstacles, and further development will produce models that can clear six to eight-foot obstacles. Consider then, what the GEM's capabilities might be . . .

- ☐ As a military landing craft, thundering in from over the horizon and right up onto the beach to park and unload—
- ☐ As an offshore oil-rig tender, carrying drillpipe, supplies and personnel over tidewater marshes, mud flats and open sea with equal ease—and without any dock—
- ☐ As an airport or harbor vehicle for police and rescue work—
- ☐ As a high-speed arctic exploration craft, unhampered by snow or thin ice—
- ☐ As a general-purpose carrier for underdeveloped countries where good roads are few and far too costly.

How big a future

As yet, nobody is entirely sure what the GEM's total potential for the future really is. Finding out is a big part of Republic's job. Considering that it took man some millions of years to discover the wheel—and another 7,000 to learn how to do without it—that could be a pretty sizeable order.

Republic will develop and produce air-cushion vehicles in this hemisphere under a licensing agreement with Vickers and Hovercraft Development Ltd. of Great Britain. Republic Aviation Corporation, Farmingdale, Long Island, New York.

REPUBLIC AVIATION CORPORATION

SILICOLOGY

Energy Absorption of Semi-Rigid Foams Increased Six-Fold by New One-Shot Process

In devising a new one-shot system for manufacturers of semi-rigid urethane foams, we met head-on (like football players) with some unique problems. Silicone surfactants played a major role in solving them.

Almost all semi-rigids are used as shock absorbers. Automotive crash pads and sunshields. Protective padding for delicate instruments and heavy equipment. Gaskets. Athletic equipment. (We understand football players often clash with the force of a car going fifty miles an hour.)

These end uses place harsh demands on manufacturers. They must supply cushioning material rigid enough to prevent strike-through. Yet the material must be soft enough and resilient enough to absorb shock without permanent deflection.

What is needed is a hybrid between a flexible foam with a high percentage of open cells and a rigid foam with mostly closed cells. Union Carbide's new one-shot system for manufacturing semi-rigid urethane foams is designed to balance these cellular problems . . . and, do it economically.

Two silicone surfactants provide the key. One acts as a stabilizer. It gives the necessary film healing while the foam develops and rises. The other silicone surfactant opens the right number of cells at exactly the right time.

Together, in a one-shot process, these two surfactants perform a job that formerly required a more expensive two-step prepolymer system.

They give a much superior product, too. A foam that absorbs up to six times the energy of previous urethane foams, according to standard rebound tests. Density is reduced by 33%, and, significantly, compression set is reduced from 40-50% to zero-1%. (The table has more details.)

By varying the formula, manufacturers can obtain a considerable range in reactivity rates and physicals. A viscosity of 300 centistokes makes molding easier ...permits free flow into thin and intricate molds, eliminates rejections and void-repair problems.

Excellent green strengths are obtained without post-curing. Curing time-temperatures and cream times are compatible with current production equipment and schedules.

Union Carbide is the originator of surfactants for one-shot polyurethane foams and the leading innovator in silicones technology. You can select from the most complete product line, and benefit, too, from all the silicone research we are doing. Just see your Silicones man or mail the coupon below for any kind of information you want about silicones and their uses.

Property	UNION CARBIDE'S One-Shot System	Typical Prepolymer Properties
Compression Set	0-1%	40-50%
Density	4.5-6.5 lb/ft³	8-11 lb/ft³
Resiliency (Rebound Ball Test)	5%	30%
Humid Aging (loss of load bearing)	25-35% decrease	40-50% decrease
Fillers (to eliminate shrinkage and to obtain properties)	None required	Required
Viscosity of System	300 centistokes	2000-4000 centistokes
"Green Strength" (time to reach minimum compression set)	<1 hour	>3 hours

UNION CARBIDE

SILICONES

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MARCH, 1914: "According to press dispatches, Mr. William Marconi is meeting with considerable success in his wireless telephone experiments and is confident that transatlantic radiotelephony will be an accomplished fact at some not far distant day. Mr. Marconi has been conducting experiments from the Duke of Abruzzi's flagship, the *Regena Elena,* off Agosta in Sicily, and has succeeded in maintaining radiotelephonic communication with ships from 18 to 43 miles distant."

"Some very interesting recent researches by Størmer and Birkeland on the aurora borealis render it probable that this phenomenon is due to corpuscular radiation proceeding from the sun to the earth. These corpuscles are doubtless electrons, which are known to have great penetrative power."

"Three years ago the trustees of the British Museum undertook what has proved the largest, and in many respects the most important and fruitful, excavation which they ever promoted. Three years have seen six campaigns in the soil on which there is no reasonable doubt once stood Carchemish, the leading city among the Hittite peoples of Syria. Mr. C. L. Woolley, well known for his Nubian researches, and Mr. T. E. Lawrence, who worked under Mr. Thompson and Mr. Hogarth, have been in charge for the most part of this time, carrying on the excavation for a spring season and an autumn season in each year with between 200 and 300 men."

"M. Maurice Colliex made his first flight recently with a gigantic sea plane, which might be called a flying tug-boat. It has the regular ship-like under-structure characteristic of Curtiss hydro-aeroplanes and looks something like a small river tug. Even the funnel in the middle is not missing. The hull of the little boat is 26 feet long, and it has a beam of seven feet. The wings are about 82 feet long and have a spread of about 150 square yards of canvas. Colliex tested the machine on the Seine, near Triel. It rose easily from the water and alighted without difficulty."

"Prof. Lowell telegraphs to us from Flagstaff as follows: 'The canals of Mars are now exhibiting a very striking seasonal development from north to south over the planet's surface, being darkest and strongest near the edge of the melting north polar snow cap and thence gradually pushing farther and farther southward. This observed development of the canals is somewhat similar to the annual inundation of the Nile.' "

Scientific American.

MARCH, 1864: "The gunboat *De Soto* has thus far proved herself the most successful of all the vessels on the Atlantic blockade. She has captured 17 blockade runners, whose aggregate value is near $1,200,000."

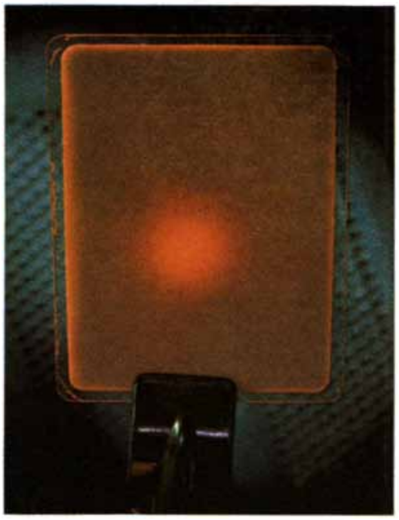
"A correspondent of the London *Times,* writing from Richmond on Dec. 21st, thus discourses of naval armament: 'Again I feel tempted to raise a warning voice about the disparity of the armament on board of the English and American vessels. Judging from the officers of Her Majesty's Navy who have at rare intervals brought vessels of war into Confederate ports, it appears still to be held that the 68-pounder, or eight-inch smooth bore, is England's best weapon of offense against iron-clad vessels. The experience gained at Charleston enables me confidently to affirm that as well might you pelt one of the Yankee monitors or the *Ironsides* with peas as to expect them to be in any way damaged by eight-inch shot. Another disagreeable question forces itself upon an Englishman's attention when he is cognizant of the terrible broadside thrown by the eight 11-inch guns of the *Ironsides*—one of the most formidable broadsides, in the opinion of the defenders of Charleston, which has ever been thrown by any vessel upon earth. Have we any ship in existence which could successfully resist such a broadside and respond to it with anything like commensurate weight and vigor?' "

"A very beautiful hypothesis has been framed by Mr. Sterry Hunt, F.R.S., to account for the increased temperature

Kodak reports on: **an unsophisticated-looking receptor**
. . . keeping our weapons off the dinner table
. . . and asks a lot of questions

Infrared goes in, orange comes out

No, it's not raw film. Roomlight or daylight does it no harm. In fact, it is intended to be left lying around exposed to fluorescent-lamp light. That's how you charge it up. That's *all* there is to charging it up. Then you take it to the laser room. Don't rush. The energy won't leak away that fast. If the 5 o'clock bell rings and it's Friday, forget about it until Monday. But do *not* forget to protect your eyes with 7 mm of Pittsburgh No. 2043 glass (or the equivalent thereof) before firing the laser at it.



The whole point of this picture is that this is a far-field pattern not of a visible-light laser but of an infrared one.* Thus we demonstrate what should be the big market for sheets of a product for which purchasing directories will have to establish a new category, a product we choose to call KODAK IR Phosphor, an interesting bit of business from our chemists of the inorganic persuasion.

Except for a technicality, one could say that it converts infrared to orange, replacing more sophisticated-looking receptors that less vividly show the location and approximate distribution of the output from an infrared laser. The technicality is that infrared (0.7μ to 1.3μ) merely stimulates the phosphor to release as orange light (peaking at 640mμ) the energy it has soaked up while lying around in white light.

The pattern can be photographed from the phosphor on any panchromatic or color film but preferably one that comes in a yellow box.

It is very easy to acquire 2" x 3" sheets of KODAK IR *Phosphor. All you do is multiply the number you can use around the place by $25 and dispatch a purchase order valid for the product of these two numbers to Eastman Kodak Company, Apparatus and Optical Division, Rochester, N. Y. 14650.*

* Reason for the goggles: an unlucky reflected jolt of infrared can damage an eye with little immediate awareness. Putting your eye behind the sheet is even less lucky.

Blue dye

USDA Photo

KODACHROME Film can show a plague of locusts against a blue sky. Now please pay attention to a complex message.

Nobody is cheering for the locusts. If it's we or they, we must win. Chemistry has provided effective weapons. Into the mouths of such mighty cannon we must be smart enough not to stick our own heads. In short, let's keep track of these potent pesticides so that we don't eat, drink, or breathe them. A contribution to this endeavor appears in *Science*, *139*, 835 in the form of a paper on Indophenol Blue as a color-fixing agent for halogenated aromatic hydrocarbons on paper chromatograms and spot tests.

Now back to KODACHROME.

The dye that gets cleverly laid down in the blue areas of a KODACHROME picture is—yes, you guessed it—Indophenol Blue, now somewhat modified. Two of us did not guess it—the sales executive who spotted the paper in *Science* and the chemist who was asked in consequence to make Indophenol Blue in happy innocence of its status as one of the company's most successful products for 29 years. Thanks to a mild silver oxidizing agent the chemist applied to the task in ignorance of the established manufacturing procedure for the dye, he wound up with an embarrassingly purer product than ever yielded by the method developed by his boss's boss long ago, which was only as good as it had to be and carried our blue Technical Grade label.

Now N-(p-Dimethylaminophenyl)-1,4-naphthoquinoneimine *bears a harder name to remember than Indophenol Blue, a white label signifying a purity that justifies a price of $7.00 for 5 g., and the designation* EASTMAN *478 that marks it as one of some 4400* EASTMAN *Organic Chemicals that professionals order from List No. 43 of Distillation Products Industries, Rochester, N.Y. 14603 (Division of Eastman Kodak Company).*

Prices subject to change without notice.

2 colors to wiggle in?

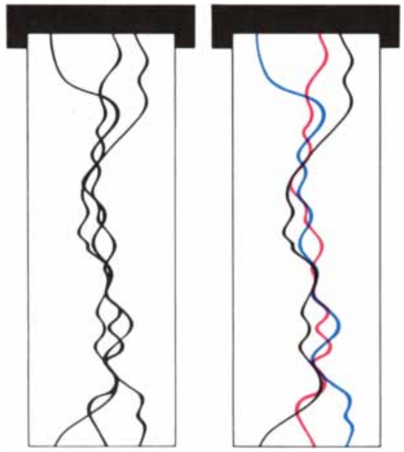
We have made some 2-color oscillograph paper on a thin, quick-drying stock of high dimensional stability.

Should we make some more? Would you buy any of it?

Do you ever have trouble separating superimposed traces?

Would you be willing to modify your conventional oscillographs by insertion of KODAK WRATTEN Light Filters between lamps and galvanometer mirrors? Are you by chance an oscillograph manufacturer instead of a user?

Are you a little more interested than when color oscillograph paper had to be thick and far more expensive than black-and-white paper?



Do science and engineering benefit from this kind of small improvement in the tools of the trade?

Is there an oscillograph-processing machine down the hall? If not, why not? If there is, would anybody mind if you slipped a different set of chemicals into the four tanks once in a while when you felt the need of color?

Do you believe those tales about organizations that seek out the brightest young engineers that money can lure and then put them to work with assorted crayons marking each of 50 separate channels of data on a 400-foot length of oscillogram? Do you believe in the dignity of labor?

Is it enough to say that one seldom has occasion to demand higher trace-writing speed than this new 2-color paper can handle? And that it can be processed at 4 to 6 feet per minute?

Do we pant too hard?

How can we help you unless you ask a few questions of your own from Photorecording Methods Division, Eastman Kodak Company, Rochester, N. Y. (Phone 716-562-6000, Ext. 3257)?

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

of the earth's surface in former geologic times. Adopting Professor Tyndall's views on the subject of absorption of heat, he shows that during palæozoic times the presence of large quantities of carbonic acid in the atmosphere was sufficient to prevent the radiation from the earth of the heat derived from the sun and thus to increase the temperature of our planet. We have every reason to believe that during the earlier geological periods all that carbonic acid which we now have in our various limestones and as carbon in our coal formations was distributed through the atmosphere. This having been the case, it is evident that the quantity of heat radiated from the earth during these epochs must have been vastly less than that which passes away in our times; hence the temperature must also have been considerably higher, thus explaining why a vegetation like that of the Tropics once existed within the frigid zones. In fact, the carbonic acid surrounded the earth like a huge protecting dome of glass."

"Several of the French papers publish the following account: 'Recently a curious spectacle collected 400 or 500 persons on the Place d'Ault, Department of the Somme. This was the trial of a mechanical carriage, invented by the man who carries the mail between Woincourt and Ault. The carriage was arranged to be propelled by a screw driven by the wind. The departure was effected with a little difficulty in consequence of the hill which it is necessary to mount in order to reach the route from Saint-Valéry to Eu. Arrived there, however, the evolutions succeeded to a marvel, amid the applause of the curious who had followed the vehicle. But it was not the same in returning to Ault. The descent drew the carriage and its conductor with a speed equal to that of an express train, and this speed, which increased every moment, would infallibly have taken the car to the base of the coast had not the inventor deemed it urgent for his safety to turn his locomotive against the end of a house which was by the side of the road. The gable was crushed in and the ruins fell upon a lot of rabbits which were below, killing some and wounding others. The inventor happily escaped uninjured.' "

"A telegram has been received from Mr. Cyrus W. Field (who is now in London), stating that Messrs. Glass, Elliot & Co. have chartered the *Great Eastern* for laying the Atlantic telegraph cable in 1865."

Fingerprints are unique to each individual. Likewise, each organic compound gives an NMR spectrum entirely its own.

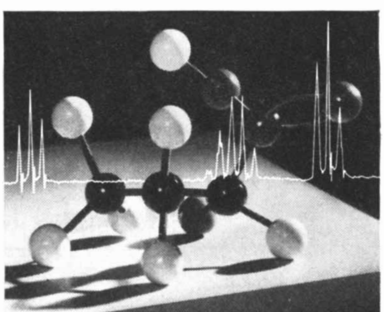
You can tell a man by his prints; you can identify a compound by its NMR spectrum. Even a minute change in the structure of a compound creates a slightly different magnetic environment for the hydrogen atoms within a molecule, which the nuclear magnetic resonance spectrometer will detect and record.

Varian NMR spectrometers can resolve differences equal to 1 part in 2 x 10^8. Comparing it to today's fine optical instruments, it is roughly equivalent to having a telescope which would let you distinguish one black cat from another near it *on the surface of the moon!*

Such a powerful analytical tool has, of course, been used for many years by leading research laboratories around the world. Since the development of the Varian A-60 Spectrometer, however, the use of nuclear magnetic resonance for routine analysis of organic compounds has grown steadily.

In part, this increase is due to the fact that the A-60 is less expensive than the more powerful research spectrometer. But what's more important is the A-60's ease of operation. Because it provides reproducible spectra on pre-calibrated charts you can use the A-60 to collect and catalog spectra for fast, routine identifications.

You can get additional technical and applications data by writing LeRoy Johnson, Analytical Instruments.



When Varian scientists began their investigations into the uses of nuclear resonance, they unknowingly committed Varian to the manufacture of electromagnets.

It was a case of necessity in view of our interest in analytical instrumentation. Experiments which involved observation of phenomena in intense uniform magnetic fields began to be limited by the quality of available magnet systems.

In particular, we needed exceedingly stable fields which had high homogeneity over a large experimental volume — prerequisites for advanced NMR studies.

There was only one thing to do. We had to improve the state-of-the-art performance for large electromagnets.

Since a wide variety of scientific investigations needed similar high performance magnet systems, we formed a Magnet Product Group to make these products and skills available to the scientific community.

As a result, Varian now offers an ever-growing line of magnet systems which range from a simple 4-inch 'C' frame magnet system through the 6-, 9-, 12-inch and the high-field 15- and 22-inch magnet systems. This experience has also been applied to the development of unique high-performance superconducting solenoid systems, and to the revolutionary new FIELDIAL* magnetic field regulator.

For more information write Bob Abler, Magnet Products Manager.

*Trademark

A geomagnetic micropulsation bears a remarkable analogy to a wind ripple on the ocean's surface.

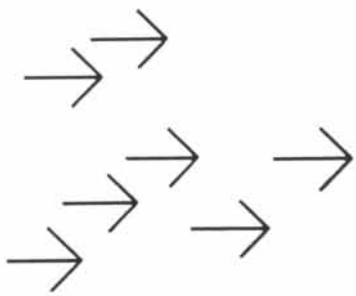
The vast *magnetic sea* also has tides, currents, squalls and storms just as do the earth's waters. The mere detection of these magnetic time variations presents a serious challenge to the geophysicist; their interpretation remains a complex puzzle.

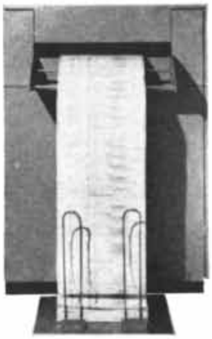
These are the longest electromagnetic waves known. Some stretch out 18,600,000 miles, and the upper limit is still undefined. Despite their great length, the term micropulsation is applied due to their small amplitude. With the development of highly sensitive optically pumped magnetometers they can now be easily measured. Varian supplies these instruments to geomagnetic observers all over the world for use on land, on arctic ice, deep in the ocean, and in outer space.

It is now possible to record total magnetic intensity and detect variations in the magnetic field equal to 1 part in 5,000,000. Using the principles of optical pumping, the versatile new Model V-4938 rubidium magnetometer achieves this extreme sensitivity across a wide band of frequencies. Information can be recorded directly on paper chart or magnetic tape, or it can be transmitted from the observatory site to your data center.

Many scientists will use magnetometers in their studies during the magnetically quiet, but scientifically active, International Year of the Quiet Sun. Would you like additional technical information? Write Sheldon Breiner, Instrument Special Products.

Why NCR is No.1 in Total System Capability.





Executives well-informed in the ways of electronic computers know that an EDP system is only as good as the input machines where the processing cycle begins. Input equipment must be fast, simple, easy to operate or the speed and efficiency inherent in the computer is limited. In computer jargon, this is called "input limited." □ Many EDP manufacturers have great difficulty in solving their "input limited" problems. Since they haven't been in the business of manufacturing a complete line of input machines, as NCR has, they must usually rely on duplicating data in a second operation with other devices. □ NCR is not "input limited." And NCR's answer is the most practical and economical. All NCR original entry equipment... cash registers... adding, bookkeeping and accounting machines... can be linked to an NCR electronic computer system —or even someone else's computer. NCR takes you all the way—captures the necessary information for linkage to a computer as a by-product of recording the transaction at the source. □ For example, the On-Line Savings System for banks. The teller's machine (input device) is linked directly to an NCR 315 Computer (maybe miles away) that instantly verifies a transaction, transmits data back to the teller's machine which then updates the passbook (output). One uninterrupted process that takes only seconds. This is an excellent illustration of what we mean by total system capability. □ Also, a retail store can now automate their sales records, inventory and accounts receivable... and data enters the system when the sale is recorded. For example, as a by-product of recording sales, punched paper tape or optical journal is produced which can be processed directly by a computer. □ NCR users do not have to duplicate original entry information. □ NCR users are also dealing with a company that has been designing business systems for over 80 years. Experience that counts for a lot in creating the total system "software package" that goes with an NCR EDP System. COBOL and NEAT, for instance, and other advanced programming techniques are available now. And 7500 servicemen keep NCR products "on the air." □ If you're in banking, industry, retailing, government or education and thinking EDP, think in terms of total system and call your local NCR representative or NCR, Dayton 9, Ohio. □ And see the NCR Pavilion at the World's Fair, New York.

NCR

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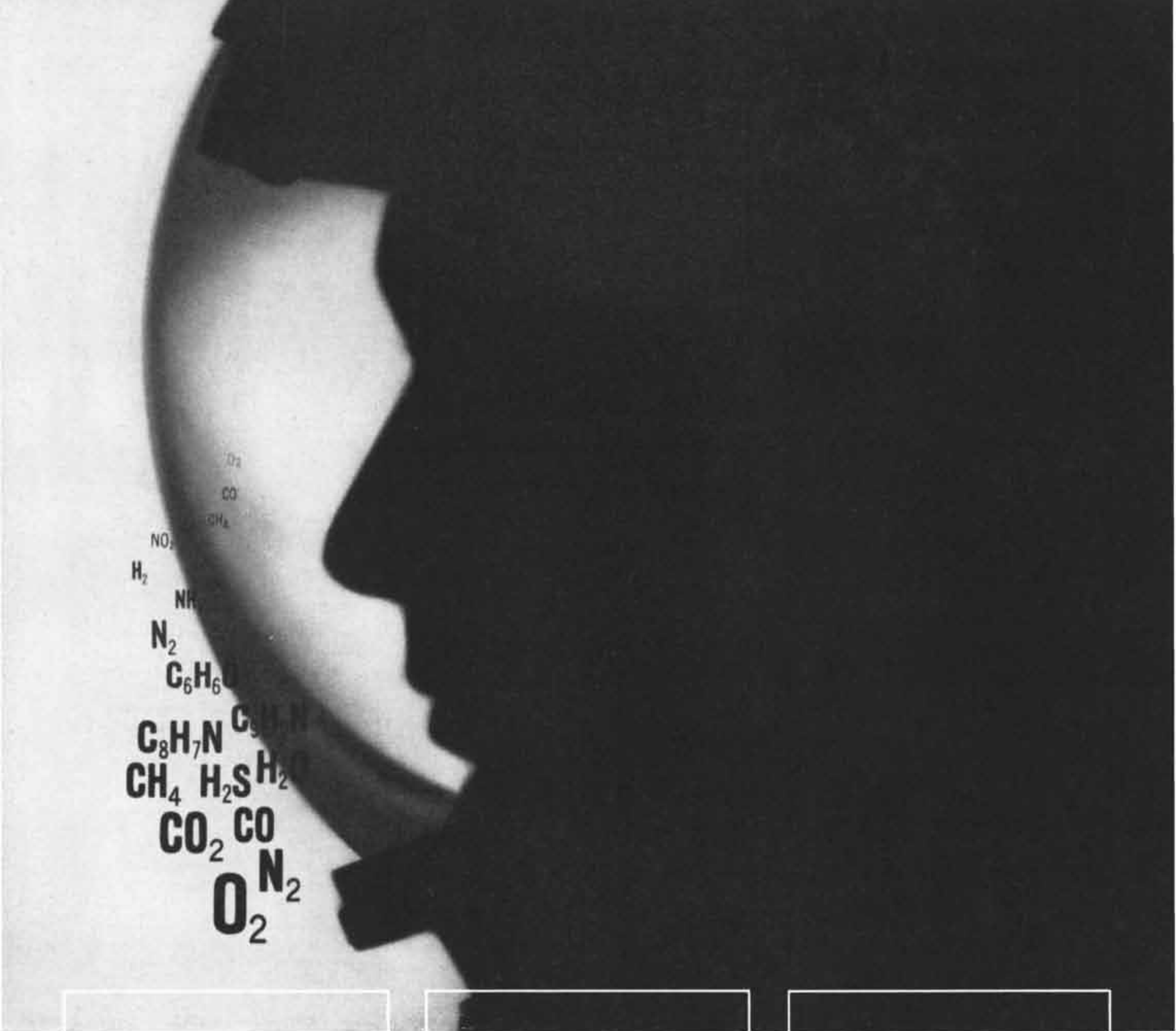

CO
H_2
N_2
C_8H_7N
CH_4 H_2S
CO_2 CO
O_2 N_2

THE AUTHORS

FRANK B. BRADY ("All-Weather Aircraft Landing") is director of the airport equipment programs in the Research and Engineering Branch of General Precision, Inc. Brady studied radio and electrical engineering at the University of Cincinnati from 1933 until 1939, when he joined the Aircraft Radio Laboratory at Wright Field in Dayton, Ohio. At Wright Field he helped to develop ultrahigh-frequency and microwave equipment for aircraft approach and landing. This work led to an assignment as project engineer for the development of the airborne-receiver portion of an early military version of the present Instrument Landing System (ILS). In 1943 Brady directed the establishment of a prototype all-weather airway from Mitchel Field in New York to Harmon Field in Newfoundland. In 1944 he was sent to Europe by the Aircraft Radio Laboratory to conduct joint British-U.S. trials on the first complete prototype of ILS. These tests resulted in the adoption of this system by the U.S. Strategic Air Force in Europe and by the Royal Air Force. After the war Brady returned to Wright Field, where he continued his work on electronic navigational and instrument-landing aids. In 1946 he became a member of the original Air Navigation Traffic Control Group of the Air Transport Association. During his 10-year stay with this organization he helped to introduce ILS into commercial airline operations and formulated national and international standards for electronic and visual aids to air navigation. Brady joined the staff of General Precision in 1957.

A. I. BRAUDE ("Bacterial Endotoxins") is professor of medicine at the University of Pittsburgh School of Medicine and director of microbiology at the Presbyterian-University Hospital. Braude received a B.S. and an M.D. from the University of Chicago in 1937 and 1940 respectively. During World War II he served in the Army Medical Corps as a medical laboratory officer in India and in the Caribbean area. After the war he did research on the causes of undulant fever and other infectious diseases in the laboratory of Wesley W. Spink at the University of Minnesota, where he received a Ph.D. in 1950. He taught medicine at the University of Michigan from 1950 to 1953, when he was appointed associate professor of medicine at the Southwestern Medical School of the University of Texas. During this period he also worked as a bacteriologist at Parkland Memorial Hospital in Dallas. He joined the Pittsburgh faculty in 1957.

JAMES R. WEEKS ("Experimental Narcotic Addiction") works in the Pharmacology Research Laboratories of the Upjohn Company in Kalamazoo, Mich. After obtaining a B.Sc. in pharmacy from the University of Nebraska in 1941, Weeks served for four years as an officer in the Army Chemical Warfare Service. He returned to the University of Nebraska after the war and received an M.S. in pharmacology there in 1946. He acquired a Ph.D. in pharmacology from the University of Michigan in 1952. Weeks joined the faculty of the College of Pharmacy at Drake University in 1950 and was professor of pharmacology at that institution when he left to become a research associate at Upjohn in 1957. In addition to his work on narcotic addiction, Weeks does research mainly on hypertension and artificial heart stimulants.

REGINALD E. NEWELL ("The Circulation of the Upper Atmosphere") is assistant professor of meteorology at the Massachusetts Institute of Technology. Newell was born in Peterborough, England, in 1931 and received a B.Sc. in physics from the University of Birmingham in 1954. He came to this country in 1954 to study meteorology at M.I.T., where he acquired an S.M. and an Sc.D. in 1956 and 1960 respectively. His doctoral work was on the application of weather-radar and radioactive-tracer information to the study of large-scale atmospheric circulation. He took up his present post in 1961.

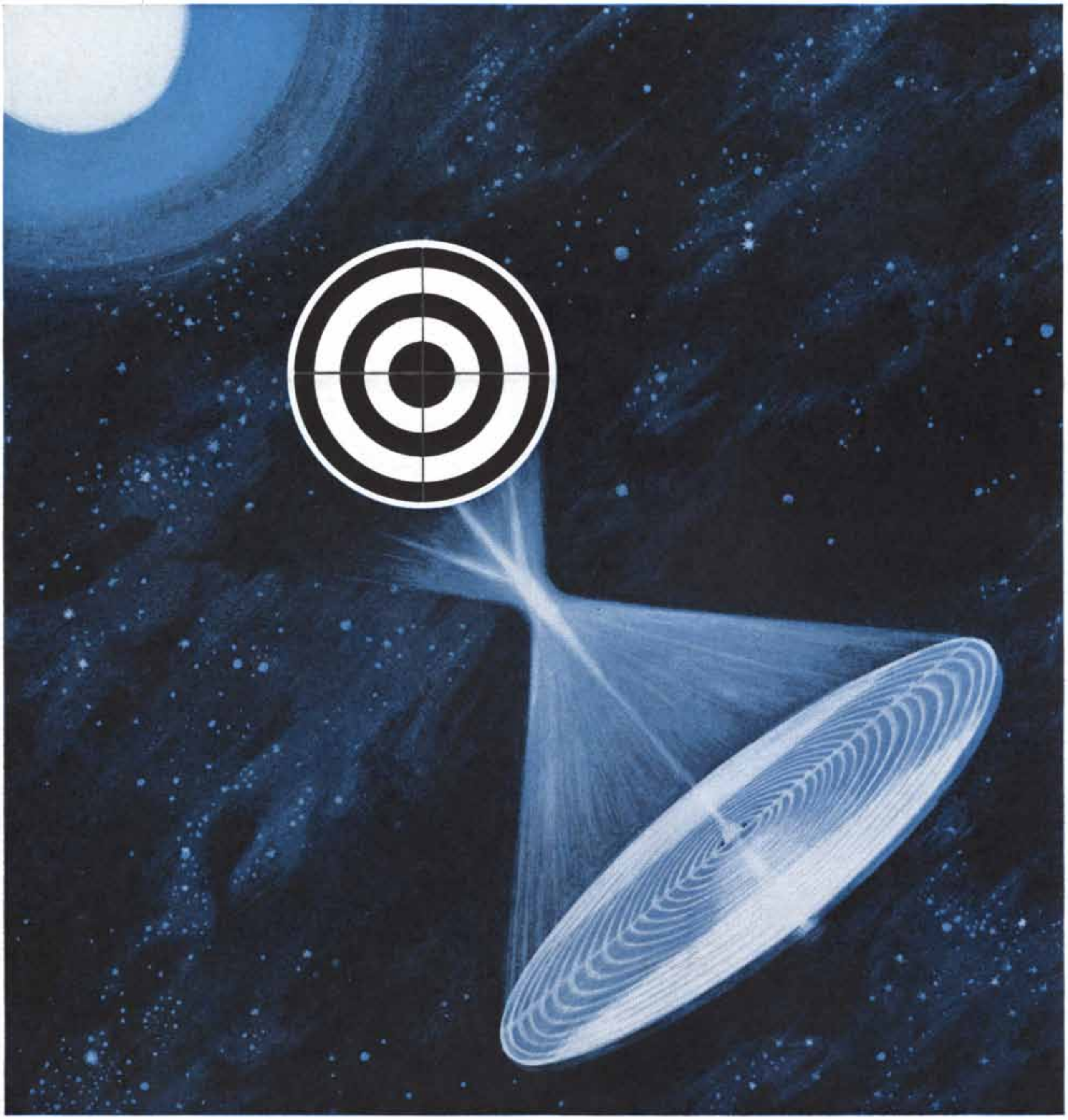
LAWRENCE CRANBERG ("Fast-Neutron Spectroscopy") is professor of physics at the University of Virginia. Cranberg was graduated from the City College of the City of New York in 1937 and acquired an A.M. from Harvard University in 1941. He received a Ph.D. in physics from the University of Pennsylvania in 1949. From 1940 to 1946 Cranberg worked as a physicist at the Engineering Laboratories of the U.S. Army Signal Corps in Belmar, N.J., where he helped to develop infrared communication and detection devices for military use as well as an experimental infrared obstacle-detector for the blind. In 1950 he joined the staff of the Los Alamos Scientific Laboratory, where the system for fast-neutron spectroscopy described in the present article was put into operation.

BENTON J. UNDERWOOD ("Forgetting") is professor of psychology at Northwestern University. A graduate of Cornell College in Iowa, Underwood received an M.A. from the University of Missouri in 1939 and a Ph.D. in psychology from the State University of Iowa in 1942. He taught experimental psychology at George Washington University from 1945 to 1946, when he joined the Northwestern faculty. From 1953 to 1957 he was a member of the research evaluation panel of the National Science Foundation.

ALBERT B. STEWART ("The Discovery of Stellar Aberration") is professor and chairman of the department of physics at Antioch College. He is also chairman of the educational policy committee at Antioch. A graduate of Antioch, Stewart acquired a Ph.D. in physics from Johns Hopkins University in 1948; he joined the Antioch faculty later that year. His own research has centered mainly on audio-frequency oscillations generated by gaseous conductors. He became interested in the subject of the present article, he writes, "when a persistent student in a course I was teaching for upper-class students of the humanities and social sciences made me uncomfortably aware that I did not know just how Bradley made his observations that established aberration to a half-second of arc."

W. R. A. MUNTZ ("Vision in Frogs") is a research fellow at St. Catherine's College of the University of Oxford. He also works at the Institute of Experimental Psychology at Oxford. A native of New Zealand, Muntz acquired a B.A. and a D.Phil. from Oxford in 1958 and 1962 respectively. His summers as a student were spent mostly at the Zoological Station in Naples doing research on the behavior of the octopus; he received his doctorate on the basis of this work. In 1961 he spent six months at the Research Laboratory of Electronics at the Massachusetts Institute of Technology, where he first became interested in frog vision. His research at Oxford on the development of vision in various amphibians is supported in part by the Nuffield Foundation and also by the U.S. Office of Naval Research.

MAX BLACK, who in this issue reviews Aldous Huxley's *Literature and Science*, is Susan Linn Sage Professor of Philosophy at Cornell University.



on target with solar power — America scored a space first when the Air Force successfully launched its Project EROS (Experimental Reflector Orbital Shot) and orbited the world's first solar collector. Built by Allison, the collector unfolded itself in space . . . was kept aligned with the sun's rays for about one minute during each orbit by a single-axis sun tracking system. The intense heat built up by the collector provided proof-of-principle data that energy collected in space can operate Allison research devices like the Stirling engine and liquid metal cell. The ability to turn principle into practice is another talent that keeps our other programs . . . including significant aerospace and nuclear projects . . . on target.

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All-Weather Aircraft Landing

Jet aircraft are now routinely landed with the help of instruments when visibility is only half a mile. The traditional goal of fully automatic landings under any conditions, however, is still elusive

by Frank B. Brady

On September 24, 1929, James H. Doolittle landed a Navy training plane at Mitchel Field on Long Island solely by reference to instruments. Many people thereupon assumed that the problem of "blind landing" had basically been solved. Now, more than three decades later, any experienced air traveler has been delayed often enough by bad weather to know that this conclusion was, to say the least, premature. In spite of the many remarkable advances that have been made in aircraft instrumentation, Doolittle's feat is still not routinely performed.

A comparison of his landing with a typical bad-weather landing by one of today's jet transports will help to explain why. Doolittle's aircraft, a highly maneuverable single-engine biplane, weighed only a few thousand pounds. His cockpit was fitted with an opaque hood that effectively prevented outside vision. Doolittle was not alone, however: another experienced pilot sat in an open cockpit ready to take over if anything went wrong. Although the flight procedure was simple, it required the utmost skill with the instruments then available. Doolittle descended to about 200 feet and aligned his aircraft carefully on a radio beam while in level flight. After passing a radio marker at the edge of the landing field he descended at 600 feet per minute until the altimeter showed 50 feet. He then flattened his angle of approach so that he could touch down at 400 feet per minute on a broad, level, grassy field. Doolittle himself described the final approach and landing as "sloppy."

The commercial jet transport weighs more than 200,000 pounds and, compared with the little trainer, responds somewhat more slowly to its controls. The pilot has full responsibility for the safety of perhaps 150 people, which does not add to what one British airline pilot aptly called his "tranquillity of spirit." He approaches the airport at 175 miles per hour, sinking at a rate of nearly 700 feet per minute. Another jet is probably landing just ahead of him and another is behind. He is not engaged in an experiment—he is on instruments because the weather is bad. The approach and landing are intricate operations in which the pilot checks off dozens of instrument readings and control settings on a long list, including the lighting of the "No smoking" and "Fasten seat belt" signs. He has to refer to a complex approach chart [*see illustration on page 34*], concentrate on instructions from the airport control tower and continue to observe his instruments. He is prepared to react to sudden gusts of wind and other unpredictable events. Even at the best-equipped airports he is permitted to continue his approach only if he can see enough on reaching an altitude of 200 feet to complete his landing visually. There is no question of landing on a broad field—his huge craft is either lined up with the center of the 150-foot-wide runway or he must pull up.

Near the threshold of the runway and less than 10 seconds from touchdown he begins a "flare" maneuver by curving the flight path to make his angle of descent almost horizontal and to lessen the rate of descent to 200 feet per minute. One or two seconds before touchdown he must usually "kick out drift," or "decrab," in order to turn the aircraft away from its position facing somewhat into a cross wind and to line it up perfectly with the runway. He hits the ground at 135 miles per hour.

Safety, of course, is the most important consideration in aircraft landing. Had Doolittle's procedures and equipment been applied to routine operations flown by pilots of varying degrees of skill and under adverse weather conditions, it is likely that accidents would have resulted—perhaps one in 1,000 such landings. In terms of the present tremendous volume of aircraft operations, which in the U.S. includes more than a million instrument approaches each year, such an accident rate would be totally unacceptable. An analysis of accidents involving scheduled air carriers in the U.S. during 1959, 1960 and 1961 has shown that more than 20 per cent of all major landing accidents took place during less than 2 per cent of the time, when ceiling and ground visibility were near the minimums permitted. In 1963, however, not one of the total of four fatal accidents from all causes involving scheduled air

APPROACH AND RUNWAY LIGHTS at Kennedy International Airport in New York were photographed on a clear night. The groups of five lights in the lower three-quarters of the photograph are approach lights. Flashing lights of the approach lane do not show. The runway is marked by edge lights and by the "narrow gauge" pattern of three lights on each side of the center. The latter are flush with the pavement, as are the center-line lights that here begin where the narrow-gauge lights stop. Dim lights curving to left off center line mark route to taxiway and help the pilot to clear the instrument runway quickly for the next aircraft.

carriers in the U.S. appears to have been related to poor visibility during landing. This is an impressive record.

The vast improvement in sensing, communication and control devices for aircraft since 1929 has been matched by the explosive growth in the quantitative aspects of air transport: the number, speed, size and complexity of aircraft. Although it has been made possible for even the fastest modern airplanes to land with lower and lower ceilings and less and less visibility on the ground, true blind landing not only has never become routine but also is not expected to be routine in the near future. Nonetheless, experimental automatic landings are made successfully almost every day with many types of aircraft. Further improvement in electronic systems, visual aids, instrumentation, weather reporting and pilot training will make safer landings possible under even poorer visibility conditions. Eventually pilots may accept fully automatic landing if they are convinced of its reliability and if they have dependable instruments that enable them to monitor the entire operation visually so that they can intervene when necessary.

Before any new systems can be placed in operation, however, difficult economic and administrative barriers must be overcome. The cost of equipment for automatic landing rises almost exponentially as the capability approaches true blind landing. Possibly even more important, all instrument-landing systems require a high degree of technical compatibility between ground and airborne equipment. Even a minor improvement may involve conferences among the 101 nations that belong to the International Civil Aviation Organization, followed by changes at hundreds of airports and in thousands of aircraft. Because of the global character of air operations standardization is often preferable to technical improvement.

In aircraft and airports throughout the world the basic approach system is ILS; the letters stand for Instrument Landing System, a misnomer because by itself it does not enable the pilot to land blind. Rather, it provides him with information he needs for a blind approach to the airport. ILS grew out of developments that began before World War II.

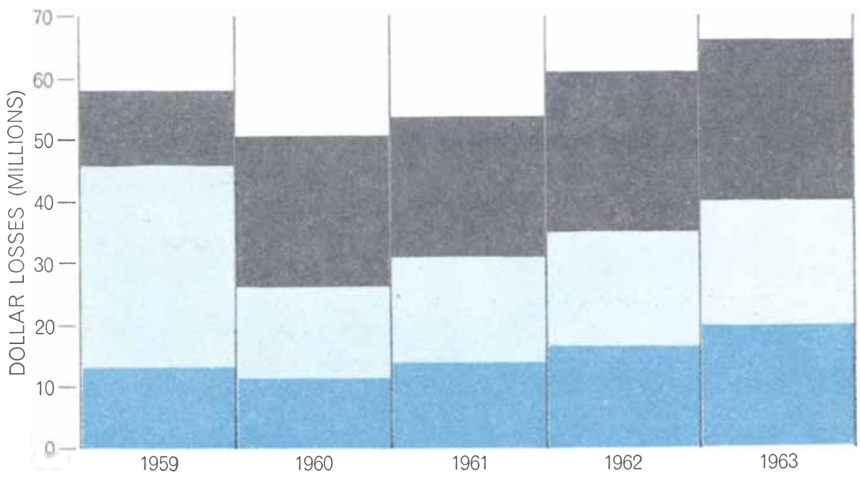
Several elements make up the system. The first is a "localizer" course—a radio beam formed by two audio-modulated, overlapping frequency patterns projected along the center line of the runway. The pilot normally attempts to intercept the beam six to eight miles from the touchdown point, at an altitude of 1,000 to 1,500 feet. About five miles from touchdown the aircraft reaches the "outer marker," a radio beacon that turns on a slowly flashing purple light on the instrument panel and produces a distinctive tone in the radio headset. This notifies the pilot that he should be picking up the second major element of ILS: the "glide slope," a radio beam defining a straight descent path to the runway. In the cockpit a single instrument, known in its simplest form as the "cross-pointer indicator," shows the pilot his position in relation to the localizer and glide-slope beams [*see top illustration on page 30*]. At a height of about 200 feet a rapidly flashing amber light goes on and another tone sounds in the headset, informing the pilot that he is passing the middle marker. Here, with 15 to 20 seconds and less than a mile to touchdown, the pilot must be able to go off instruments and proceed by sight or he has to pull up. (The U.S. has elected not to use an inner marker.)

A product of wartime is Precision Approach Radar (PAR), also known as Ground Controlled Approach (GCA). It is now available at many of the busier airports. A complete approach system in itself, it can be used independently of ILS. It consists of two radar systems, each with a flat "fan" beam. One swings like a diving board through a vertical arc, the approximate midpoint of which defines the angle and path of descent. Radar echoes returned from the aircraft appear in the control tower on a radarscope in an elevation view that shows the position of the plane in relation to the desired descent path. The other radar beam swings like a ship's rudder through a horizontal arc. Its echoes are presented in a separate display on the same radarscope, showing a plan view of the position of the aircraft with respect to the center line of the approach path. The controller in the tower can detect even minor deviations from the correct path and also the distance of the aircraft from touchdown.

When PAR is the primary approach system, the controller gives the pilot a running verbal account of his deviations from the correct flight path and provides him with heading and descent information that will return him to the correct path. When used with ILS, PAR serves as a monitor and the controller advises the pilot whenever he has strayed too far from the path.

When it became apparent after World War II that routine blind landings of commercial transports would not be feasible in the near future, new emphasis was placed on visual aids for the pilot at the airport. Numerous lighting systems were proposed, and after a surprising amount of controversy one was finally adopted. In the U.S. the system consists of a series of 14-foot bars, each bearing five steady lights, spaced 100 feet apart for a distance of 3,000 feet from the start of the runway. The bars are mounted at right angles to the center line of the runway; under present minimum weather conditions they should come into view before the aircraft reaches the middle marker.

On a line with the steady lights is a series of high-intensity flashing lights that go on and off in such a way that they give the illusion of a white-hot ball racing down the lane of approach



ESTIMATED MONETARY LOSSES to airlines resulting from flight-schedule disruptions by bad weather are shown for five years. Losses in passenger revenue due to decreased demand are shown in gray. The costs of landing accidents are given in light color and increased costs due to flight delays, cancellations and diversions are shown in dark color.

lights to the threshold of the runway. The "ball" makes the 3,000-foot trip twice a second. Its purpose is to assure the pilot that he is seeing approach lights and not some other kind.

The bright approach lights caused pilots to complain that in bad weather the runway itself was a "black hole," delineated only by relatively dim lights along its edges. New standards call for lights flush with the pavement of the runway, both along its center line and in what is called a narrow-gauge pattern. This pattern consists of two rows of medium-intensity lights parallel to the center line at a distance of 30 feet on each side of the line and spaced at 100-foot intervals. So far only a few airports have complete installations. The center-line lights are also used to guide the pilot off the runway onto the taxiway to the terminal, an important contribution to clearing the instrument runway for the next airplane [see "Air-Traffic Control," by Seymour Deitchman and Alfred Blumstein; Scientific American, December, 1960].

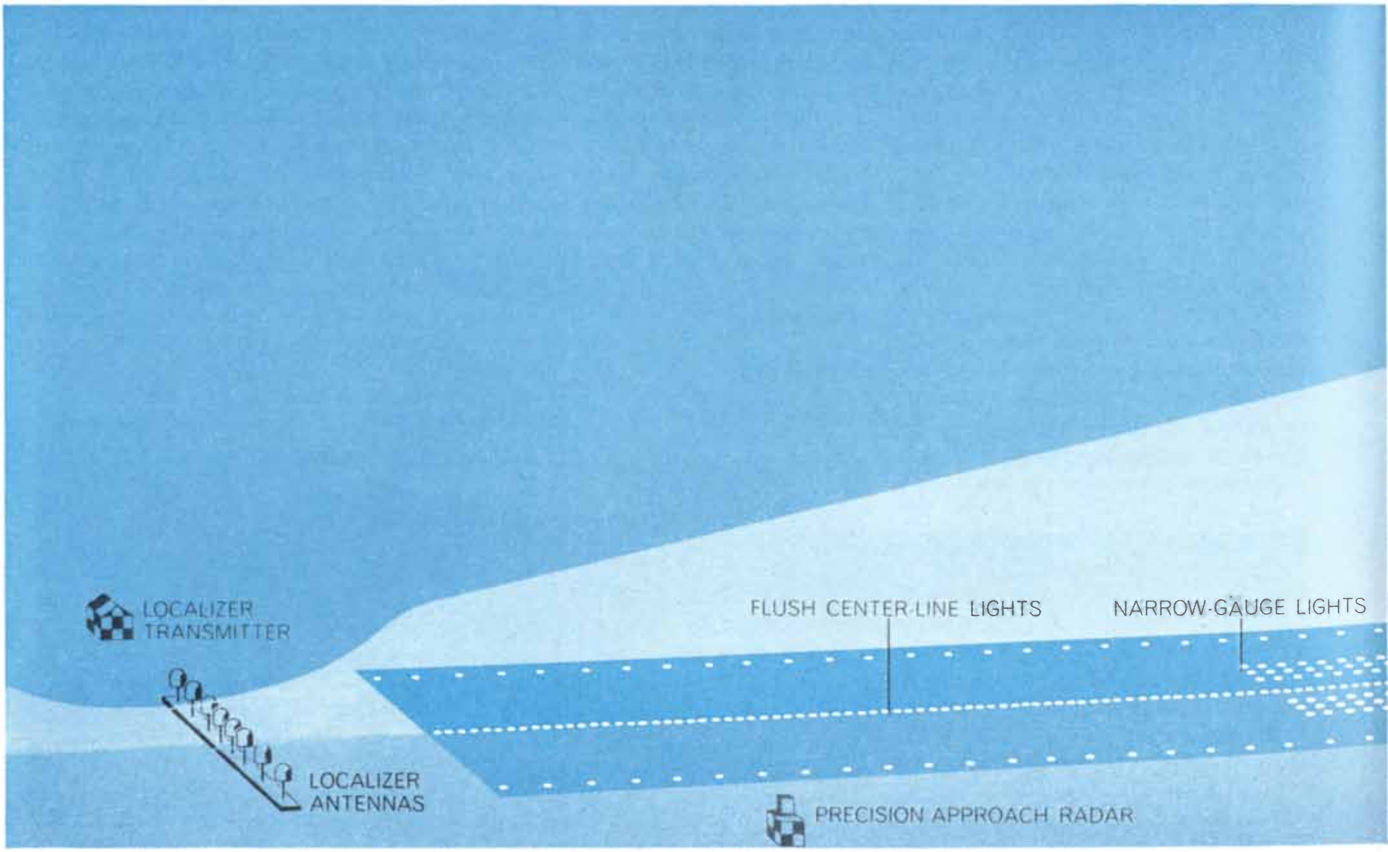
In addition to the lights, various bold patterns of parallel stripes, dashes and other markings are painted on the runway to identify it, to show the center line and the edges of the runway and distances along it. Under certain daytime fog conditions these patterns can be seen when lights are completely ineffective.

If a pilot is to make an instrument approach in minimum weather, he must know in advance the conditions he can expect when he breaks through the ceiling. Two ground devices—a ceilometer for measuring the height of the ceiling and a transmissometer for determining visibility distance along the ground—provide most of this information.

The rotating-beam ceilometer, which is near the middle marker, employs a narrow searchlight beam that rotates in a vertical plane. On the ground about 400 feet away a photosensitive detector is aimed at the zenith. As the beam sweeps overhead, fog or low clouds reflect its light to the detector. The height of the ceiling, which is the bottom of the cloud or fog, determines the angle of the beam. As the ceiling drops, the beam will be at a lower angle to the horizontal when the detector registers the maximum amount of reflected light. The height of the ceiling is then derived by triangulation from the known angle of the beam and the distance along the ground from the searchlight to the detector.

The transmissometer consists of a horizontal light projector aimed at a detector 500 feet away on a line parallel to the edge of the runway. The detector compares the amount of light it is receiving with the amount it receives under ideal conditions, and the resulting figure is converted to range of visibility. Both the ceilometer and the transmissometer operate by day as well as by night.

As the problems of making runways more visible were being solved, development engineers did not give up the idea of automatic approach and landing. Thinking in such terms yielded an unexpected bonus in improved instrumentation for manual flight. The system, known as Flight Director, uses ILS transmissions and relieves the pilot of much of the strain of manual instrument approach. One of the two Flight Director instruments shows the aircraft heading and the displacement from the localizer beam. The other instrument



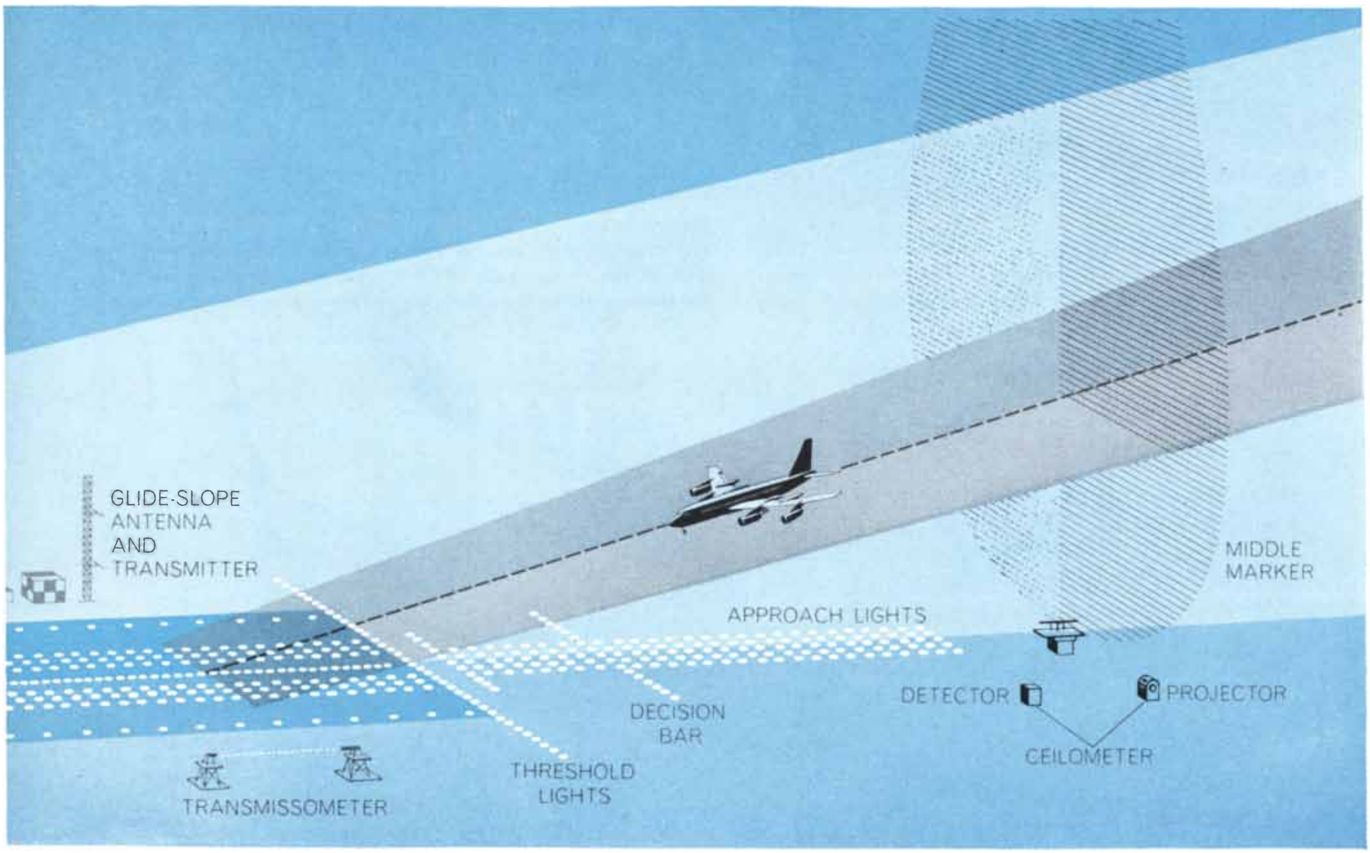
COMPLETELY EQUIPPED RUNWAY, as shown in this diagram, is used by jets landing with a minimum ceiling of 200 feet and minimum visibility along the runway of half a mile. The localizer beam is represented by lightest color and the glide-slope beam by light gray. The middle marker is shown by hatching. These radio beams are part of the Instrument Landing System

resembles the older attitude indicator known as the artificial horizon but includes pointers that tell the pilot how much to tilt the nose of the aircraft up or down or to steer right or left in order to get onto the localizer beam and glide slope. Thus the pilot always knows his position in relation to the approach course as well as what he must do to get on course. This frees some of his attention for dealing with other matters. Flight Director is now standard in most airline jets. It is a prerequisite for permission to land at the lowest ceiling and visibility minimums unless the automatic pilot has been coupled to the ILS instruments for the approach.

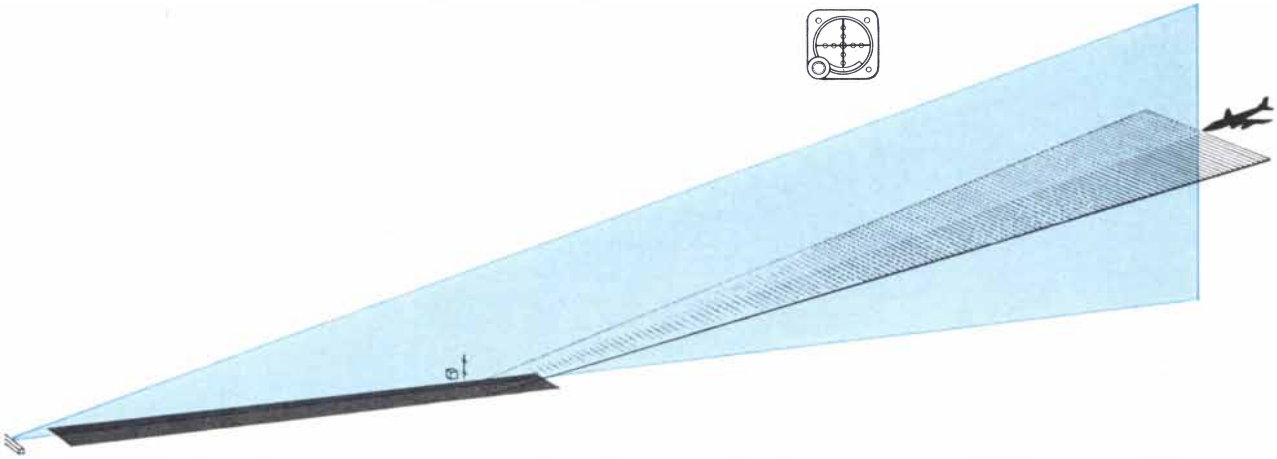
Recently two systems that depend on ILS transmissions have been developed in an attempt to solve the critical problem of the transition from instruments to visual flight at the low altitude of 200 feet. One system presents the pilot with a pattern of lines, apparently outside the windshield, to represent the runway center line and the horizon. By guiding the aircraft to keep a mark between two reference points the pilot can also follow the glide slope. The projected lines are in register with the actual runway when it finally comes into view.

The second version, developed in England, represents a completely new kind of instrument and is quite interesting from a psychological point of view. Called the Para-Visual Director, it consists simply of small units resembling barber poles, one mounted vertically at about shoulder height on each side of the pilot and one mounted horizontally below eye level in front of him. (A U.S. version uses only one composite unit in front of the pilot.) The side units rotate together, and through his peripheral vision the pilot sees them apparently moving either forward or backward. To get the plane on course and stop the motion, he simply moves the controls in the direction of apparent movement of the barber poles. The craft is then making the proper climbing or descending maneuver. The unit in front provides information for making the turn needed to bring the plane in line with the course; the pilot turns his wheel in the direction of apparent motion until this pole too stops moving. Surprisingly enough, the pilot never has to look directly at these instruments. He gets their message quite forcefully while looking at other instruments or out through the windshield. In the U.S. extensive tests are now being made with the Para-Visual Director, which has aroused considerable interest in a comparatively short time.

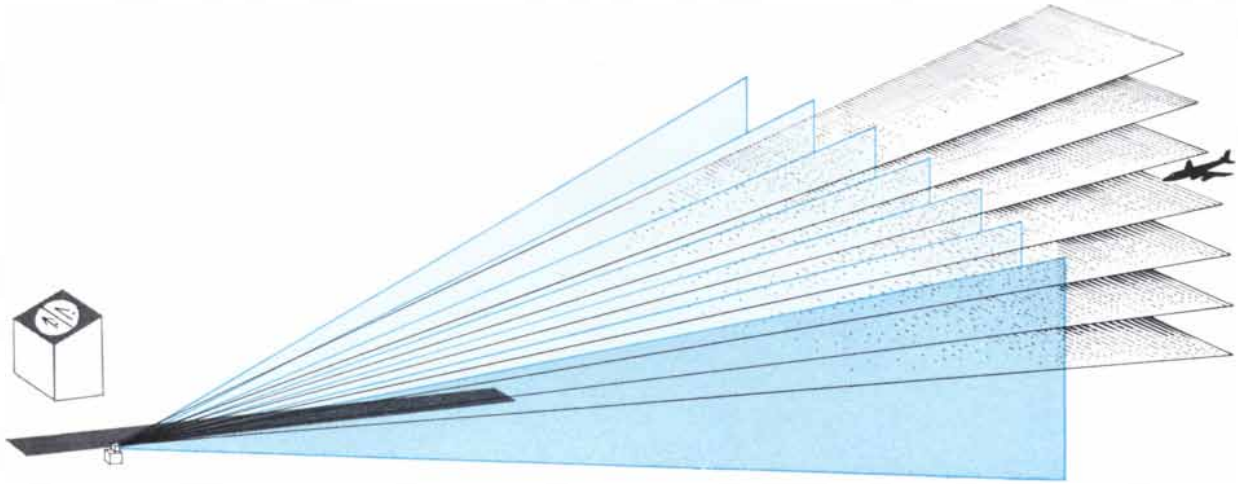
In addition to ILS and the instruments employing it, another device has played a key role in aircraft operations. This is the altimeter, a sensitive barometric device that has changed little since it was developed in the early days of flying. Just before descending, the pilot receives a barometer reading taken at the control tower so that he can set his altimeter to give an accurate reading near the ground. In the later stages of low approach this assures him that he is not descending below the minimum permitted height before seeing the ground. The barometric altimeter is frequently in error by as much as 40 feet under landing conditions, and more accurate instruments are needed for operations at lower minimums than those permitted at present. Experimental automatic landing systems now employ radio or radar altimeters, which can be made accurate to within one foot at low altitudes if there is a smooth surface



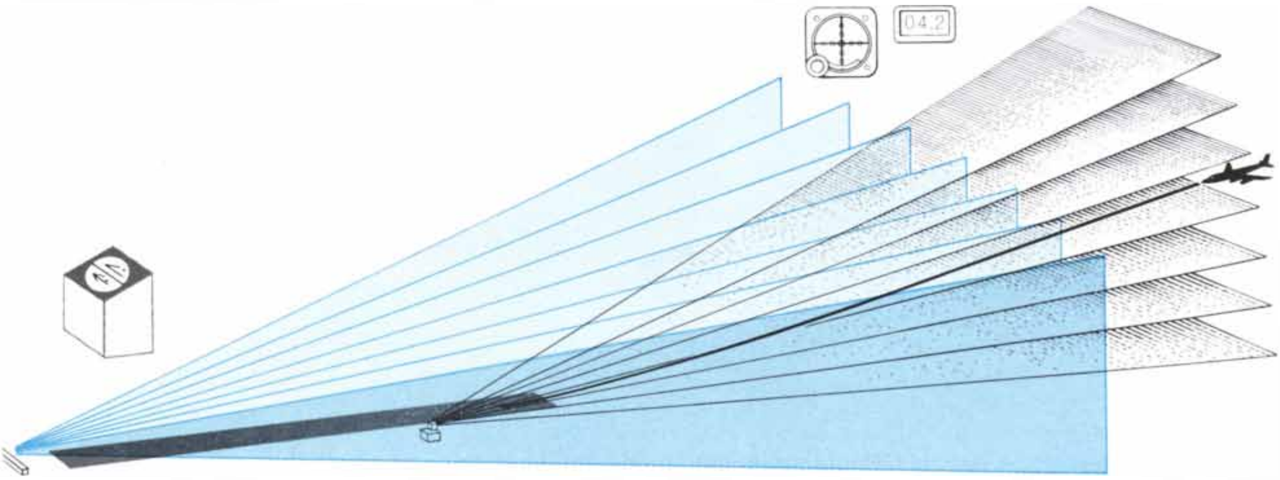
(ILS). The pilot must be able to see the approach lights when he is no lower than 200 feet or he cannot land. The ceilometer and transmissometer measure the height of the ceiling and the visibility distance along the runway. Precision Approach Radar (PAR) lets the control tower monitor approach of the aircraft and can be used by itself as an instrument-approach system.



INSTRUMENT LANDING SYSTEM was standardized throughout the world after World War II. The localizer beam (*color*) is used to line up the plane with the center of the runway. Glide-slope beam (*gray*) provides descent path to runway. Its tilt, which is only two or three degrees, is exaggerated here. At upper right is the ILS cross-pointer indicator, which is in the aircraft.



PRECISION APPROACH RADAR has horizontal scanning beam (*color*) and vertical scanning beam (*gray*). The radarscope shown at lower left is in control tower. There a controller can watch the progress of the aircraft and direct the pilot verbally to keep him on the correct path. PAR is used in conjunction with ILS for landings by jet transports in conditions of minimum visibility.



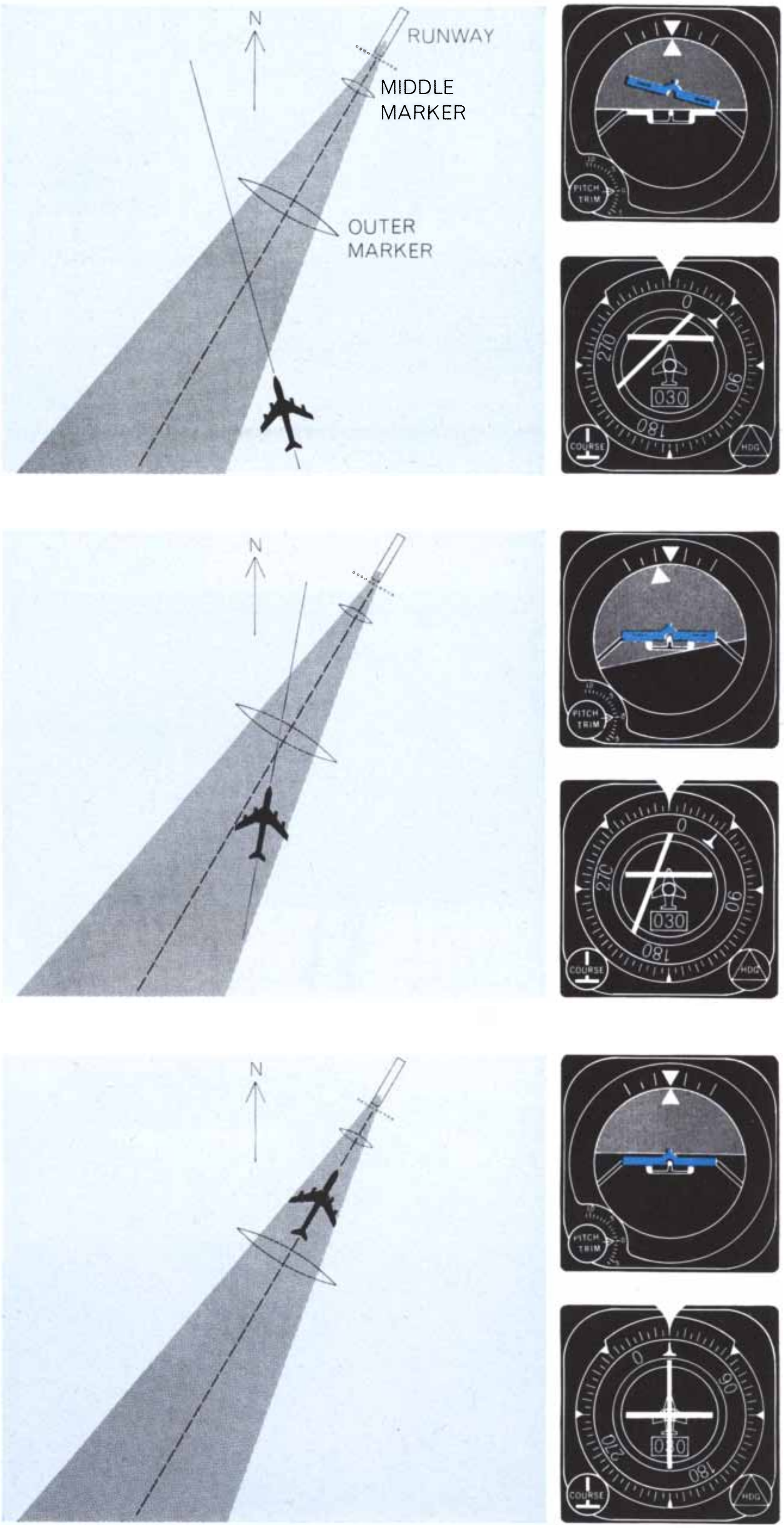
MICROWAVE SYSTEM, still experimental, would send out beams from fast-moving antennas. Each beam would carry pulses coded to tell angle of antenna at time beam was sent. Aircraft instrument on right at upper right shows distance of touchdown. Radarscope in control tower is shown at lower left. Heavy black line marks flare path programed into computer in the aircraft.

directly under the aircraft. For this reason they are used mainly over runways.

Aircraft engineers have long dreamed of using the automatic pilot, which became standard equipment in early transport planes in the 1930's, for automatic approach and landing. Actual touchdown landings were made with a radio-controlled autopilot as early as 1937, but the system was crude compared with today's requirements. The coupling device mentioned earlier, however, links the autopilot with ILS signals from the ground, making possible automatic approach. The landing itself still has to be accomplished visually and manually by the human pilot. Although several major airline fleets have carried coupling equipment for years, a lack of standardization has made its performance unpredictable. Criteria evolved recently have led to a program to standardize adjustment of both ground and airborne equipment. This program will guarantee the pilot an acceptable automatic approach in spite of great differences in airport characteristics and wide variations in wind conditions.

The introduction of automatic approach and landing into airline operations has been hampered somewhat by the pilots' understandable desire to maintain their landing proficiency. With operating costs of large jets now nearing $1,000 per hour, practice approaches and landings must be used to the best over-all advantage; there is some reluctance to give up a practice landing in favor of watching the automatic system do it. A pilot on long transcontinental or overseas flights can easily put in a full month of flying time with only a few landings, most of them not involving instrument approaches. Fortunately jet-transport simulators on the ground can now provide an astonishingly realistic imitation of all kinds of flying conditions and aircraft responses, and airlines often operate these units 16 hours a day to keep their pilots in practice.

When jet transports were introduced in 1958, the problem of bad-weather landing became acute. These huge, fast-landing airplanes originally were not authorized to land at the same visibility minimums as piston-engine craft. If the weather closed an airport such as New York (now Kennedy) International Airport, thousands of passengers were landed "nearby" in Boston, Montreal, Philadelphia and Baltimore. The expense and inconvenience of processing them through inadequate customs facilities, of feeding and lodging them and of arranging for ground transportation be-



FLIGHT DIRECTOR INSTRUMENTS are the Horizon Director Indicator (*upper right in each panel*) and Course Deviation Indicator (*lower right in each panel*). In top panel they show aircraft to right of glide slope, as seen in plan view from above (*left*). It is also below the slope. Command bar (*color*) of horizon indicator tells pilot to turn right and go up. Course indicator shows him his position in relation to glide-slope and localizer beams. In middle, the aircraft is almost on course. At bottom it is fully on course.

LOCALIZER-BEAM ANTENNAS of the Instrument Landing System send out radio signal in line with center of runway. These units are at far end of an instrument runway at Kennedy International Airport. They are low so as not to be obstructions.

COCKPIT OF JET TRANSPORT contains numerous complex instruments and controls overhead and on panel in front of pilots. The controls for the automatic pilot are between the two seats. The pilots cannot see what is above or directly below the aircraft.

came almost overwhelming. Passengers were bitter. The Federal Aviation Agency and the airlines together developed a program to lower jet-landing minimums to those of piston aircraft. This level of performance, called Airline Category I, has been achieved by improved pilot training, Flight Director instrumentation or automatic-approach equipment in aircraft and mandatory use of high-intensity approach lighting and runway lighting.

The next step, Airline Category II, will cut weather minimums to approximately half their present value. To achieve this level of performance many airlines will use automatic approach, although Flight Director can also reach the minimums. Both center-line and narrow-gauge runway lighting will be required, along with several transmissometers beside the runway rather than one. The training of pilots will also be more stringent than it is for Category I.

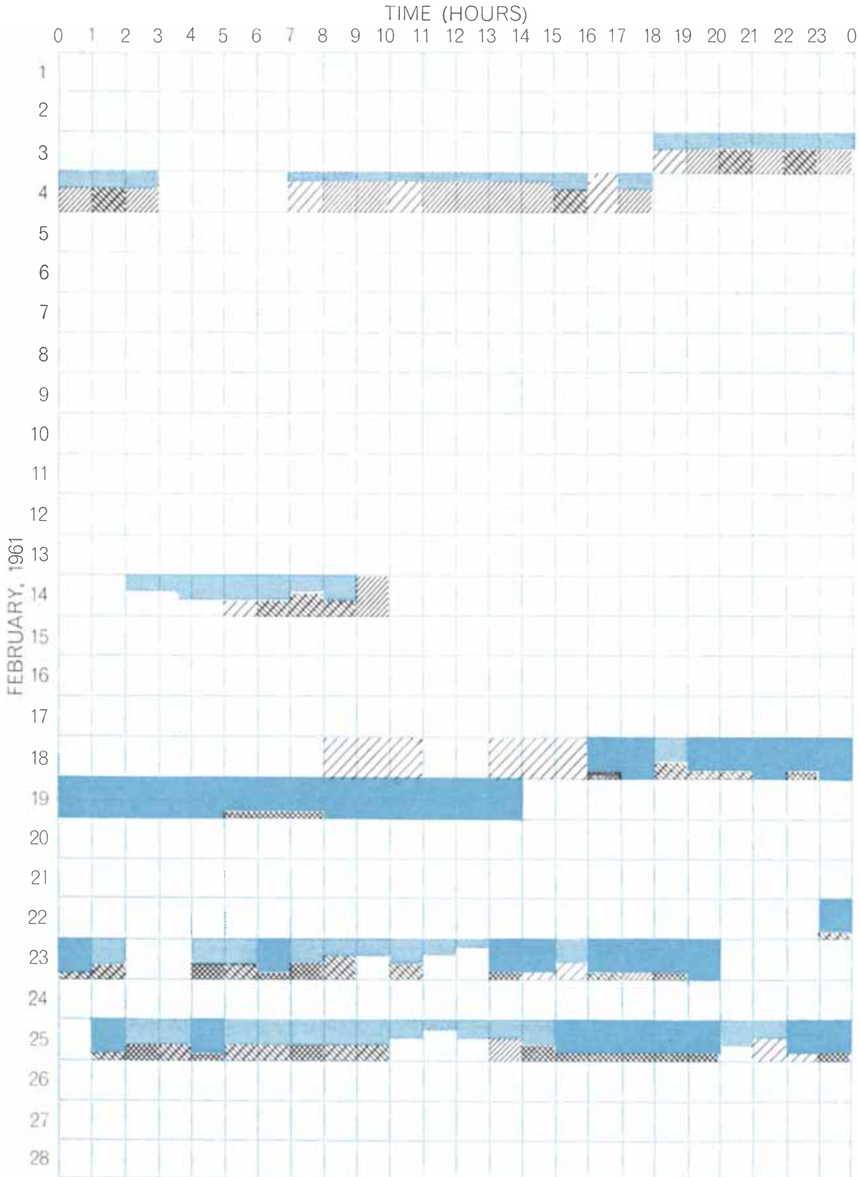
Category III is all-weather landing, and so far its requirements have not been fully specified. Of course there is always the question of whether or not it is economically sound to pay the tremendous cost of a foolproof all-weather landing system. Airports can be closed not only by zero visibility but also by high-speed cross winds and heavy snow or ice on the runways. Moreover, there is little point in landing at an airport when ground transportation is at a standstill.

If landings in Category III are adopted, however, the approach, flare, decrab, touchdown and possibly rollout will be performed automatically, perhaps with the pilot monitoring the events visually on electronic devices. Transmitters along the edge of the runway could signal the projection of images on the windshield corresponding to runway lights, so that the pilot would see the rudimentary outline of the runway in its true position and perspective.

A number of recent national and international conferences on all-weather landing have indicated a widespread opinion in favor of maintaining the present basic ILS system, of improving it without changing its fundamental characteristics. One technical development that will help is the use of a wave guide in transmitting the localizer beam. By confining the beam "spray" the wave guide can prevent reflections from hangars, power lines and other nearby radio obstructions that frequently cause the localizer course to bend. Aircraft flying overhead also produce confusing reflections; this problem is being solved with both wave-guide transmission and regulations that keep airplanes out of the sensitive region.

It has proved far more difficult to make the glide slope equally dependable at altitudes below 200 feet. The slope beam is particularly sensitive; for it to work all the way to touchdown calls for very level ground for a considerable distance around its transmitter. Most airports simply do not have such surroundings.

Thus the problem is whether or not the ILS system can be improved enough, without changing its world-wide standard characteristics, to meet the needs of today's fast, heavy jets and tomorrow's supersonic transports. In case it cannot, the FAA has sponsored a program to develop a highly precise microwave landing system. This system includes scanning antennas, one sweeping horizontally to provide a localizer path and the other vertically for glide-slope information. They send out pulses that are coded according to the angle of the antennas. Equipment in the aircraft decodes the pulsed signals to determine the precise height, azimuth and distance from touchdown. The system, operating at the extremely high frequency of 15.5 gigacycles (kilomegacycles), not only provides conventional instrumentation of the ILS type in the



HOURS OF BAD WEATHER at Kennedy International Airport in February, 1961, are indicated by color and hatching in the squares. Smallest amount of color denotes a 400-foot ceiling. Color comes down in square as ceiling drops. Hatching indicates less than a mile of visibility; increased density of hatching means that the range of visibility is proportionately shorter. Dark color and/or crosshatching signifies airport is closed.

cockpit but also has a precision-approach radar component for monitoring by ground controllers. The coded pulses enable the pilot to select the optimum approach angle and also allow the aircraft to follow a programed flare path to touchdown. It is so completely new that even after it is adopted the normal processes of budgeting, manufacture and installation will delay its widespread employment for several years.

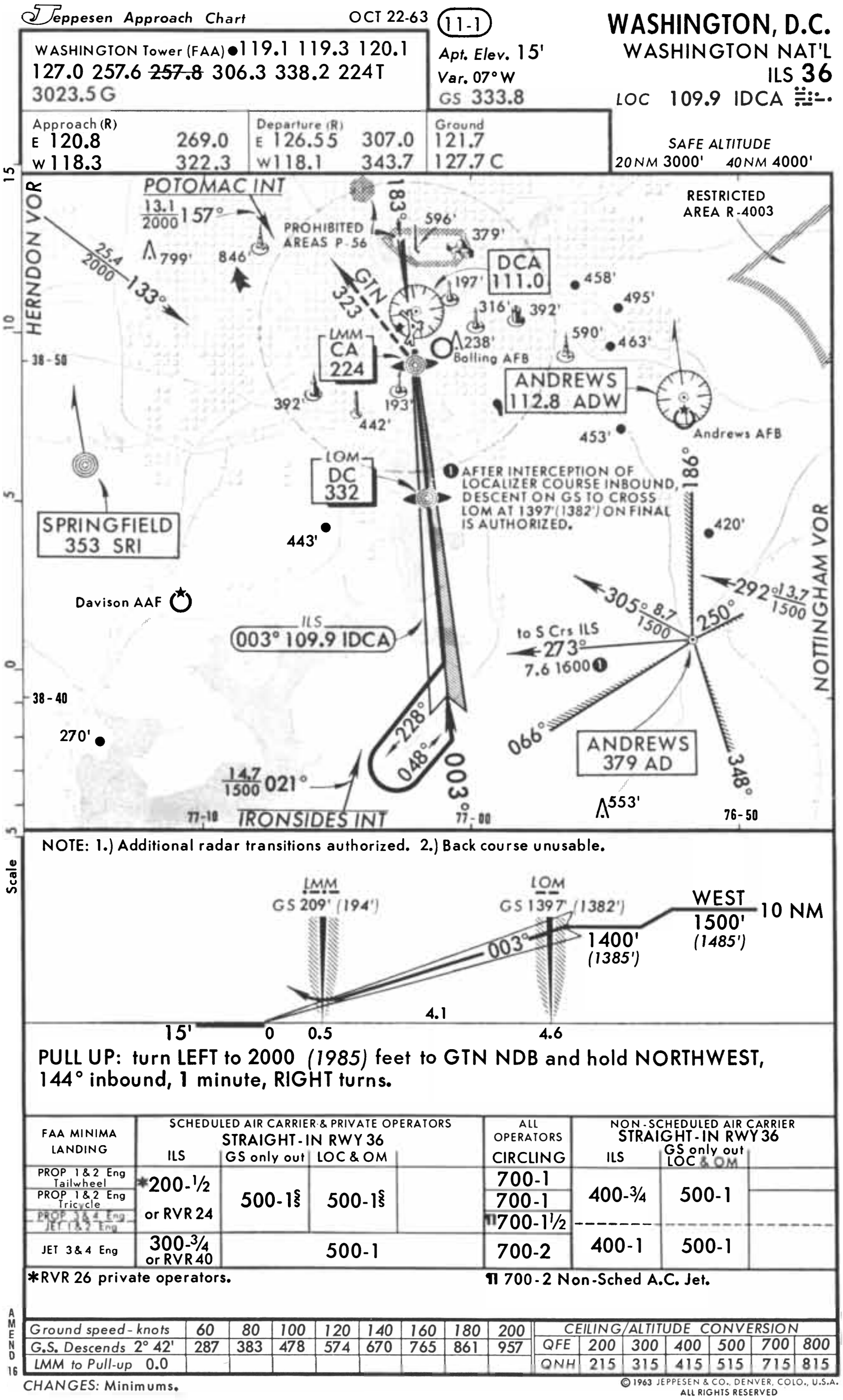
Fully automatic landing operating with existing ILS ground equipment has been brought to its highest degree of refinement in the "Autoland" system developed by the Blind Landing Experimental Unit in the United Kingdom. The frequency of foggy weather in the British Isles has been the inspiration for the work. The system brings the aircraft down to an altitude of 300 feet automatically on both ILS beams, after which the airplane continues under localizer-beam guidance but without the glide-slope signal. At an altitude of approximately 60 feet a radio-altimeter signal initiates flared descent to touchdown. Automatic throttle control reduces the power at the proper moment; the control system even decrabs the aircraft.

Autoland has directed thousands of automatic landings and is being installed in the new generation of British airliners as well as British military aircraft. The FAA had a Douglas DC-7 transport aircraft fitted with Autoland and brought it to the U.S. in 1962. The results of the testing program have been outstanding. A total of 1,149 fully automatic landings have been completed at 47 different airports equipped with ILS. The FAA plans to equip a large jet transport with the system for further tests. Autoland could well become the prototype landing system for U.S. airline jet fleets.

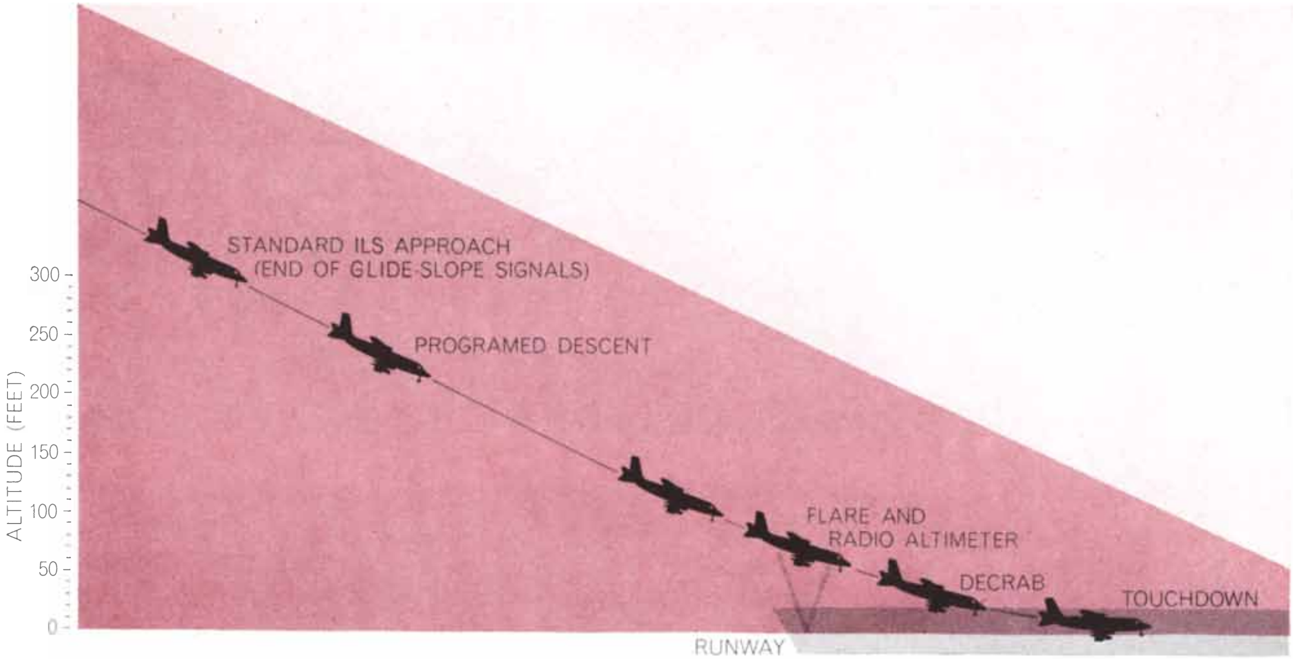
The essential elements of a successful assault on the all-weather landing problem are now available: a sound technical solution, a determined airline industry, a co-operative Government agency and a detailed step-by-step program of implementation. Lest this lead to unjustified optimism, however, it might be salutary to recall a paper presented in November, 1938, before the Air Transport Meeting of the Institute of Aeronautical Sciences in Chicago. The authors, Joseph Lyman and Francis L. Moseley, eminent in this field for many years, concluded:

"In reviewing the history of instrument landing, one now finds nearly all of the problems have been solved. Scheduled air transportation will soon be making landings under conditions of zero visibility. But development work does not cease there. Each part of the entire system must go through a constant refinement and simplification. The means of making instrument landing are all at hand. But we must learn how best to use them."

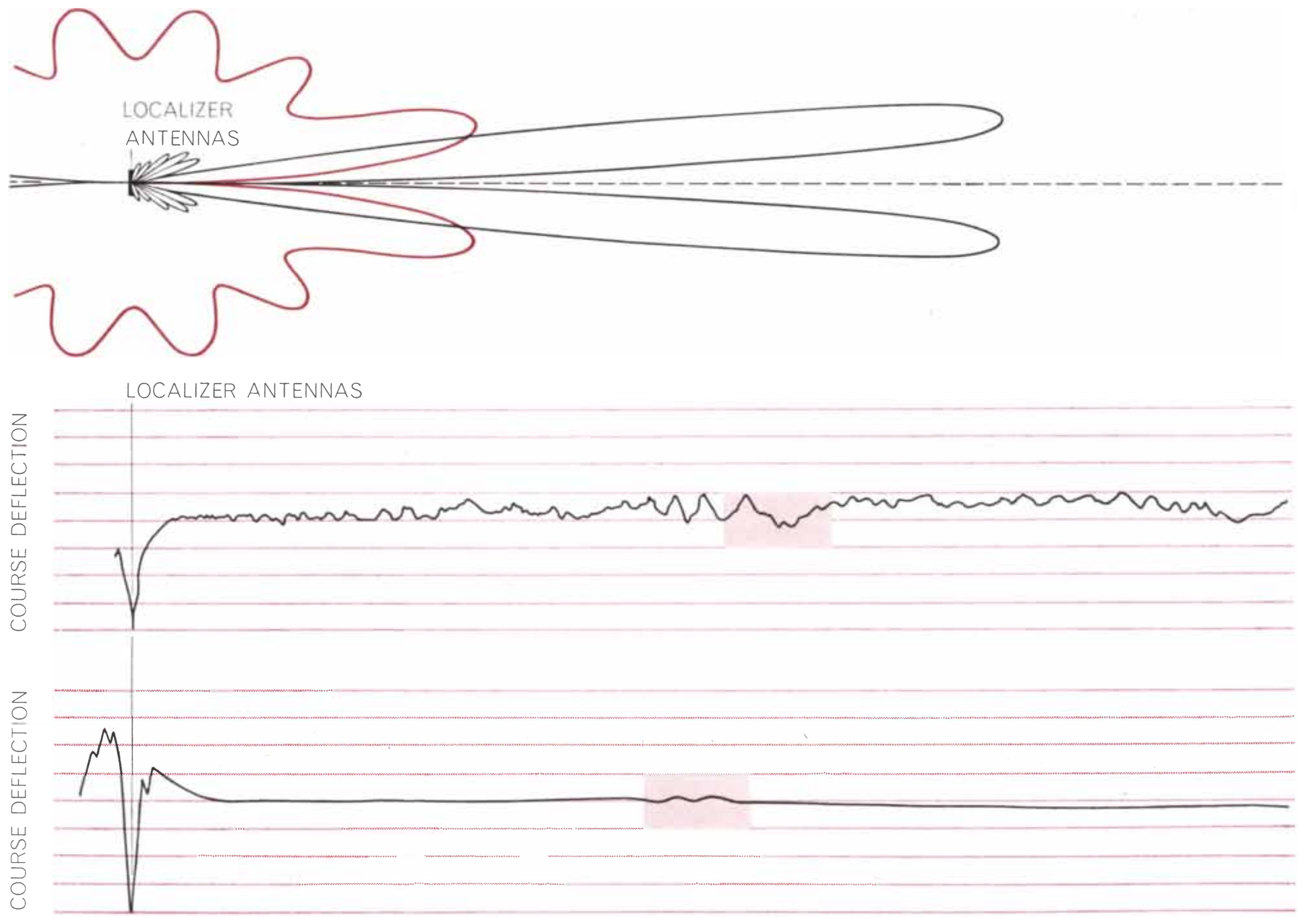
For 34 years the technology of all-weather landing has kept pace with the rapid advance of air transport. Nevertheless, the objective of the airlines to deliver passengers to their destinations on schedule in all kinds of weather remains elusive.



APPROACH CHART for Washington National Airport provides pilot with information on the Instrument Landing System, approach angles, physical obstructions and many other matters. He carries such charts for all airports and receives frequent revisions as conditions change. The charts are produced by Jeppesen & Company of Denver.



BRITISH "AUTOLAND" is the highest refinement of the ILS system. Using ILS signals, it brings the aircraft automatically to 300 feet above the ground. From there the plane follows the localizer course and a programed descent path. A radio altimeter initiates flared descent at a height of about 60 feet and triggers the "decrab" maneuver one or two seconds before touchdown.



WAVE-GUIDE ANTENNA to focus localizer beam eliminates much interference. Top diagram shows pattern of localizer around its antennas without wave guide (*color*) and with wave guide (*black*). Course as recorded by an aircraft approaching Wold Chamberlain Airport in Minneapolis is shown before installation of wave guide (*upper graph*) and after installation (*lower graph*). Deflections in rectangles are caused by a nearby hangar. Wave guides hold promise for smoothing glide slope also.

BACTERIAL ENDOTOXINS

Some disease bacteria excrete toxin; others do not excrete it but contain it. These latter substances are called endotoxins. How they act on the body is the subject of much current study

by A. I. Braude

Most disease-producing bacteria can be divided into two classes: those that secrete toxin into the surrounding medium and those that harbor the toxin within the bacterial cell. In the first case the toxin is called exotoxin; in the second, endotoxin. Among the diseases caused by exotoxins are diphtheria, tetanus, gas gangrene, botulism and scarlet fever. The endotoxin diseases include cerebrospinal meningitis, dysentery, typhoid fever, undulant fever, gonococcal arthritis, kidney infections and tularemia. Against the exotoxic diseases (notably diphtheria and tetanus) medical research has achieved great success simply by developing antitoxins. Progress toward control of the endotoxic diseases has been considerably less spectacular. The mode of action of endotoxin inside the body is still largely a mystery. For that very reason it is also one of the liveliest and most fascinating fields of current research in bacteriology.

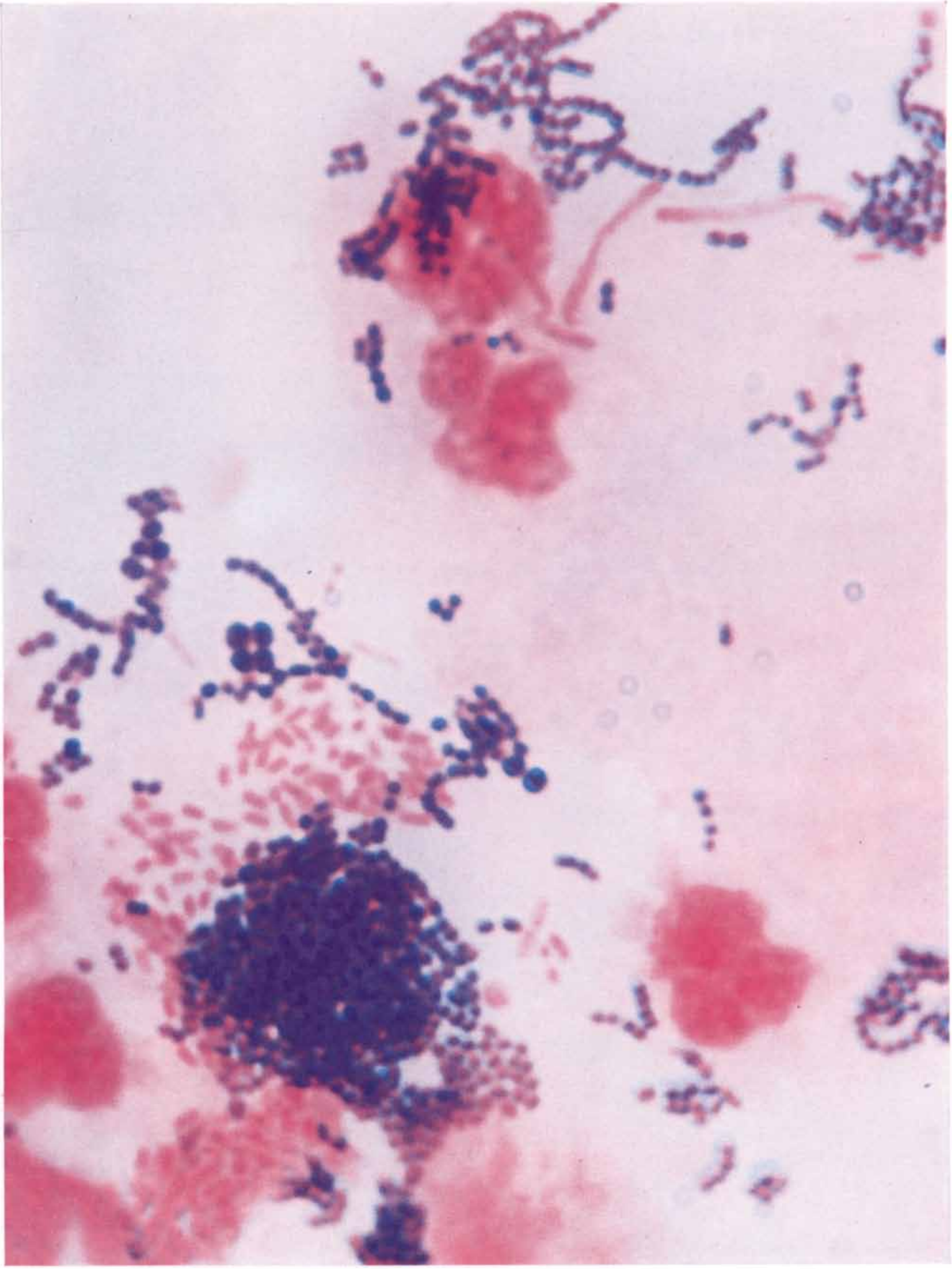
Endotoxins were first isolated some 30 years ago by the late André Boivin of the Pasteur Institute in Paris. In extracting them from bacteria (by the use of trichloroacetic acid) Boivin made a remarkable discovery. The bacteria that produced endotoxins were all of the Gram-negative type. "Gram-negative" refers to a traditional method of classifying bacteria that goes back to an accidental discovery made by the Danish physician Hans C. J. Gram in 1884. Gram found that when bacteria were stained with a dye consisting of crystal violet and iodine, the dye could easily be removed from some bacteria with alcohol, whereas other bacteria fixed the dye so that alcohol could not dissolve it. Bacteria that held the dye became known as Gram-positive and those that lost it when they were treated with alcohol were designated Gram-negative. Boivin's discovery converted this mysterious distinction into something meaningful: it now developed that almost all Gram-positive bacteria produced exotoxins and that all Gram-negatives contained endotoxins.

It is an odd fact that even noninfectious Gram-negative bacteria contain endotoxins. These bacteria, called saprophytes because they feed on dead organic matter, have occasionally got into human blood banks, and in a few rare cases their endotoxin has killed patients who received transfusions of the contaminated blood. Puzzled by this unexpected phenomenon, my colleagues and I, then at the University of Michigan Medical School, undertook a survey to find out if endotoxins were present in a wide variety of noninfectious Gram-negative bacteria. Examining a large number of soil bacteria that are incapable of growing at the temperature of the human body, Frank Carey, Jennie S. Siemienski and I found that all of them did indeed contain endotoxins. Their toxins were as potent as those produced by any infectious bacterium.

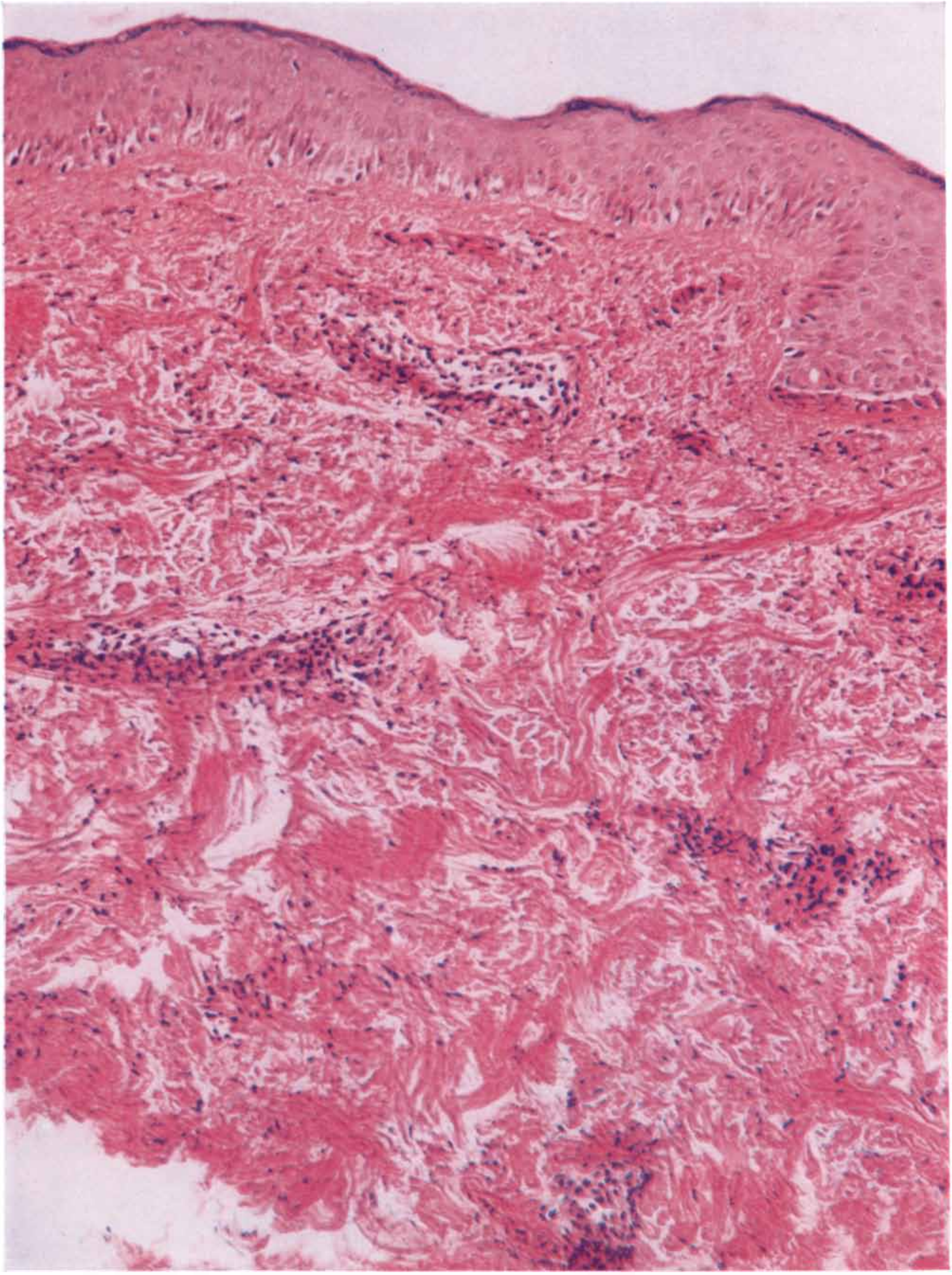
The remarkable universality of the endotoxins in Gram-negatives shows itself in another way. Exotoxins—the toxins of Gram-positives—produce specific and individual effects in the infected organism, so that each exotoxic disease has its own symptoms and is easily distinguished from the others. In contrast, the endotoxins all produce the same general symptoms in experimentally exposed animals, regardless of what bacterium may have furnished the toxin. This uniformity of effect seems to be demonstrated by the various diseases caused by endotoxins. In the long-lasting but comparatively mild infections such as typhoid fever and kidney infections the toxin gives rise to fever, sweating, weakness and generalized aches. In the acute types of endotoxic attack, such as fulminating meningococcal infection, peritonitis or poisoning by a contaminated blood transfusion, the symptoms are much more severe but similar: the patient is overwhelmed by high fever, shock resulting from a drastic fall in blood pressure, diarrhea, hemorrhages into the tissues and muscular pains.

One of the distinctive features of the endotoxins is their fast action. Within a few minutes after the intravenous injection of a small amount of endotoxin in an experimental animal 60 per cent of the white cells disappear from the bloodstream. Experiments with radioactive tracers indicate that the endotoxin almost instantly enters these cells and acts to drive them out of circulation. The first to go are the granulocytes (granule-containing white cells). During the next few hours the lymphocytes (smaller, nongranular white cells) gradually decline in number, and platelets (the colorless, oval bodies involved in blood clotting) also drop out of circulation. As the white cells disappear from the blood they turn up in increasing numbers in the tissues of the lung and other organs. Then, some four hours after the endotoxin injection, granulocytes suddenly flood into the bloodstream, raising the number of white cells to an abnormally high level. With them may come a rush of immature red cells. The influx of white and red cells probably represents a general outpouring of reserves from the centers of blood-cell formation and storage in the bone marrow.

The second response to an intravenous injection of endotoxin, following the initial disappearance of granulocytes from the blood by about half an hour, is a rise in the body temperature. This fe-



EXOTOXIC AND ENDOTOXIC BACTERIA are both visible in this photomicrograph of infected human urine stained by the Gram method. The entire sample was first stained with a violet dye, then washed with alcohol and finally restained with a red dye. The small violet bodies retained the initial dye and are called Gram-positive bacteria; they excrete exotoxins. The small pink bodies lost the initial dye and are called Gram-negative bacteria; they contain endotoxins. Large pink structures are white blood cells.



SECTION OF HUMAN SKIN was photographed three and a half hours after an injection of endotoxin. The dark dots are white blood cells that have clustered around the small blood vessels and plugged them. This quick reaction to endotoxin resembles allergic reaction known as anaphylaxis, which depends on the response of circulating antibodies. Magnification is about 300 diameters.

ver stems largely from a slowing of the circulation of blood through the skin, which sharply reduces the normal rate of radiation of body heat from the surface. Since it is known that body heat is regulated by thermostatic centers in the hypothalamus of the brain, we must assume that the endotoxin acts on the hypothalamus in some way.

Two hypotheses have been advanced to explain how the injected endotoxin may extend its effect to these centers. One is that the white cells damaged by the toxin release a pyrogen, or fever-inducing substance, that travels to the hypothalamic centers. Such a substance has been extracted from white cells by Ivan L. Bennett, Jr., and Paul B. Beeson at the Yale University School of Medicine; injected intravenously in animals, it produces fever in 10 to 15 minutes. Bennett and Beeson have named the substance "leucocyte pyrogen." ("Leucocyte" is synonymous with "white cell.") The existence of such a fast-acting pyrogen in the bloodstream of febrile animals has been demonstrated by Elisha Atkins of the Yale School of Medicine and W. Barry Wood, Jr., of the Johns Hopkins University School of Medicine.

The other hypothesis suggests that endotoxin itself acts on the hypothalamus, reaching it from the bloodstream by way of the cerebrospinal fluid that circulates around the brain. Bennett found that when he injected endotoxin directly into the cerebrospinal fluid instead of into a vein, only a thousandth as much of the toxin was needed to produce fever, and the fever developed in less than 15 minutes. The two experimental findings indicate that perhaps fever is produced by both agencies—by endotoxin itself and by a pyrogen to which it gives rise in the white cells.

Fever can be induced by amazingly small intravenous doses of endotoxin: as little as a billionth of a gram in rabbits and comparably small amounts in other mammals, including man. With larger doses other and more serious effects become apparent.

A dose 100,000 times larger than the minimum for fever will cause a collapse of the blood circulation amounting to shock. Within a few minutes after the endotoxin injection the arterial blood pressure begins to fall, and soon the blood flow is too sluggish to nourish the tissues of the brain, lung and kidneys. The shock is like that resulting from a massive loss of blood, a crushing injury or burns, but here the collapse of circulation stems not from depletion of the body's blood volume but from a shutdown in the flow of blood to the heart, so that the heart is no longer able to pump the normal amount of blood into the arteries. It has been found that in dogs the blood is trapped in the liver by spasms of the veins that prevent its flow. Where the block occurs in other animals is not yet known.

Large doses of endotoxin can cause another kind of disturbance in the body. Giuseppe Sanarelli of the University of Rome and Gregory Shwartzman of Mount Sinai Hospital in New York independently found that if they injected a somewhat less than fatal dose of endotoxin into a rabbit and followed this with another 12 to 24 hours later, the second dose led to massive destruction of the kidney tissues. It appears that in this case the endotoxin causes fibrin, the blood-clotting substance, to collect in the capillaries of the glomeruli, the tiny capsules that act as the kidney's filters. As a result the glomeruli gradually become clogged and the kidney tissues then die for lack of blood circulation.

Shwartzman found that the second endotoxin injection also killed skin tissue at the site of the first injection. Here white cells and platelets joined clumps of fibrin in blocking blood flow. The damage could be forestalled, however, by giving the animals heparin, which prevents the formation of fibrin and clotting of the blood. Heparin also had the same preventive effect in the kidneys.

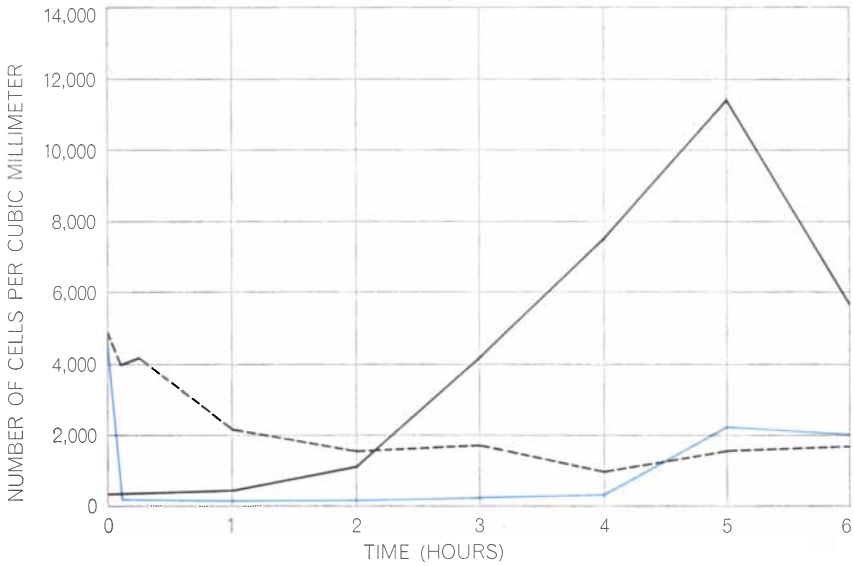
Other experiments have shown that the action of endotoxin in stopping blood flow can produce other kinds of tissue damage. For example, in an animal with a rapidly growing tumor an injection of endotoxin into the bloodstream will lead in a few hours to hemorrhages in the tumor and the death of its cells. Endotoxin also will kill the fetuses in a pregnant mouse.

What sort of substance, then, is this endotoxin, which causes such diverse effects? Precisely how does the toxin work? Because of the variety of its actions some investigators have sug-

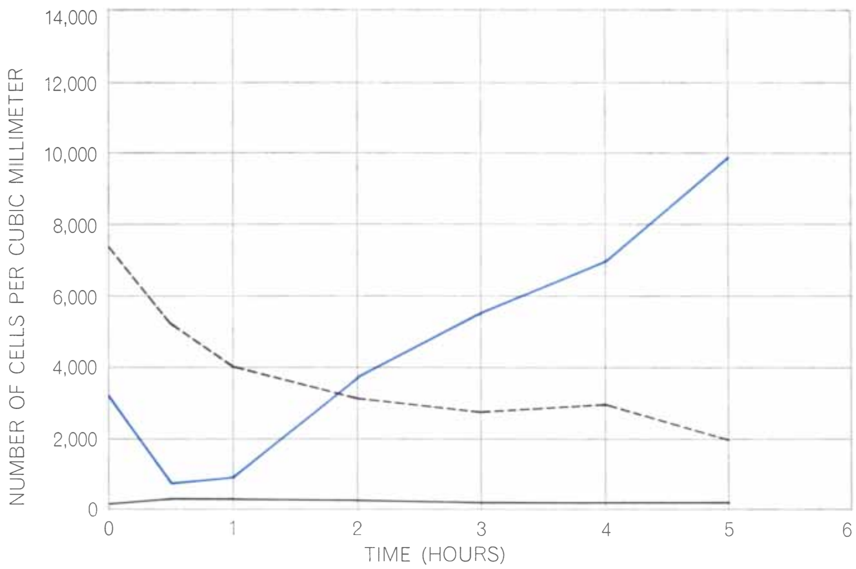
CHARACTERISTIC REACTION of human skin to an injection of endotoxin is caused by an accumulation of red blood cells, the normal flow of which is interfered with by white cells and other substances blocking small blood vessels (*see illustration on opposite page*).

gested that endotoxin is made up of several constituents that act in different ways. There has been no success, however, in breaking it down into separate toxins. The available evidence indicates that all its toxic properties are wrapped up in one molecule.

When Boivin extracted the first endotoxin from bacteria three decades ago, he found that it was a large molecule and that it had protein, lipid (fatty) and polysaccharide (complex sugar) fractions. He isolated the lipid and polysaccharide fractions with acid; it then turned out, according to his studies, that the lipid fraction was toxic and the polysaccharide fraction was nontoxic. On the other hand, Walther F. Goebel of the Rockefeller Institute separated the fractions with alkaline alcohol and found that the polysaccharide portion was toxic. This ambiguity and other evidence make it seem most likely that the entire molecule is essential for the action of the endotoxin in producing disease.



NORMAL REACTION to an injection of endotoxin into the bloodstream of a rabbit is characterized by a sudden drop in the number of granulocytic white cells (*colored curve*) and a gradual decline in the number of nongranular white cells called lymphocytes (*broken black curve*). After a few hours large numbers of immature red cells (*black curve*) rush into the bloodstream. In this graph and in the one below numbers of red cells have been divided by 100 to bring them into a scale comparable to that of the white cells.



TOLERANT REACTION to an injection of endotoxin into a rabbit that has been exposed previously to small doses of the same endotoxin is much milder than the normal reaction. Granulocytes (*colored curve*) do not disappear from the bloodstream so rapidly and hardly any immature red blood cells (*black curve*) appear. For some obscure reason lymphocytes (*broken black curve*) react the same way in tolerant rabbits as in nontolerant rabbits.

A clue to the mode of action of endotoxin came from a comparison of its effects and those of tuberculin, the extract from dead bacilli that is used as a test for the presence of tuberculosis. When tuberculin is injected into the skin of a tubercular person, it not only produces swelling, redness and soreness in the skin but also leads to systemic effects: fever, soreness in the lymph glands and general discomfort. Tuberculous guinea pigs may even be thrown into fatal shock by a small injection of tuberculin. Chandler A. Stetson of the New York University School of Medicine therefore was prompted to conduct a systematic comparison of the effects of endotoxin and tuberculin in rabbits. He found that both substances produced much the same symptoms: slowly developing inflammation of the skin, a drop in the white-cell content of the blood, a rise in body temperature and the death of skin cells at the site of the injection (the Shwartzman reaction).

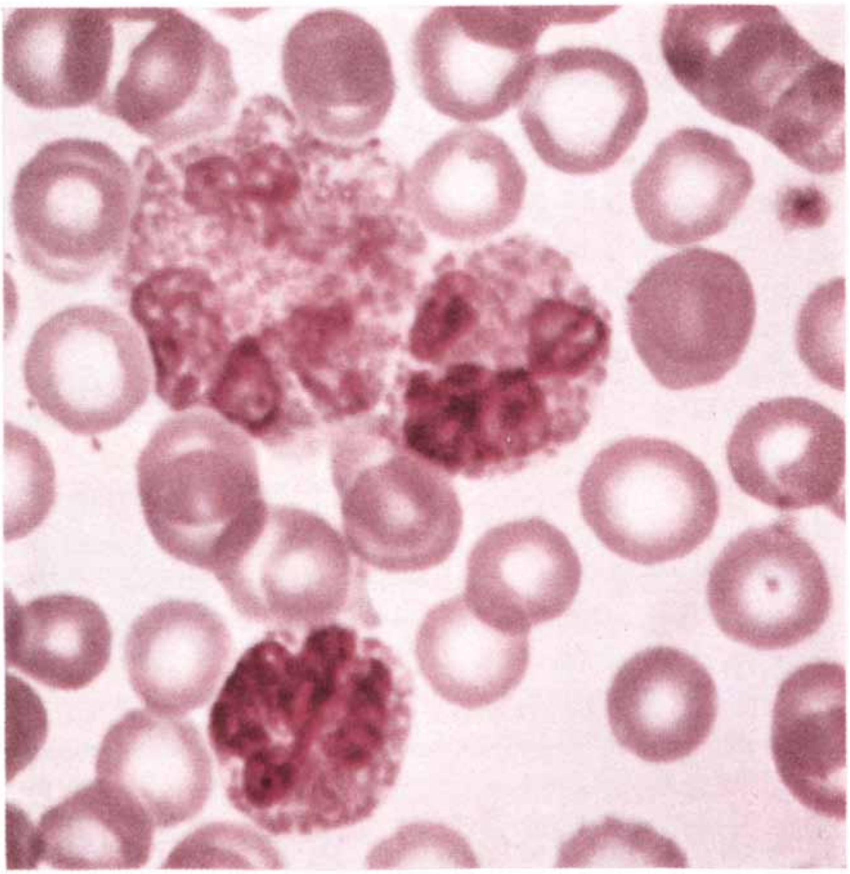
Now, the response to tuberculin is an allergic reaction: it occurs only when the subject has a susceptibility, or allergy, developed by previous exposure to the tubercle bacillus. Stetson suggested that the reaction to endotoxin was also allergic, that it arose from past infection of the rabbits by Gram-negative bacteria.

Stimulated by his observations, Jennie Siemienski, Stuart Sell and I, working at the University of Pittsburgh School of Medicine, made a similar comparison of the reactions to tuberculin and endotoxin in human volunteers. We injected harmless doses of tuberculin into one forearm and of endotoxin into the other. In contrast to Stetson's rabbits, our tuberculous human subjects showed distinctly different reactions to the two substances. First of all, the reaction to endotoxin developed faster and disappeared sooner; the inflammation of the skin became full-blown within five hours and had disappeared by 48 hours after the injection, whereas the inflammatory reaction to tuberculin did not become marked until 24 hours later and lasted more than 48 hours. This difference in timing is crucial, because the delayed appearance of inflammation is the hallmark of the tuberculin reaction. We found other differences. Before we injected the endotoxin or tuberculin we separately mixed each substance with a drop of the subject's blood. At the site of the injection into the skin the small red spot created by the red blood cells quickly disappeared after the tuberculin injection, but it lingered in the endotoxin injection. Examining small samples of the skin tissue under the microscope, we found that the red cells were held there because the endotoxin had caused white cells and fibrin to plug the blood vessels very rapidly, whereas the slower developing tuberculin reaction had allowed the red cells time to move away from the site of the injection.

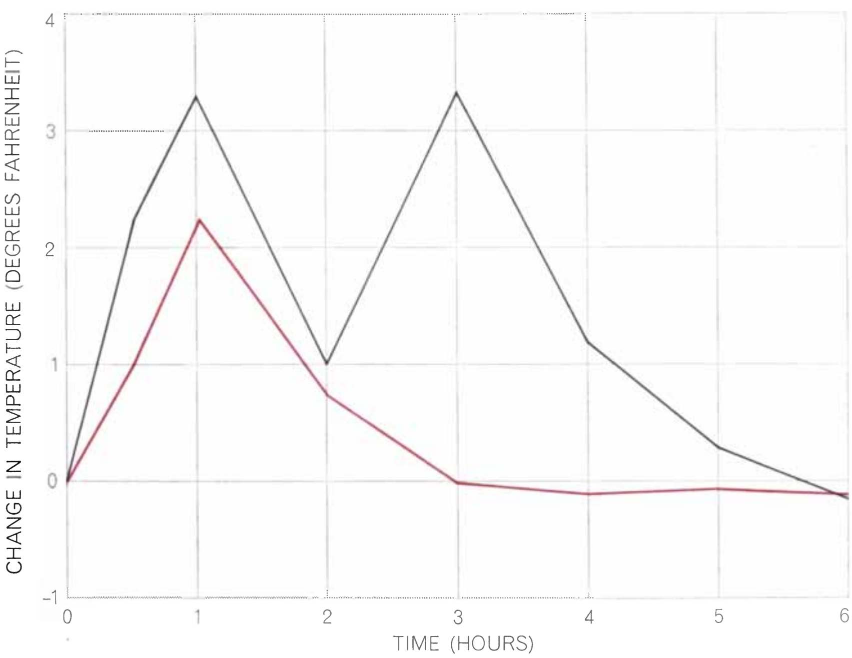
The damaged skin tissue showed something more significant: a form of injury typical of a hypersensitive skin reaction known as Arthus's phenomenon (after the French physiologist Nicholas Maurice Arthus). This kind of allergic skin reaction may be brought on by repeated injection of a foreign protein (such as egg white) and may be accompanied by generalized anaphylaxis—a swift reaction that may be violent enough to cause death in a highly sensitized person or animal. All this led us to ask: Is the body's response to endotoxin an anaphylactic reaction?

As a matter of fact, the question had been raised half a century earlier, not long after the French physiologist Charles Richet discovered the phenomenon of anaphylaxis (for which he was awarded the Nobel prize in physiology and medicine). Anaphylaxis is the result of the reaction of antibodies with the antigenic protein or polysaccharide that provoked their creation. The response to the antigen-antibody reaction may be so vigorous that the host is thrown into shock. In the early 1900's Milton J. Rosenau, later professor at the Harvard Medical School, and his co-worker John F. Anderson worked out the main features of the anaphylactic reaction. They learned that an extremely small dose of horse serum (a millionth of a cubic centimeter) could so sensitize guinea pigs that a second dose would kill them. In the course of their studies Rosenau and Anderson were struck by the similarity of anaphylaxis to the disturbances produced by endotoxin. They ventured to suggest that further study of the phenomenon of anaphylaxis might lead to an explanation of how endotoxins acted, but their suggestion was not seriously investigated until some 50 years later.

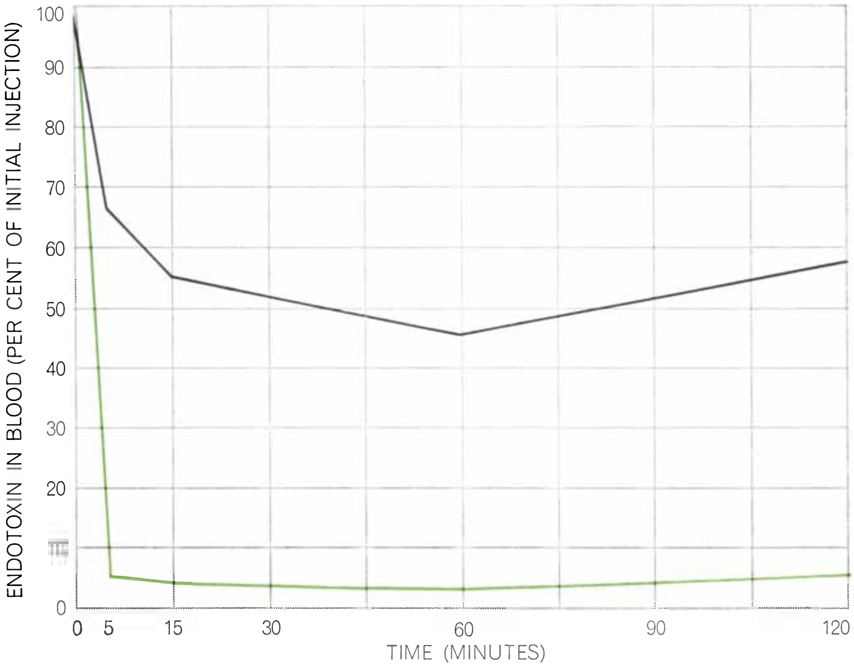
The question was taken up by Max



SWOLLEN GRANULOCYTE (*large cell at top left*) is about to disintegrate following exposure to endotoxin. Other two granulocytes have not yet been injured by the endotoxin and are normal in appearance. Disappearance of granulocytes from the bloodstream is one of the first responses to an injection of endotoxin. Smaller bodies are red cells.



FEVER REACTION to an intravenous injection of endotoxin is also milder in tolerant rabbits (*colored curve*) than in normal rabbits (*black curve*). Tolerance was produced by daily injections of small amounts of the same endotoxin that later caused the fever.



RADIOACTIVELY LABELED ENDOTOXIN disappears more quickly from the bloodstream of a tolerant rabbit (*colored curve*) than it does from the bloodstream of a normal rabbit (*black curve*). Tolerant animals can often survive normally lethal doses of endotoxin.

H. Weil and Wesley W. Spink at the University of Minnesota Medical School. They found that in dogs both endotoxic shock and anaphylactic shock were marked by many of the same symptoms: a sharp and immediate fall in blood pressure, a drop in the number of white cells and platelets in the blood and engorgement of the liver with blood trapped there by constriction of the veins. Particularly notable was the finding that in both forms of shock there was an explosive release of histamine into the blood.

Histamine is a substance that is present in the tissues of most animals, normally in harmless form. It is released into the blood when tissues are injured, and then it becomes a poison with varying effects. In a dog it causes the muscle fibers in the walls of the veins in the liver to contract, thereby narrowing the veins. In a guinea pig it tightens muscles around the airways of the lung, so that in anaphylactic shock the animal is suffocated. Investigators have shown that injection of histamine can produce shock with many of the characteristic features of both anaphylactic and endotoxic shock. The details of the effects vary in different animals. In a monkey a shock-producing dose of histamine or endotoxin does not affect the liver veins, and the fall in blood pressure is gradual. The rat has considerable resistance to histamine, endotoxin and anaphylactic shock, but a large dose of endotoxin or an anaphylactic substance will overcome its resistance. In endotoxic shock the small veins in the rat's intestinal tract are constricted, with the result that blood accumulates there and hemorrhages occur throughout the intestinal tract and the adjacent lymph glands.

The effects of endotoxin resemble anaphylaxis not only at the shock level but also in the milder forms of reaction. Hypersensitive animals receiving an injection of the protein to which they are sensitized may respond with a fever like that produced by endotoxin. In the case of anaphylaxis it was shown by Richard S. Farr and Howard M. Grey at the University of Pittsburgh School of Medicine that the fever results from a reaction between the injected protein and antibodies in the animals' blood. This observation brings to the fore a crucial question: Do antibodies play a part in the effects of endotoxin?

That question raises another: How would such antibodies arise in the body in the first place? In the case of an anaphylactic allergy the body has already been exposed to the foreign substance and has manufactured antibodies by virtue of that fact. Endotoxin, however, produces the same kinds of reaction regardless of whether or not the animal has previously been infected by bacteria. This suggests that the body may possess a "natural" antibody to endotoxin. If so, what stimulates its formation? We can make a reasonable guess: The symbiotic bacteria that live in the intestinal tract of mammals are known to contain endotoxin, and this may give rise to the antibodies.

We conducted a search for such antibodies in a number of animals. Erwin Neter of the University of Buffalo Medical School had developed a sensitive technique for detecting endotoxin antibodies: a method of attaching endotoxin to the surfaces of red blood cells so that antibodies would react with it and show their presence by clumping the cells. Using this test-tube test, I found antibodies to endotoxin in the blood of virtually all the mammals I examined. Verne E. Gilbert and I then looked for evidence that the antibodies actually combined with endotoxin in the bloodstream of animals during their responses to an endotoxin injection. We reasoned that such a combination would be signaled by the disappearance of the antibodies from the bloodstream. When rabbits were given an endotoxin dose sufficient to produce shock, that is exactly what happened. Within three hours the concentration of the natural antibodies fell sharply, often down to the point where the amount was no longer detectable. Along with the antibodies, the protein complex known as "complement," which is known to be involved in all antibody reactions and in anaphylaxis as well, also disappeared from the rabbits' blood. There is reason to believe that the interaction with complement, called complement fixation, is necessary for the development of shock; Spink and James Vick have found that in dogs endotoxic shock can be prevented by removing complement from their blood plasma before the injection of endotoxin.

In our experiments on antibody reactions we discovered that, whereas a shock-producing, lethal dose of endotoxin caused rapid removal of the antibodies from the blood, smaller doses had the opposite effect: the amount of antibody in the blood did not fall but gradually increased. A week after a small injection of endotoxin the animal's blood would show a thousandfold rise in antibody.

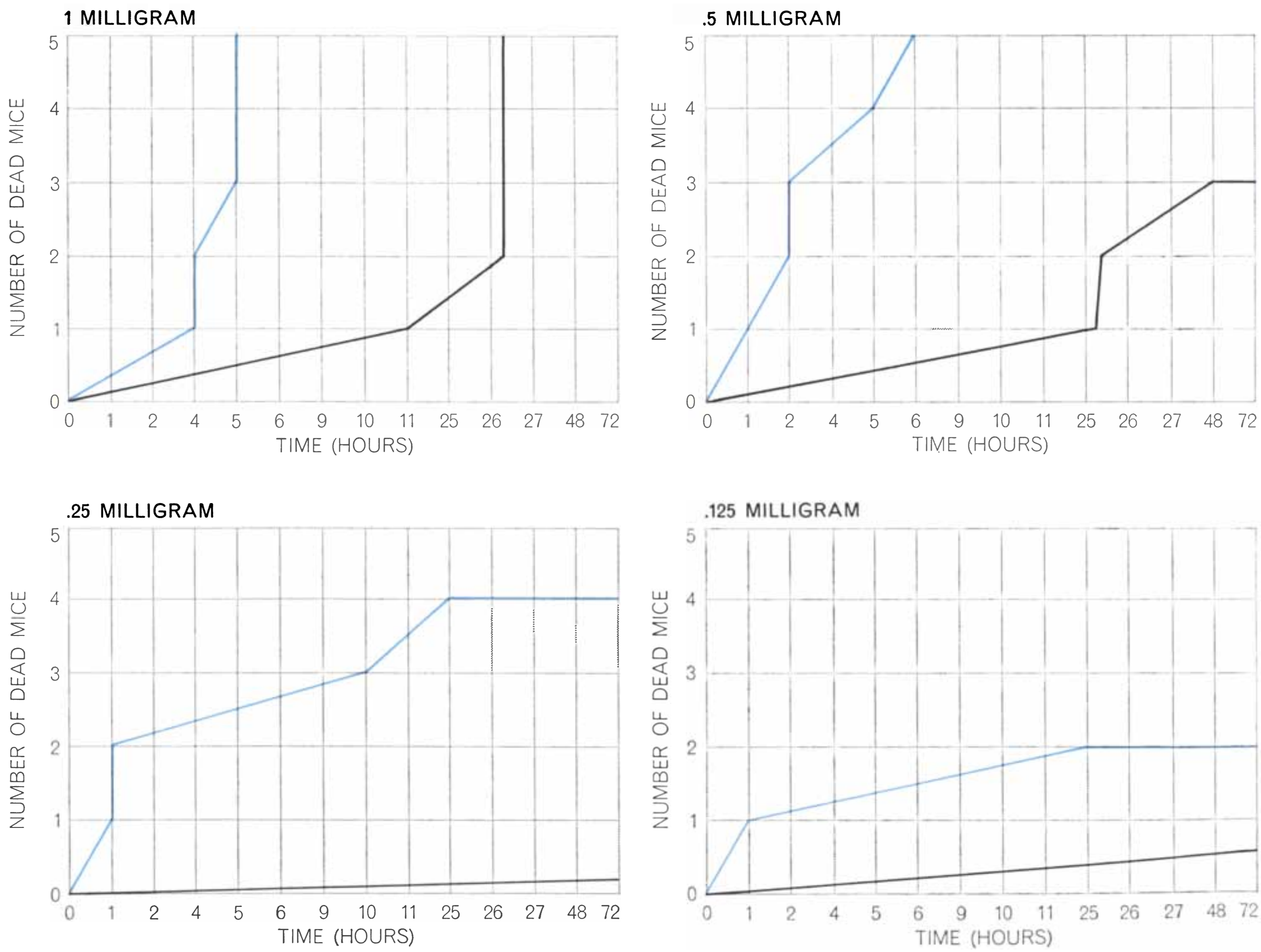
Here we encounter a paradox in the endotoxin mystery. If antibodies act as an accessory to endotoxin in producing damage, one might expect that a multiplication of antibodies would intensify the damage! This runs counter to the whole concept of antibodies as the body's defense against foreign substances. That is the way antibodies perform with respect to exotoxins, for example; serum rich in antibody gives full protection against the toxins of diphtheria and tetanus. The endotoxin situation is indeed beclouded with paradoxes. It turns out that antibodies sometimes increase resistance to endotoxin and sometimes lower resistance.

We have already noted that human skin shows a swift allergic reaction (resembling the Arthus phenomenon) to a small injection of endotoxin. In animals such as rabbits the skin reaction to a first injection is much slower, presumably because they have a much smaller population of Gram-negative intestinal bacteria (and hence much less natural antibody) than man. Stetson and Leung Lee found, however, that when they stimulated antibody production in rabbits by means of a small intravenous injection of endotoxin, the rabbits then showed a rapid skin reaction, like man's, to a later injection of the toxin. That antibodies were responsible for this acceleration of the reaction was demonstrated by the fact that an injection of antibody-containing serum into other rabbits sensitized them to endotoxin in the same way.

Other investigators—René Dubos and Russell Schaedler of the Rockefeller Institute and Herndon F. Douglas and I in our laboratory—have found that exposure to endotoxin can increase the lethal effect of the toxin, with the result that a smaller dose will kill the animal. It has not yet been demonstrated, however, that antibodies play a part in this vulnerability. When we injected only the antibody-containing serum into animals, instead of a sensitizing dose of endotoxin itself, it did not lower their resistance to large doses.

On the other hand, in most instances one or more "vaccinating" doses of endotoxin will elevate, not lower, resistance to the toxin. When a rabbit is given small injections of endotoxin (about a tenth of a microgram) on successive days, the strength and duration of its fever response diminish from day to day. Beeson found that the increased resistance was due to a heightened ability of the animal's liver and spleen to remove endotoxin from the bloodstream. In our laboratory and at the Pasteur Institute tracer studies employing radioactive chromium to label the endotoxin have shown similarly that the liver clears the toxin out of the bloodstream much faster if the animal has been pretreated with small doses of the substance.

Recent experiments in several laboratories have given evidence that an-



INCREASED SENSITIVITY to the lethal effects of endotoxin sometimes results from repeated exposure. Sensitized mice (*colored curves*) were given small injections of endotoxin during the 10 days preceding this experiment. These mice died faster and from smaller amounts of endotoxin than did unsensitized mice (*black curves*). Lethal dosage is given in the top left corner of each graph. It is not known why tolerance to repeated injections of endotoxin develops in some cases and lower resistance in others.

tibodies are involved in the heightening of resistance to endotoxin. The serum of resistant animals shows a comparatively high concentration of antibodies. The higher the level of antibody in an animal's bloodstream, the faster foreign substances are cleared out of the blood. Resistance to endotoxin-induced fever can be increased by injecting antibody-containing serum into an animal's blood, or by adding antibody to the endotoxin just before the poison is injected.

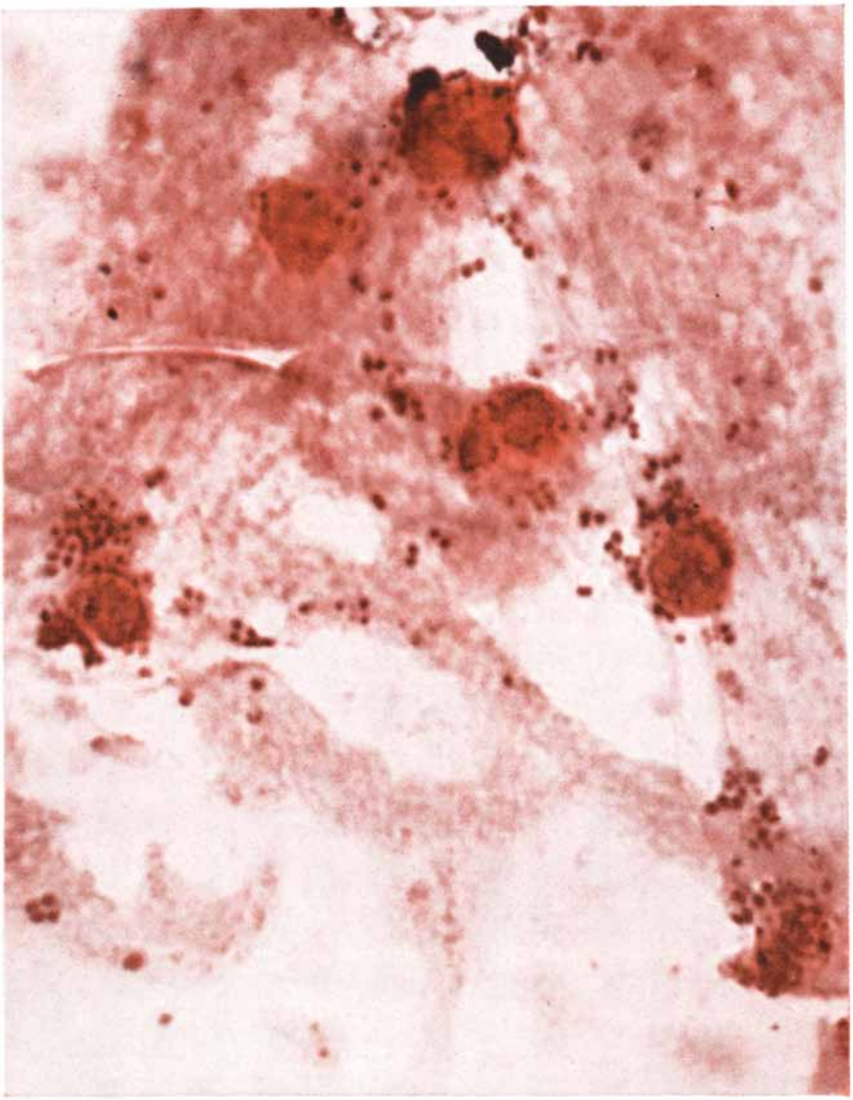
Yet we still have to account for the paradox that the antibodies sometimes heighten resistance and sometimes lower it. One possible answer is that the issue is decided by the relative proportions of endotoxin and antibody: if the amount of antibody exceeds the amount of toxin, it protects; if it does not, it may add to the toxicity. There is another possible explanation: that substances other than antibody are involved. This possibility has been explored and has yielded productive results.

Robert Skarnes and Louis Chedid of the Pasteur Institute have been among the leaders in this investigation. They have found that a blood constituent that is definitely not antibody can detoxify endotoxin, apparently by breaking down the endotoxin molecule into smaller units. Chedid and others, including workers in our laboratory, have also investigated the protective effects of the adrenal hormone cortisone. When the adrenal glands of mice are removed, the animals become almost incredibly sensitive to endotoxin: an injection of .00005 milligram will kill them. On the other hand, an injection of cortisone in a normal animal will protect it against a lethal dose of endotoxin. Cortisone and related adrenal hormones do not clear endotoxin more rapidly from the bloodstream, according to studies in our laboratory, but in some way they give the animal greater resistance to the toxin. The hormone adrenalin, in contrast to cortisone, can greatly accentuate the toxic effects of endotoxin. For example, it has been found by Lewis Thomas of the New York University School of Medicine that when rabbits have endotoxin in their blood, an injection of adrenalin into the skin will cause hemorrhage and death of the skin tissue, although adrenalin would not normally have this effect. It is possible that endotoxin sensitizes blood vessels in such a way that they overreact to adrenalin and remain contracted long enough to cause a damaging interruption of circulation.

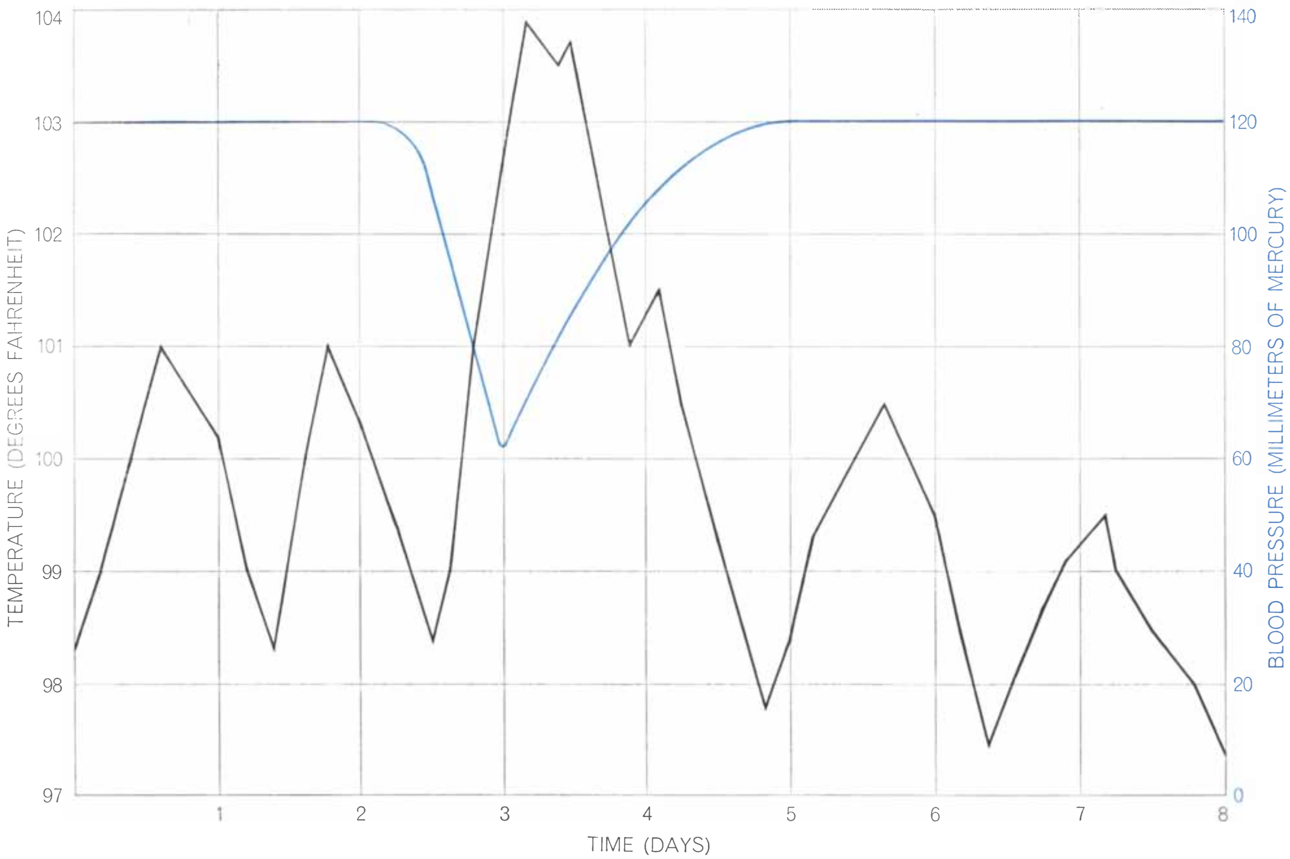
All the findings I have detailed so far were obtained from experiments with endotoxin extracted from bacteria —not with the toxin-producing bacteria themselves. Basically, of course, we are interested in how endotoxin acts in the natural situation: infection of the body by the toxin-containing Gram-negative bacteria. This primary problem has occupied many investigators since Boivin first isolated endotoxin from these organisms.

My own interest in the subject was aroused in 1949 during a medical investigation in Mexico City. The Mexican bacteriologist Maximiliano Ruiz-Castañeda, Spink and I were testing the new antibiotic aureomycin as a treatment for undulant fever, or brucellosis. It proved to be of great benefit to most patients, but in a few cases the drug caused a sudden rise in fever and shock. Since brucellosis is produced by Gram-negative bacteria of the genus *Brucella*, we surmised that the high fever and shock might be caused by a sudden release of endotoxin resulting from the destruction of the bacteria by the drug.

Spink and Robert S. Abernathy later explored this suspicion by injecting tiny amounts of *Brucella* endotoxin in patients with undulant fever. These patients reacted in the same way as those who had received aureomycin—with a rise in fever and shock. Evidently infection with the Gram-negative bacterium



GONORRHEAL INFECTION in a human knee is caused by Gram-negative bacteria called gonococci (*small dark bodies*), which contain endotoxin. Although penicillin readily destroys the living gonococci, the knee remains swollen and painful, probably owing to the persistence of some loose endotoxin. The larger dark bodies are the nuclei of granulocytes.



PATIENT WITH UNDULANT FEVER experienced a sudden rise in fever (*black curve*) and a corresponding fall in blood pressure (*colored curve*) 12 hours after being treated with aureomycin, a drug that is usually effective in reducing the fever. Apparently the aureomycin killed the *Brucella* bacteria that are known to cause undulant fever, releasing their harmful endotoxins.

sensitized the body to endotoxin. Yet Spink and Abernathy also found, paradoxically, that such patients eventually developed a resistance to endotoxin; the serum of individuals who had recovered from undulant fever gave protection against *Brucella* endotoxin when injected into mice. Similar observations have been made by other investigators, who found that patients recovering from typhoid fever or kidney infections became tolerant to injections of endotoxin. Spink and Abernathy therefore concluded that infection with a Gram-negative bacterium first sensitizes the body to endotoxin and then causes it to develop resistance to the toxin.

Janet L. Jones, Herndon Douglas and I proceeded to pursue this hypothesis further with experiments on animals. We produced a Gram-negative infection in the knee of a rabbit by injecting the colon bacillus *Escherichia coli.* This caused the rabbit to develop fever, and endotoxin appeared in its bloodstream —but not bacteria. Antibodies against the endotoxin rose to a high level in the blood, and the fever went away. We deduced from these events that the bacteria in the knee had released endotoxin into the blood, that the endotoxin then generated the production of both fever and antibodies and that the antibodies combined with endotoxin and thereby helped to curtail the fever. The antibodies did not, however, altogether eliminate the endotoxin. It persisted at the site of the infection (the knee joint) long after all the bacteria were dead, with the result that the joint remained inflamed for many weeks. Other investigators have noted a similar persistence of endotoxin in other organs.

Can the body be endowed with resistance to Gram-negative infections by "vaccination" with endotoxin? Vaccines prepared from Gram-negative bacteria have proved extremely unpleasant and even dangerous to take. Boivin discovered, however, that a nonpoisonous polysaccharide fraction of the endotoxin of the typhoid baccillus was capable of producing resistance to typhoid infection in mice. Intrigued by this finding, Hans Noll and I have explored the possibility of developing a nontoxic vaccine from the colon bacillus. Noll succeeded in detoxifying this bacterium's endotoxin by modifying its chemical structure (using a hydride of lithium and aluminum as the reagent). The altered endotoxin, as a vaccine, proved to be capable of giving rats considerable resistance to colon bacillus infections of the kidney. Presumably it acted by stimulating the production of antibodies against the damaging endotoxin. Several independent investigations give support to this view; they have shown that injections of antibody-rich serums can protect rats against kidney infections, mice against typhoid infection and guinea pigs against cholera infection.

These experiments and many others are beginning to throw light on the role and activity of endotoxin during actual bacterial infections. A major effort is now under way to purify endotoxin so that its toxic effects can be pinned down to the features of its chemical structure. When that is achieved, many of the puzzling and seemingly contradictory aspects of endotoxin's biological behavior may become understandable.

Experimental Narcotic Addiction

A new technique enables drug-addicted animals to give themselves intravenous injections at will. Now some of the factors affecting the voluntary intake of drugs can be investigated in the laboratory

by James R. Weeks

Drug addiction is a complex disease in both the medical and the social sense. The typical addict suffers from an underlying psychiatric disturbance that is often aggravated by economic and social pressures and the censure of the law; his illness does not look the same to the pharmacologist, the practicing physician or psychiatrist, the social worker and the policeman. An investigator who attempts to learn about drug addiction in humans by studying it in animals therefore runs a serious risk of oversimplification. Nevertheless, there are physical aspects of addiction that can be reproduced in rats or monkeys, and over the years much information on these effects has been obtained in laboratory studies. One thing was missing: the essential behavioral aspect of addiction, the voluntary self-administration of a drug by the addicted individual. A few years ago I worked out a method whereby rats addicted to morphine can give themselves injections at will, and subsequent experiments have yielded some interesting data on drug-seeking behavior in these animals.

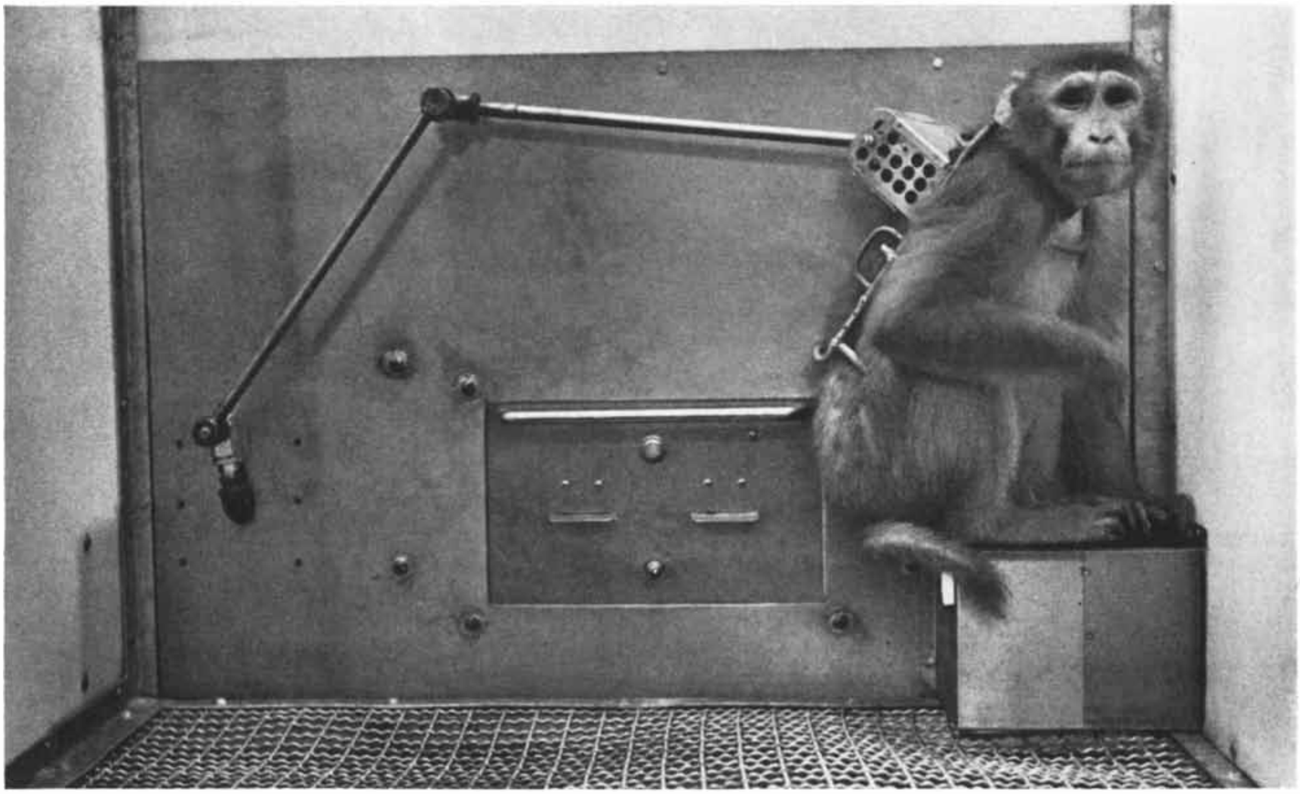
The World Health Organization describes drug addiction as a state of periodic or chronic intoxication detrimental to the individual and to society, produced by the repeated consumption of a drug and characterized by an overpowering desire or need to take the drug, by a tendency to increase the dose and by psychic and sometimes physical dependence on the effects of the drug. U.S. law specifies the drugs of addiction as opium and its derivatives (such as morphine, codeine, heroin and Demerol), cocaine and marijuana. Opium and its derivatives are narcotics—they depress the activity of the central nervous system and are used in medicine to relieve severe pain; cocaine is a powerful stimulant (its medical application as a local anesthetic is unrelated to its stimulating effect on the brain); marijuana is a mild intoxicant without medical value. The official list is arbitrary, of course, since many other substances can be addictive, including the barbiturates, amphetamine (Benzedrine) and alcohol.

The characteristics of addiction vary widely with the drug. On repeated administration of an opiate such as morphine two remarkable changes take place in an individual. First of all, he develops a tolerance for the drug, more and more of which must be taken to produce the same effect. A tolerant addict can take 20 or 30 times the usual dose of morphine without becoming drowsy or sleepy. If he can secure enough morphine, the addict remains in apparent good health and is quite able to do productive work; he is outwardly normal and difficult to identify as an addict. Physiologically, however, he is not normal. The second change in opiate addiction, and the most fascinating phenomenon to the pharmacologist, is the development of physical dependence. Once this is established the addict must receive the drug continually for his body to function normally. Deprived of morphine, the addict develops an "abstinence syndrome": he yawns, his eyes and nose water and he suffers "goose flesh," tremor, muscle twitches, restlessness, hot and cold flashes, fever, nausea, vomiting and diarrhea. He is acutely ill—and all for lack of morphine, which he craves intensely. An injection of the drug relieves his symptoms immediately.

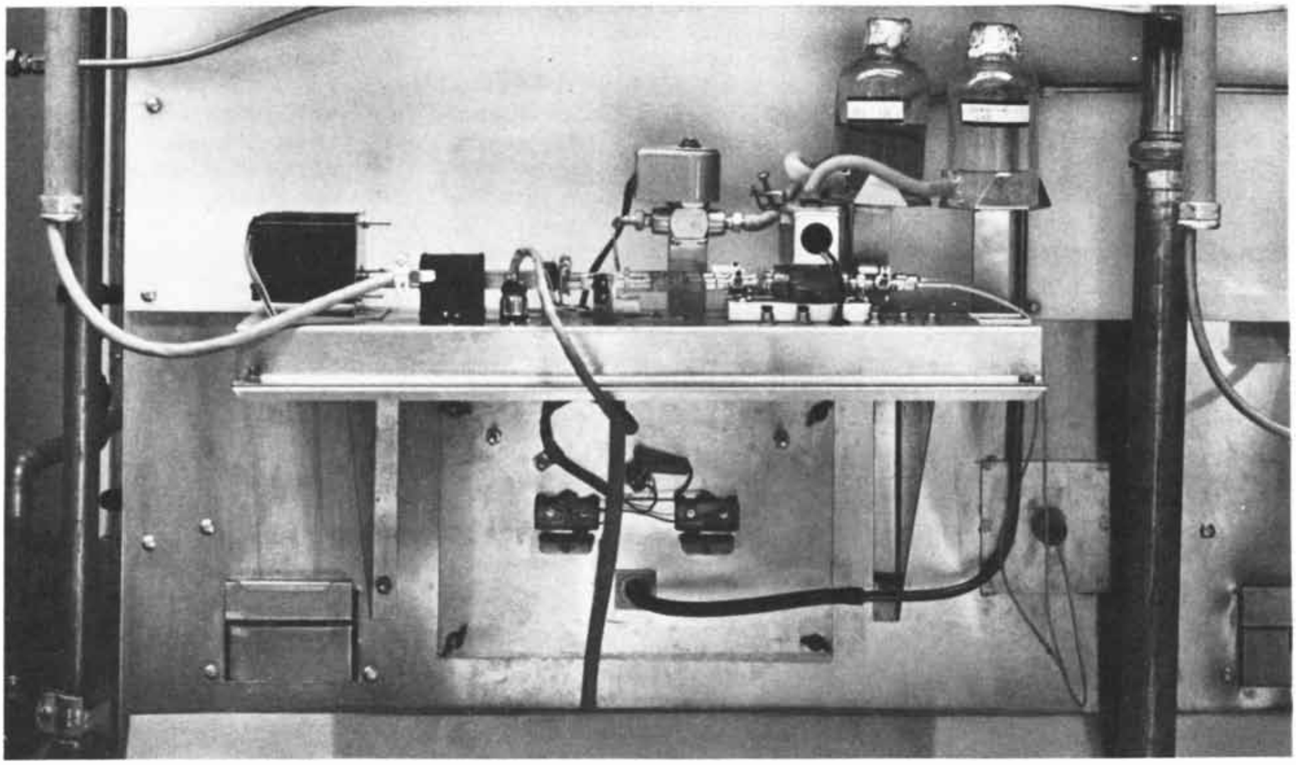
These two elements of narcotic addiction, tolerance and physical dependence, can both be induced in animals by the repeated administration of morphine. One experimental application of such addiction is exemplified in a laboratory at the University of Michigan, where Maurice H. Seevers and Gerald A. Deneau keep a colony of some 100 rhesus monkeys on morphine in order to test new drugs for addictive properties. Dependent monkeys are deprived of morphine and allowed to develop an abstinence syndrome. Then the test drug is injected; the degree to which it relieves the syndrome is a measure of its ability to be itself addictive.

Such experiments do not bear directly on the nature of addiction in animals. Do they, for example, "desire" morphine? More than 25 years ago S. D. Shirley Spragg of the Yale University School of Medicine demonstrated that animals do indeed exhibit morphine-seeking behavior. He addicted chimpanzees by giving them repeated injections of morphine. The apes had been trained to open a box with a stick to get food. Presented with two boxes, one containing food and the other a hypodermic syringe, addicted chimpanzees chose food if they had already received their regular injection; those that were past due for an injection chose the syringe even when they were hungry. (They did not, of course, give themselves an injection.)

A better experimental model would be one in which the animal voluntarily took its own drug. John R. Nichols of Southeastern Louisiana College carried out experiments of this type by adding morphine to the drinking water of rats. Because morphine has an intensely bitter taste the rats had to be forced to drink the drugged water by being deprived of any other supply. Once addicted, they selected morphine water in preference to plain water in spite of the taste. In other words, they sought morphine; they associated its ingestion with the relief of abstinence symptoms.



SELF-INJECTION SYSTEM developed by the author for rats was adapted for monkeys by Gerald A. Deneau and Tomoji Yanagita at the University of Michigan. The addicted monkey gets an intravenous injection of a drug by pressing one of the two pedals on the wall behind it. The tube that carries the drug solution is protected by lengths of steel pipe that swivel to allow the monkey some freedom of movement, and by the box on the animal's back. From the box the tube passes under skin into jugular vein.



INJECTION APPARATUS is on the outside of the cage, on the reverse side of the back wall seen in the top photograph. The two pedals, each with a microswitch above it, are in the center foreground. On the shelf above them are two syringes containing drugs from the two bottles (*top right*). Signals from a pedal activate the electric motor (*left*), and one of the syringes delivers a drug solution to the rubber tubes that are seen (*bottom right*) entering the system of jointed pipes that leads to the animal.

ALBINO RAT is prepared for experiments on addiction. A plastic tube is passed under the skin from behind the ears to the front of the neck, where it is connected to a silicone-rubber cannula that is inserted into the animal's jugular vein and leads to the heart.

For a better parallel to human addiction, however, an animal should be able to take the drug at will, by injection—preferably intravenous—and over a long period of time. Self-administration by injection would avoid the complicating effects of thirst and the unpleasant taste of the drugged water. When the way to do this occurred to me it seemed so simple that I wondered why no one had ever tried it. My idea was to put some kind of tube into a vein of the animal and connect the tube to an injection machine the animal could operate itself. To receive an injection the animal would have only to press on a pedal in its cage, thus activating a syringe driver that would inject a metered amount of morphine into the vein. This is essentially the "operant conditioning" technique developed by B. F. Skinner of Harvard University and other workers. In a typical experiment of this type an animal is trained to respond to some stimulus—to press a pedal, for example—by receiving a "reinforcement," usually a reward of food or water, as soon as it responds correctly. Morphine would be my reinforcement.

As far as I know the first such self-injection experiments were those I carried out with rats in 1960 at the Upjohn Company Research Laboratories in Kalamazoo, Mich. Working out the details of the apparatus was more difficult than conceiving the idea, the main problem being to keep an injection tube implanted in the vein without restraining the animal. The solution was to run a sprocket chain of the kind found on bicycles to a saddle on the rat's back. Polyethylene tubing woven down the chain does not twist because the chain flexes only in one plane, and the tubing is connected to the syringe driver by a sealed swivel [*see illustration on opposite page*]. From the saddle the tubing runs under the animal's skin to a cannula, or fine tube, of silicone rubber that is passed down the jugular vein to the heart. (The cannula has to be placed in the heart because it would not remain functional in a rat's small veins for more than a few days.)

Before a rat could be expected to inject itself regularly I had to establish tolerance and physical dependence in it. The syringe driver, controlled by a program punched on film, automatically administered a series of gradually increasing doses, beginning with two milligrams per kilogram. (Drug doses are generally stated in terms of the experimental subject's weight. A dose of "two milligrams per kilogram" would be an injection of half a milligram in the case of a quarter-kilogram rat.) The injection was repeated every hour, each time with a dose 2.5 per cent larger than the previous one. After 122 hours the dose had reached 40 milligrams per kilogram, and this dose was repeated every hour for a day or two. Then the automatic injections ceased, a pedal switch was put in the cage and the syringe was set to inject 10 milligrams of morphine per kilogram every time the rat pressed the pedal.

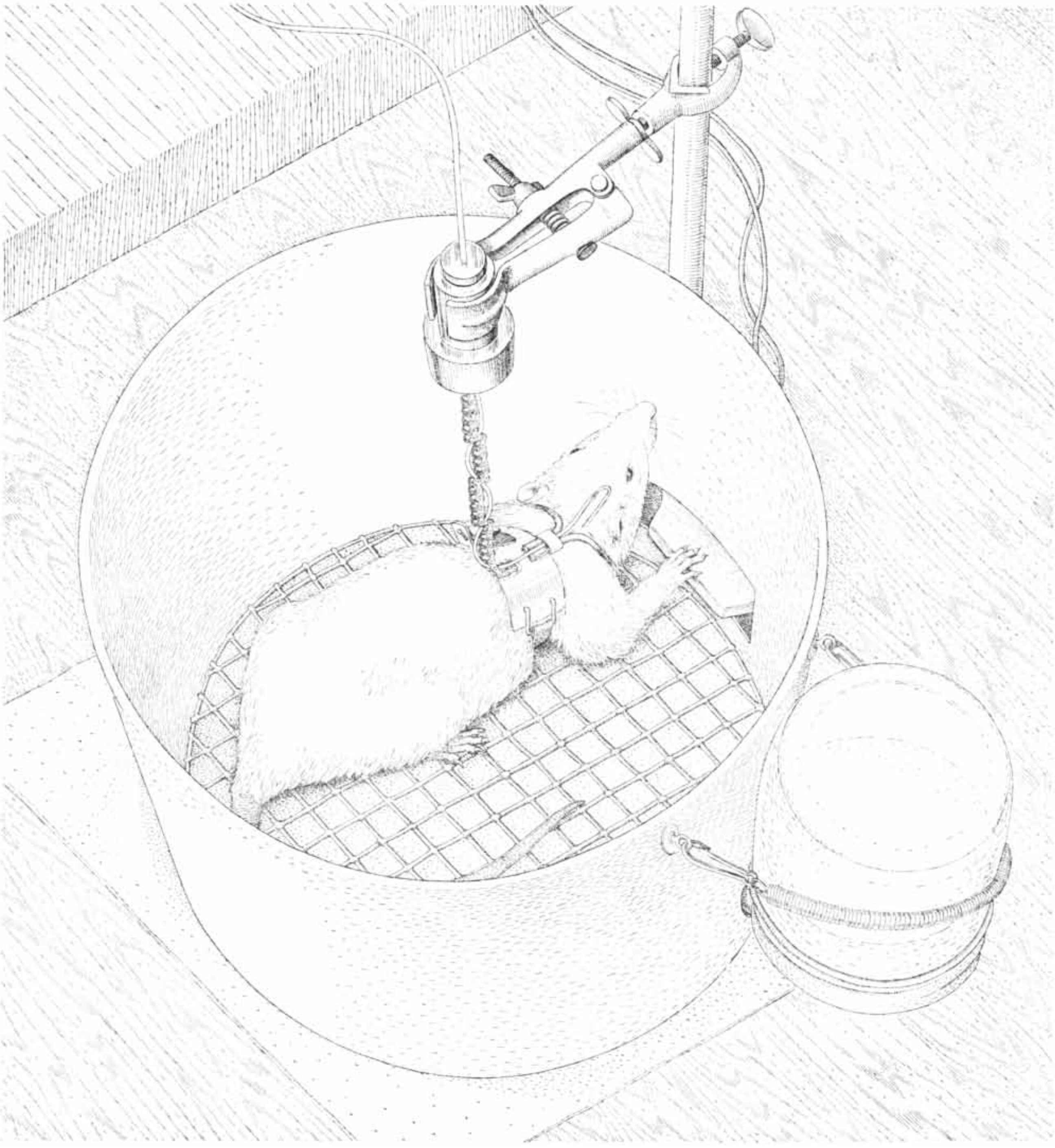
In this situation it was not long before the rat happened to press the lever. Immediately it got a shot of morphine. After a few repetitions of the response (pressing the pedal) and the reinforcement (the injection) the rat began to press the lever at regular intervals—about once every two hours, more or less, depending on the individual. Some of the rats went into a sort of trance immediately on receiving the injection, sometimes resting on the pedal for about a minute. But as soon as they were prodded they would move about normally without any evidence of the depressive effects of morphine.

One might be tempted to assume at this point that the rat "liked" the morphine, but it is important not to read human reactions and emotions into an animal's behavior. Moreover, although human morphine addicts say they "like" the drug, even in humans it is not clear to what extent the drug is a positive pleasure and to what extent it simply brings relief from the rigors of abstinence. The fact is that the rat may not "like" the morphine at all but has learned that pressing the pedal stops the punishment of early abstinence.

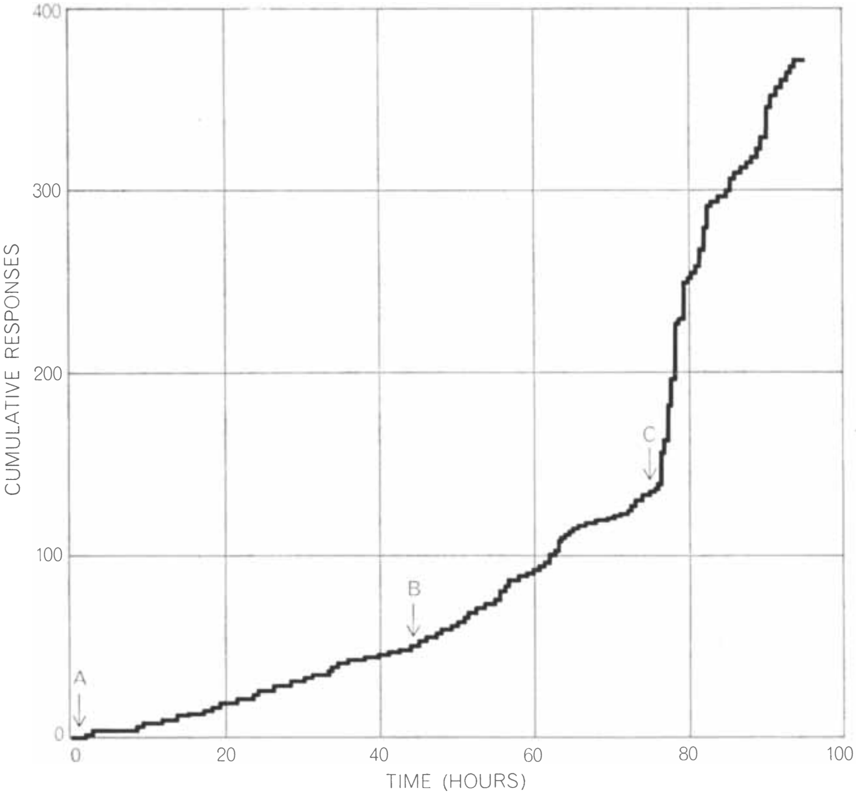
Having established addiction and self-injection, I tried decreasing the dose administered with each response on the pedal. When the dose was cut from 10 to 3.2 milligrams per kilogram, the rats responded more frequently in an effort to satisfy their habit [*see top illustration on page 50*]. Then I disconnected the syringe completely so that the rats received no drug at all for their efforts. There was an abrupt increase in the frequency of responses, which then diminished gradually as the rats developed a severe abstinence syndrome. They became nervous and agitated (but never vicious), breathed rapidly, tried to escape from their cages and were sensitive to handling, as if being touched were painful. Gastrointestinal activity increased, the feces became soft and by the next morning the rats had suffered as much as a 20 per cent loss in weight. They were very sick rats, but a single injection put an end to all their symptoms.

In a second experiment the one-to-one relation between response and injection was changed. When a rat had to respond 10 times in order to get one dose, it would press the pedal rapidly until it received an injection and then leave the pedal untouched until it was time for another shot. This seemed to me one of the most intriguing aspects of the study. One might have expected that the motivation for the response was a gradual increase in the severity of the abstinence syndrome, but in that case the rat would at first respond only sporadically—not trying very hard—and then respond more rapidly until it finally got an injection. What seems to happen instead is that at a precise and reasonably predictable moment the rat is motivated to start working for the drug and that it then presses the pedal steadily until it gets the injection, which produces almost immediate satiation. It is probably the onset of abstinence that triggers the first responses, but there are no obvious symptoms at that point.

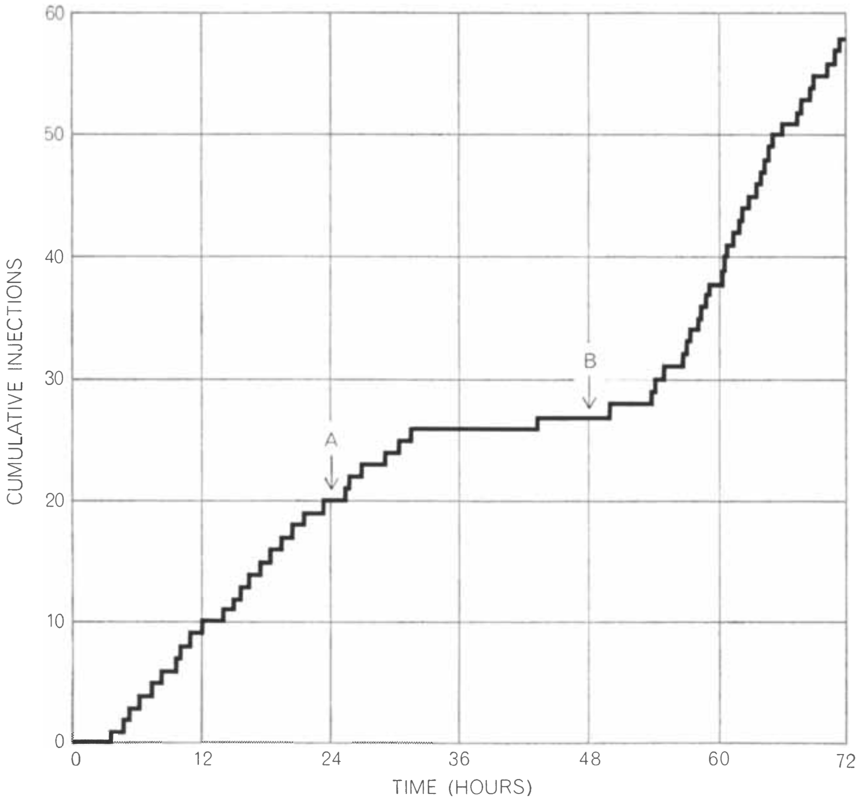
With R. James Collins I went on to increase the ratio between responses and injections, leaving the dose fixed. First we stabilized the addiction for a few days at a ratio of 10 responses to one injection. Then we increased the ratio each morning, first to a ratio of 20 to one and then in an approximate geometric progression to 32, 50, 75, 120, 180, 270 and 400 [*see illustration on page 51*]. With the change from 10 to 32 the number of injections obtained per day decreased somewhat, but as the ratio went from 32 to 120 there was only a small further drop in injections: the rats nearly compensated for the ratio change by responding more often. The reason they did not compensate completely apparently was that the effects of an injection still lasted about as long as at lower ratios; it took longer and longer to get an injection, but once the shot was administered satiation was complete and the rat did not start re-



ADDICTED RAT takes drug injections at will by pressing the pedal. The drug solution comes down the tube to the clamp, where it passes through a liquid-tight "stuffing box" and a swivel and thence into another tube that is woven along a sprocket chain. The chain prevents the tube from twisting as the animal moves about its cage. The jar at right contains drinking water.



RESPONSE RATE varied with the size of the dose. After addiction the rat began to respond (*A*), at first receiving 10 milligrams of morphine per kilogram of body weight. When the dose was cut to 3.2 milligrams per kilogram (*B*), the rate increased. When the drug was then cut off completely (*C*), the response rate rose sharply again, then slowed.



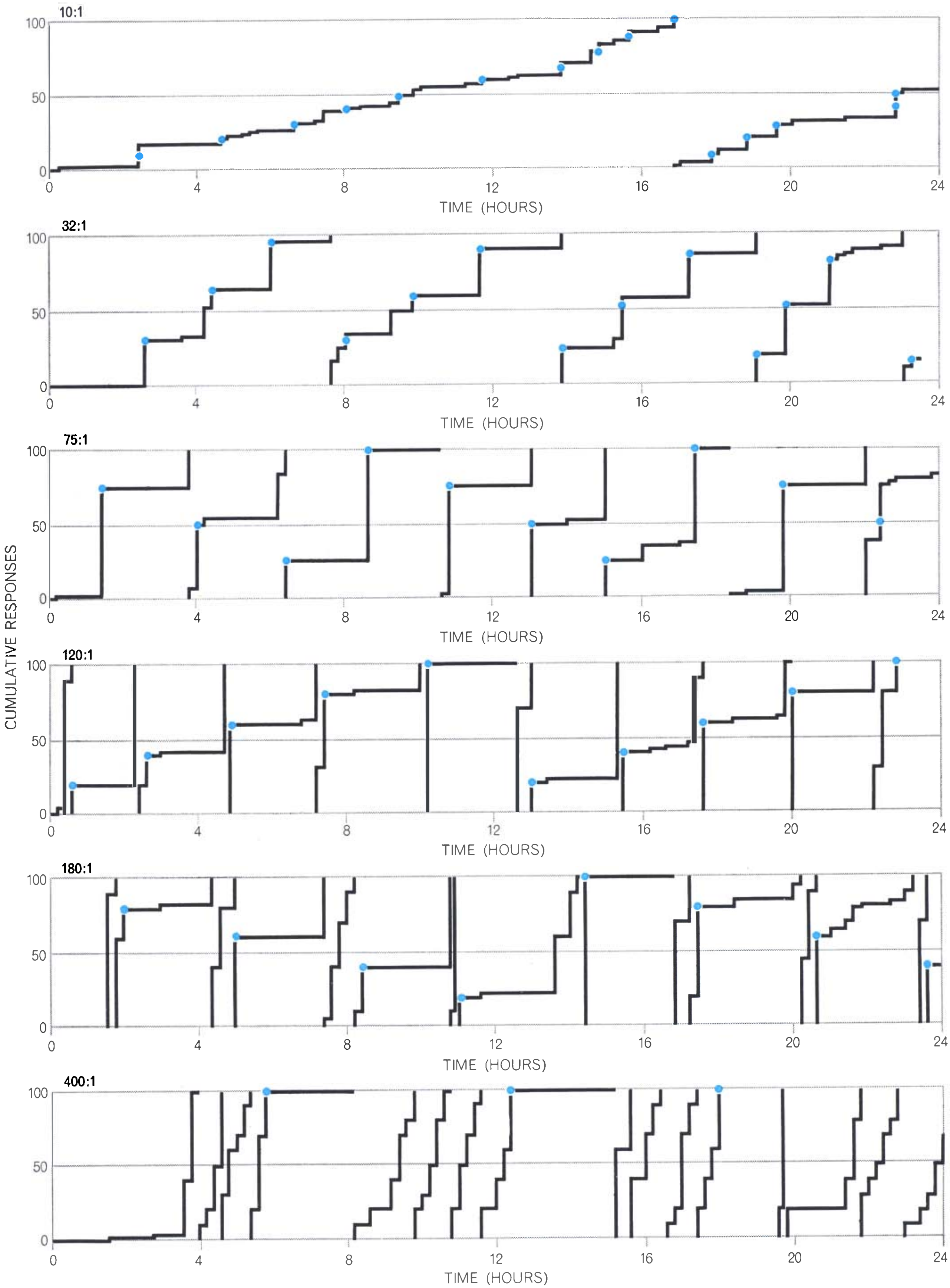
MORPHINE-LIKE DRUG etonitazine was added to the drinking water of an addicted rat at *A*. After ingesting enough of the new drug the rat stopped taking morphine shots. The etonitazine was removed at *B*, and after a while the rat resumed its self-injections.

sponding again until it needed more of the drug.

As the ratio passed 120 the number of injections decreased, until at 400 to one the rats were obtaining very little morphine. Whereas responses had been steady at the lower ratios, above 120 the rats would stop pressing the pedal for a few minutes and then begin again, further lengthening the response period. There were some indications that when injections were delayed by the long response periods required, the interval before the next injection was also prolonged. Unlike human addicts, rats do not anticipate their needs!

In the next modification we kept the ratio at one response per injection but decreased the dose every day. We had noticed that in the first experiment a reduction in the dose from 10 to 3.2 milligrams per kilogram had only about doubled the number of doses per day, with the result that the total intake of morphine decreased. There was also a tendency, at the lower dose level, sometimes to take more than one dose at a time. We tentatively interpreted this as an effort by the rat to "titrate" its morphine requirements—to find the exact dose that would satisfy it. To test this hypothesis we began with 10 milligrams per kilogram and reduced the dose each morning in a geometric progression: 10, 3.2, 1, .32 and so on. We expected that the rats would manage to keep their total daily intake about the same for at least two successive dose levels, making up for the reduction in dose by increasing the number of injections. Instead we found that as the dose was cut each day to about a third of what it had been, the number of injections continued merely to double. When the dose went below .32, there was little further increase in the number of injections and the rat was receiving hardly any of the drug. We have no good explanation for this result. It does seem to indicate that the size of the individual injection is a factor in maintaining a high drug intake, possibly because of a "jolt" at the moment of injection or some effect of a momentarily high drug level in the blood.

We were able to use our experimental system to compare the relative potency of various opiate drugs by substituting them for morphine in addicted rats. Dihydromorphinone (Dilaudid) and methadone (Dolophine), both of which are more potent than morphine in human beings, were also more potent in rats. On the other hand, codeine, which is not so potent for human addicts, was



VARYING THE RATIO between responses and injections affected the total intake of morphine as shown in these sample records. The dose remained at 10 milligrams per kilogram for each injection, but the rats were made to respond from 10 to 400 times to get each injection (*colored dots*). At low ratios they compensated quite well, working faster to maintain their intake. At higher ratios they responded more sporadically and took longer for each injection, until finally they were receiving very few.

almost as effective as morphine itself in the animals. An attempt to substitute the synthetic drug meperidine (Demerol) was a failure: the rats killed themselves with an overdose. Apparently nothing short of a lethal dose of this drug was able to satisfy the rats' addiction.

In a final series of experiments we investigated the effect on morphine intake of the administration of a second drug. We began by putting into the rats' drinking water five milligrams per liter of etonitazine, a synthetic morphine-like drug that apparently does not taste bad to rats. The drugged water was substituted for plain water at eight o'clock one morning and removed 24 hours later, and it caused a marked decrease in morphine injections [*see bottom illustration on page 50*]. The decrease was not apparent at first because rats, being nocturnal animals, do most of their drinking (and eating) at night, but late in the day morphine intake practically ceased. The injection-free period lasted for several hours after the drugged water was removed because the animals first had to eliminate the etonitazine consumed in the early-morning hours.

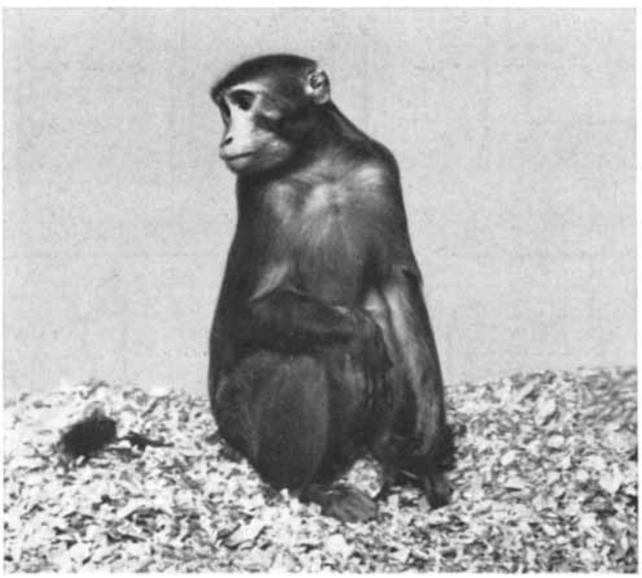
To conduct more precise experiments we connected a constant-rate infusion pump to the intravenous tubing along with the syringe driver in order to administer various drugs by continuous infusion and determine their effect on the voluntary intake of morphine. The test drugs were infused for 24-hour periods alternated with periods in which salt solution was infused as a control. As we had expected, the infusion of morphine or codeine reduced the voluntary injections, and the decrease was related to the rate of infusion. Meperidine, which had killed rats when it was directly substituted for morphine, now simply decreased the morphine intake, because the amount of meperidine administered was less than enough to satisfy the rats' requirements.

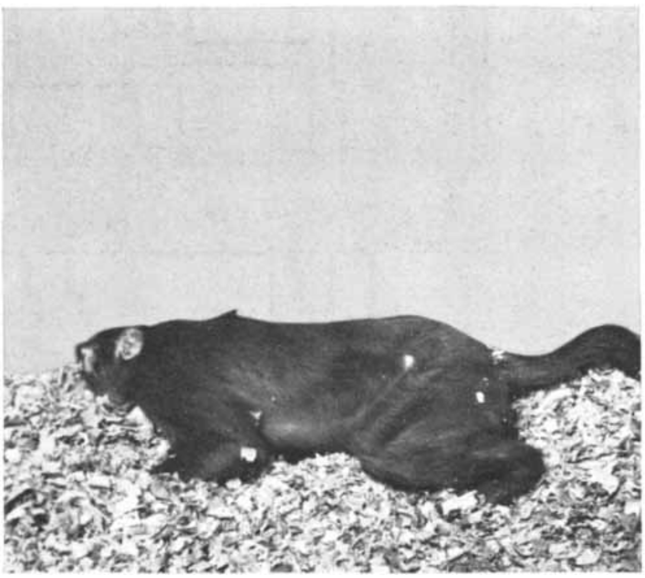
The morphine molecule can be modified slightly by substituting an allyl group (C_3H_5) for a methyl group (CH_3). The resulting molecule is a morphine antagonist called nalorphine. In medicine this drug is used to treat an overdose of morphine and also to detect morphine addiction quickly. Given to an addict, nalorphine temporarily counteracts the morphine in his body and precipitates a short-lived withdrawal reaction. When nalorphine was continuously infused into addict rats, it stepped up their morphine intake. Apparently it nullified the effect of some of the morphine in their bodies and made them feel the need for more of the narcotic.

Monkeys react to addicting drugs more like humans than rats do. It therefore seemed to workers in the University of Michigan group that self-injection experiments with monkeys might provide information with more direct bearing on problems of human addiction, and particularly data on the comparative effects of various drugs. Recently Deneau and Tomoji Yanagita have solved the technical problems involved in designing a saddle-and-swivel arrangement for monkeys—a challenging task in view of the almost uncanny ability of monkeys to undo fastenings and escape from restraint. The Michigan experiments are still in a preliminary stage, but they have already demonstrated that monkeys can keep themselves addicted by self-injection for many months; one monkey has maintained its addiction for 21 months.

Intravenous administration of drugs to relatively unrestrained animals has so far been applied only to the study of addiction, but it has many other potential applications. To the behavioral scientist it offers a means of studying the effects of various intravenously administered compounds as reinforcing agents, alone or in combination with conventional reinforcements. Apart from behavioral studies, continuous intravenous administration promises to improve the precision of administration of drugs in long-term experiments. Such investigations usually involve dosing animals two or three times a day, with resulting peaks and valleys in the concentration of the drug in their blood; continuous infusion will maintain a fairly constant level.

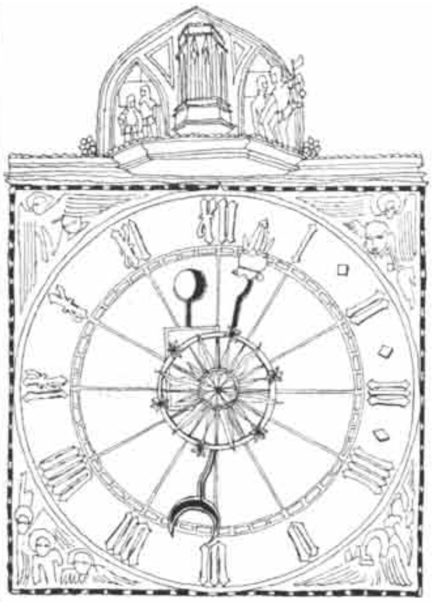
It should be emphasized that animal studies of addiction can illuminate only certain phases of the problem of human addiction. These include physical-dependence phenomena in particular and perhaps some of the fundamental aspects of behavior in relation to drugs. Human addiction must, however, be regarded as a combined physical and mental illness, and an understanding of its mechanism and treatment will have to come from research not only by pharmacologists but also by physicians, psychiatrists and social scientists.





ADDICTED MONKEYS in the test colony at the University of Michigan remain contented and apparently in good health as long as they are receiving morphine every six hours (*left*). Deprived of morphine, they develop abstinence syndrome (*right*).

SCIENCE AND



Weak Quantum

Tentative evidence has been reported for the existence of the "intermediate boson," also called the *w* particle. This subnuclear particle may be the quantum, or carrier, of the "weak" force of physics, in the same sense that the pion is the quantum of the nuclear, or strong, force and the photon the quantum of the electromagnetic force.

If the *w* particle exists, it can be observed only in particle interactions of great rarity, and then only indirectly. According to theory it may be created by the collision of a high-energy neutrino and a proton. The collision would produce a *w* particle and a muon. The *w* should decay almost instantly into a muon and a neutrino or into an electron and a neutrino. In a bubble-chamber or spark-chamber photograph the muon or electron from the *w* decay would appear to arise at the same point as the muon produced as a direct result of the collision. In other words, the "signature" of the *w* particle would be two tracks identifiable as two muons or as a muon and an electron.

To search for this signature an elaborate experiment has been under way for almost a year at the European Organization for Nuclear Research (CERN) in Geneva. Protons accelerated to 25 billion electron volts in the CERN alternating-gradient synchrotron are brought out of the machine and strike an external target. The collision produces a beam of pions that decay in flight into muons and neutrinos. The resulting beam impinges on some 6,000 tons of steel shielding, which filters out everything but the neutrinos. These virtually inert particles, which have no electric charge and no mass, enter two massive particle detectors: a 30-ton spark chamber and a bubble chamber containing half a ton of a heavy liquid. Although the beam contains 100,000 neutrinos per second per square centimeter, only about four interactions are observed per day for each ton of material in the detectors. The only established interaction is one in which a neutrino transforms a neutron into a proton, with the simultaneous emission of a muon.

The CERN experiment has confirmed the discovery made earlier at the Brookhaven National Laboratory that there are two kinds of neutrino, one produced in association with muons and the other in association with electrons (see "The Two-Neutrino Experiment," by Leon M. Lederman; SCIENTIFIC AMERICAN, March, 1963). According to Victor F. Weisskopf, director of CERN, the experiment has also yielded evidence that the *w* particle is produced in about 1 per cent of all the neutrino interactions. CERN investigators are continuing their experiments and rechecking their results before saying flatly that *w* exists.

Hypotheses Confirmed

Two of the central hypotheses concerning the genetic code and the synthesis of proteins have been confirmed by experimental studies. The first hypothesis is that the sequence of amino acid subunits in a protein is specified by the sequence of nucleotide subunits in the gene bearing the code for that particular protein. The second hypothesis, for which there was already some evidence, is that the number of nucleotides needed to specify one amino acid is three.

Confirmation of the first hypothesis was revealed in *Nature* by A. S. Sarabhai, A. O. W. Stretton and Sydney Brenner of the Medical Research Council's Laboratory of Molecular Biology in Cambridge, England, and A. Bolle of the University of Geneva. They made a detailed study of mutations affecting the protein that forms the jacket of the head of a bacterial virus known as *T4D*. Their first step was to cross and recross virus mutants to produce a map showing in linear sequence the location of 10 different mutation sites in the gene bearing the code for the jacket of the virus. Each of the virus mutants was then grown in the presence of various nonradioactive and radioactive amino acids, which the virus assembled into polypeptide chains (either the entire protein for the jacket or a fragment of it). When the polypeptides were analyzed, it was found that those made by the mutants lacked one or more of the radioactive amino acids. Moreover, the length of the polypeptide chain could be correlated with the genetic map of mutation sites. Evidently a mutation inserts a "nonsense" codon, or "word," in the genetic code so that the code can be "read" only up to that point when a polypeptide is being synthesized.

That the number of nucleotides in a codon is three was reported in a separate *Nature* article by Theophil Staehelin, Felix O. Wettstein, Hikokichi Oura and Hans Noll of the University of Pittsburgh School of Medicine. It had been clear that the length of the codon could be determined if one could determine the number of nucleotides in a particular gene and the number of amino acid subunits in the protein specified by that gene. For this purpose the Pittsburgh group studied the length of "messenger" ribonucleic acid (RNA), which is formed on a template of the genetic material deoxyribonucleic acid and contains the same number of nucleotides as the genetic message copied. Messenger RNA then becomes a part of the protein-assembly mechanism known as a polyribosome (see "Polyribosomes," by Alexander Rich; SCIENTIFIC AMERICAN, December, 1963). Polyribosomes consist of several small bodies called ribosomes linked together by a single strand of messenger RNA. Ribosomes travel along the strand from one end to the other, producing as they go a polypeptide chain in accordance with the instructions contained in the messenger RNA.

By studying the rate at which various polyribosome fractions sediment when they are spun in an ultracentrifuge, the Pittsburgh group computed that the messenger RNA that carries the code for the blood protein hemoglobin has a length of about 450 nucleotides. Since the protein has about 150 amino acid subunits, the ratio of nucleotides to amino acids is three to one.

Luminescent Moon?

New observations of the moon suggest that at least some lunar rocks emit light in response to bombardment by subatomic particles from the sun. The observations may also have identified the specific type of meteorite whose impact created the lunar crater Kepler. The investigation was reported in *Nature* by Zdeněk Kopal and Thomas W. Rackham of the University of Manchester.

The observations were stimulated by laboratory studies of meteorites by C. J. Derham and J. E. Geake, also of the University of Manchester. They had subjected samples of many types of stony meteorite to a beam of protons with an energy of 40,000 electron volts; protons of this energy are characteristic of the "wind" of particles expelled by the sun. Most of the material evinced no luminescence of interest, but powdered samples of three different enstatite achondrites (stony meteorites without grainy inclusions and relatively rich in the mineral enstatite) emitted a strong peak of luminescence at a wavelength of about 6,725 angstrom units, in the red region of the visible spectrum, and a much weaker peak at about 4,000 angstroms, in the blue.

On the night of November 1–2 last year, at Kopal and Rackham's request, the 24-inch refracting telescope at the Pic-du-Midi Observatory in France, equipped with filters that excluded almost all light except that at 6,725 angstroms, was used to make photographs in the region of the craters Aristarchus, Copernicus and Kepler. For comparison a photograph with a green filter was made shortly after each exposure in the red. On the first and third of three photographs in the red, the region around Kepler showed strong luminescence, whereas no unexpected glow and no change was visible on the three plates exposed in the green. The next night, November 2–3, there was no luminescence in the red.

Kopal and Rackham reported that two solar flares occurred on November 1, the first about 8½ hours before the initial appearance of luminescence around Kepler and the second also about 8½ hours before the second appearance of the luminescence. No flares were observed on November 2. Kopal and Rackham suggest that high-energy protons from the flares, which would have been about 300 times more numerous and 10 times more energetic than those in the quiet solar wind, caused the region of Kepler to glow red. They also point out that the protons would have had to pass close to the earth on the way to the moon and might have been focused by the earth's magnetic field, which would help to account for the strength of the glow at Kepler. A further interpretation is that the meteoritic debris in and around Kepler closely resembles the three enstatites studied by Derham and Geake. (It was not suggested that the luminescence was in any way related to the glowing red areas on the moon seen by five U.S. astronomers and reported in this department last month.) Kopal and Rackham add that the results open up possibilities for investigations of the sun through studies of the reaction of the surface of the moon to solar events.

Redistricting by Computer

A proposal for establishing election-district boundaries more objectively has been advanced by James B. Weaver and Sidney W. Hess of Wilmington, Del., respectively an engineer and an operations research analyst. Writing in the *Yale Law Journal,* they say that both courts and legislatures involved in districting might find helpful —particularly in light of the Supreme Court's 1962 decision in Baker v. Carr that the courts can review the constitutionality of state legislative apportionments—a districting procedure that "divorces the results reached from the claims of partisan interests."

The authors suggest that an official body undertaking to draw election-district boundaries equitably would want to use at least the criteria of population equality, contiguity and compactness. Population equality means simply that each district should have about the same number of people in it as any other district; contiguity is the absence of "uncouth shapes." Weaver and Hess concentrate on presenting a measure of compactness that emphasizes population as well as geography.

For this they draw on "analogous measurements in mathematics and physics," notably the "moment of inertia" that measures the dispersion of a rotating body's weight about the axis of rotation. The moment of inertia for a populated area (the authors use as basic populated areas the Bureau of the Census' "enumeration districts," each of which has a population of about 1,000) is ascertained by multiplying the population by the squared distance from the area to the assumed population center of a "legislative district," which is a region electing an official such as a member of the state legislature. Adding the moments of inertia for the enumeration districts gives the moment of inertia for the legislative district; the smaller the sum, the greater the compactness. Because arriving at these figures requires numerous calculations, the authors propose the use of a computer.

In a trial run the authors went through their procedure for the six seats that Sussex County in Delaware has in the state House of Representatives. They arrived at a plan of contiguous districts ranging in population from 12,053 to 12,342 and meeting their definition of compactness. They write that their method "will tend to locate districts of maximum compactness around centers of population" and "to favor districts coincident with communities of economic or other interests."

Single-Cell Muscle Control

The contraction of a muscle is a summation of many tiny and transient twitches in a number of "motor units," each composed of a few microscopic muscle fibers and the single nerve cell that controls them, a motor neuron in the spinal cord. Now John V. Basmajian of Queen's University in Kingston, Ontario, has demonstrated that a person can control an individual motor unit—can, in other words, consciously call on one motor neuron in many thousands in the spinal cord and cause it to fire while suppressing the activity of its neighbors.

Neurophysiologists knew that the electrical impulses associated with the twitches of neighboring motor units differ from one another and can be identified by their characteristic shape on an oscilloscope. In 1960 Virginia F. Harrison and Otto A. Mortensen of the University of Wisconsin Medical School recorded individual motor-unit activity in a leg muscle. Basmajian decided to explore the extent to which such activity could be consciously controlled.

He inserted fine wire electrodes into a small muscle at the base of the thumb. The wires were connected via an amplifier to two oscilloscopes, a loudspeaker and a tape recorder. When a "wired" subject contracted the muscle, he saw the resulting spikes on the oscilloscope and heard a popping sound over the loudspeaker; he learned to make slight, invisible contractions that were apparent to him only because of these visual and audible responses, which acted as feedbacks that the nervous system normally lacks. Volunteers learned to relax the whole muscle, then to activate a single motor unit, to repress that one and activate another and then a third; some subjects went as far as five. Several subjects were able on command to activate any one of several units identified by letters: the experimenter said, "Give me *c*," and the subject twitched unit *c*. In later experiments 10 out of 11 subjects could control the frequency of single units well enough to produce galloping rhythms, doublets and drum rolls.

Through a Glass That Darkens

A reversible photochromic glass—one that darkens on exposure to light and clears again when the light fades—has been invented by S. Donald Stookey and William H. Armistead of the Corning Glass Works. Photochromism is the phenomenon of color change caused by light, and it affects many materials. Photographic film provides the most familiar example: crystals of silver chloride, silver bromide or silver iodide in an emulsion decompose to form a metallic silver image when they are exposed to light and development.

The Corning workers developed techniques whereby similar silver halide crystals are precipitated in silicate glass during a cooling and reheating cycle. The particles are much smaller than those in a photographic emulsion; there are some eight million billion of them in a cubic centimeter of the glass. On exposure to light ranging from the near ultraviolet into the visible spectrum, the crystals change to metallic silver in a matter of seconds and darken—and so does the glass. But apparently the small size of the crystals and the fact that they are embedded in rigid, chemically inert glass keeps the color centers from growing into stable silver particles. When the light is reduced or extinguished, the silver halide is reconstituted and the glass clears in a few minutes or hours. Corning expects to find uses for the new glass in windows, windshields and sunglasses that adjust their transmittance of light to prevailing conditions, in display devices and in "light valves" for optical systems.

Electrical Ecosystem

A photoelectric ecological system with a half-volt potential between a top layer of blue-green algae and a bottom layer of anaerobic bacteria is described in *Science* by Neal E. Armstrong and Howard T. Odum of the University of Texas Institute of Marine Science. The system is found as a thin mat on the bottom of shallow marine bays in southern Texas.

The algae at the top of the system are stained with an iron complex that darkens them and decreases the intensity of light reaching lower layers of algae, where maximum growth occurs. Below these layers, resting on the mud of the bottom, is a layer of decomposing algae that harbors the bacteria. Oxidizing conditions prevail in the layers of living algae and reducing conditions in the bacterial layer. In the reducing region nutrients needed by the algae, such as nitrates and phosphates, are maintained in a soluble state; they would be insoluble in the oxidizing region.

The half-volt potential detected across the layers by Armstrong and Odum may, they suggest, serve the purpose of moving positive ions up and negative ions down. Thus whereas the bacteria would be using carbon and other substances from the dead algae, the algae would obtain the positively charged ions of the soluble nitrates and phosphates from the bacteria.

Mysterious Whisky

What makes Scotch whisky taste like Scotch whisky? Numerous distillers outside Scotland have tried to duplicate the flavor and have failed. E. C. Barton-Wright, a biochemist, writes in the British magazine *New Scientist* that the flavor "is a complete mystery" and has remained so in spite of all attempts to analyze it.

Scotch is made from barley starch that is converted to malt and then mixed with water to make wort. With the addition of yeast the wort ferments to produce a beer; distillation of the beer produces whisky. Aging and blending are the final steps.

The characteristic flavor of Scotch has been attributed variously to the peculiarities of the barley, the custom of curing the malt over peat fires and the quality of the brook water mixed with the malt. Barton-Wright says that whatever the truth, it has proved inaccessible to outsiders for the related reasons that "the production of whisky is undoubtedly an art" and that "the secrets of a distillery are as closely guarded as those of a papal conclave." Yet even when the secrets have presumably been revealed, as in an Australian effort to make Scotch with "whisky experts and raw materials...sent from Scotland," the ventures have ended in failure. As a result "we are left with a genuine mystery."

The Circulation of the Upper Atmosphere

New studies identify regions in the atmosphere that operate like heat engines and others that operate like refrigerators. The latter move heat "uphill" and chill regions that otherwise would be warm

by Reginald E. Newell

One of the major tasks of meteorology is to identify persistent large-scale features of the atmosphere in the hope that they will provide clues to the highly changeable patterns seen on the daily weather map. It has been demonstrated only in the past 20 years or so that the regional weather patterns over the Northern Hemisphere are linked together by large-scale motions in the upper atmosphere. There is no doubt that the same kinds of linkages exist in the Southern Hemisphere, although the data there are much scantier.

Within the past six years, with the aid of balloons and rockets, a great mass of new information has been collected, and from it a reasonably complete picture of the general circulation of the upper atmosphere has emerged. The illustration on the opposite page shows how this circulation is dominated by four major wind cores, or jets, two in each hemisphere. The circulation is shown as it exists when it is summer in the Northern Hemisphere and winter in the Southern Hemisphere. Detailed evidence for the upper-level wind core in the Southern Hemisphere has not yet been obtained, but its existence can be inferred from observations made in the Northern Hemisphere in winter. Note that in winter both the lower and the upper cores blow from the west. In the summer the upper core reverses direction and blows from the east. I shall describe in this article how these great currents of air identify previously unsuspected regions in the atmosphere that can be compared to heat engines and refrigerators. Kinetic energy produced by the heat engines is made available to the refrigerators, which in turn create huge cold regions in the upper atmosphere that otherwise would be warm.

In viewing the illustration on the opposite page the reader must keep in mind that the depth of the atmosphere is enormously exaggerated. If the earth were represented by a ball six feet in diameter, the atmosphere up to a height of 80 kilometers (about 50 miles), which includes more than 99.999 per cent of the total atmospheric mass, would be only half an inch thick. And the air directly involved in the daily weather, the region below about 15 kilometers, would be less than a tenth of an inch thick. At the scale on which the earth is drawn in the illustration, the 80-kilometer layer of the atmosphere would be less than a twentieth of an inch thick.

Ten years ago the balloons commonly used in meteorology could carry instruments to a height of only 15 or 20 kilometers before bursting. During the International Geophysical Year, which began in July, 1957, a world-wide atmospheric sounding program was undertaken with balloons that could reach heights of 30 kilometers. These balloons could be tracked by radar to yield the speed and direction of the wind, and they carried instruments that transmitted information about pressure and temperature. In addition a number of sounding rockets were fired during the IGY to gather information on conditions above 30 kilometers. It was not until 1959, however, that a co-ordinated effort was organized by the U.S. to make rocket soundings in various parts of the Northern Hemisphere on the same day, so that a hemisphere-wide picture of the general circulation between 30 and 60 kilometers could be pieced together.

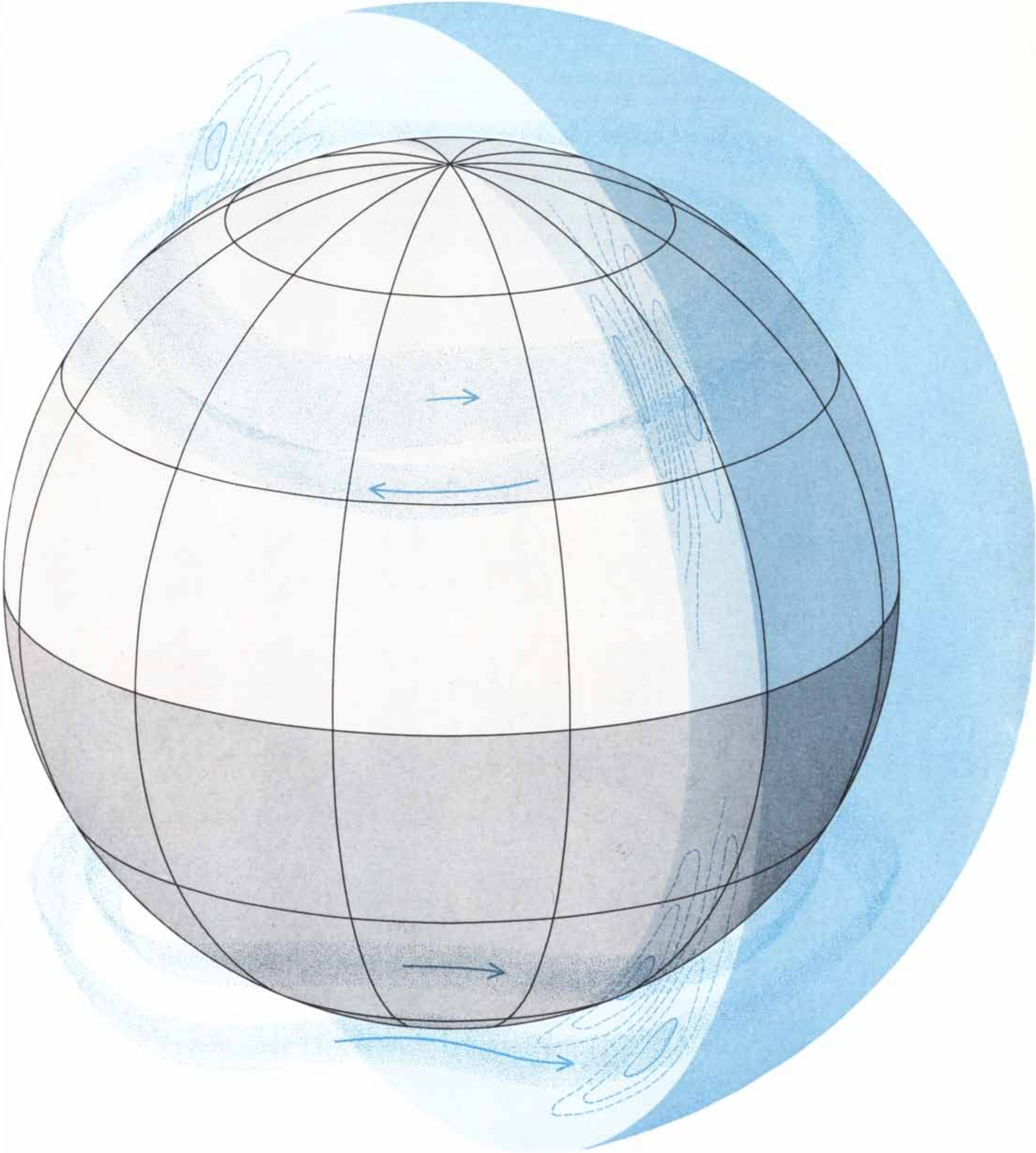
Light and relatively cheap rockets for this purpose had become available as a by-product of the space program. On reaching peak altitude these small rockets eject a radar target, such as "chaff" (small metal strips) or a metalized parachute or balloon, which can be tracked as it falls through the atmosphere. By observing how these falling objects are carried horizontally by air currents one can establish the speed and direction of the wind at various altitudes. Balloons can also provide information about changes in atmospheric density because their speed of descent is influenced by density. Temperature measurements up to altitudes of about 50 kilometers can be obtained from a thermometer-and-telemeter package, which descends by parachute.

During 1959, when the meteorological rocket network was first organized, there were fewer than 20 successful rocket firings from three different sites. Last year there were about 1,000 firings from the 13 stations shown on the map on page 64. Plans are being made to expand the network each year, with more and more countries participating until there is global coverage.

Thus in the short space of six years the meteorologist has available on a regular basis observations from heights some four times greater than before. Of course, the additional mass of air sampled is small (about a tenth of that studied previously in the lower atmosphere), and one must always bear this in mind when considering the magnitude of possible interactions of the upper and lower regions.

Balloon and Rocket Data

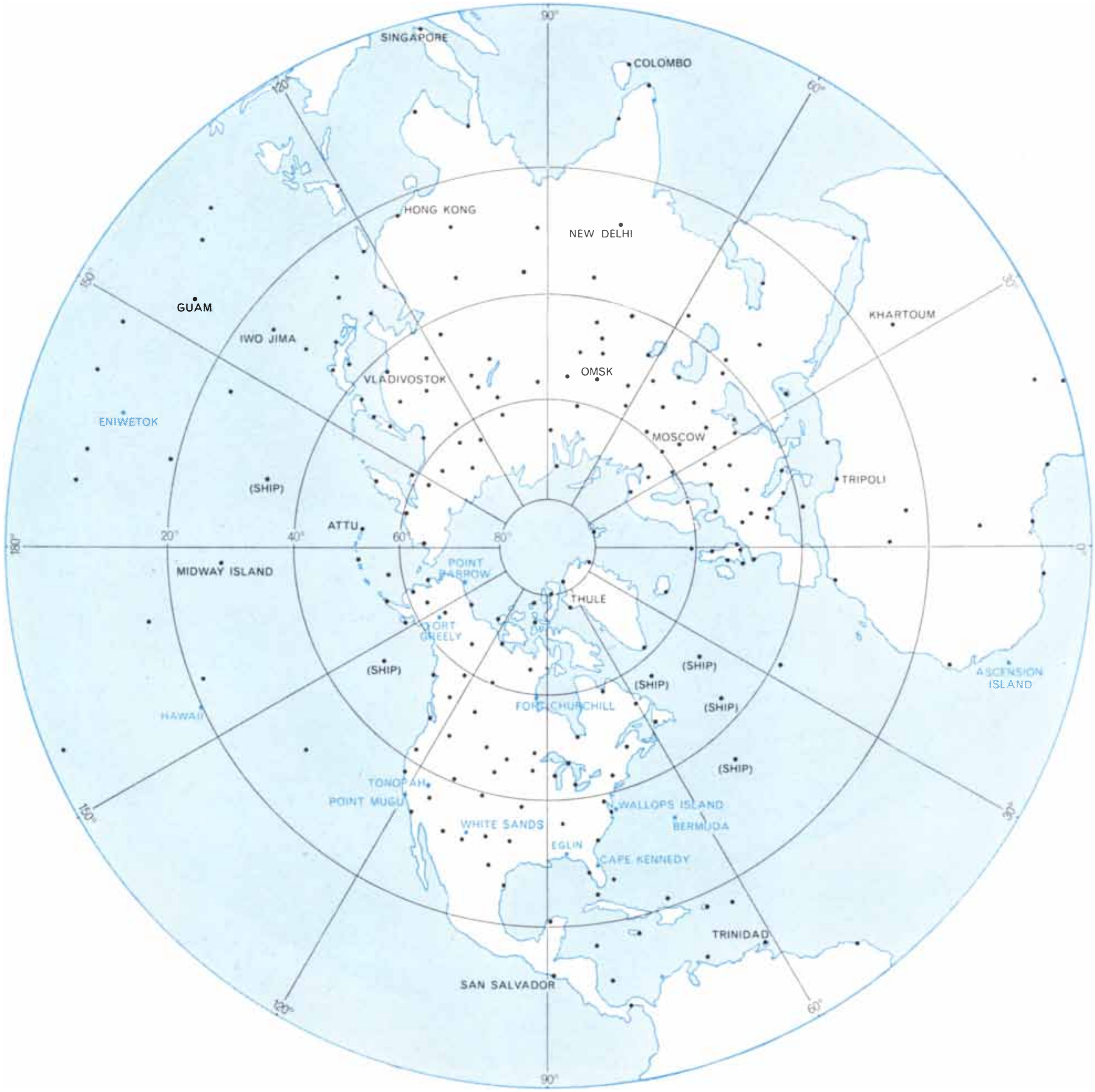
At the Massachusetts Institute of Technology we have used the newly acquired data to study the general circulation of the atmosphere in these higher regions following the procedures that have been successful for the lower atmosphere [see "The General Circulation of the Atmosphere," by Victor P. Starr; Scientific American, Decem-



FOUR WIND CORES dominate the circulation of the atmosphere. This illustration represents the atmosphere up to an altitude of 80 kilometers, or about 50 miles. If drawn to scale, this depth of atmosphere would be less than a twentieth of an inch thick. The cores are shown for summer in the Northern Hemisphere and winter in the Southern Hemisphere. Arrow lengths are proportional to wind speed. Note that the two cores circling the winter hemisphere blow from the west but that in summer the upper core reverses direction. This reversal is well established for the Northern Hemisphere and is assumed to hold true for the Southern Hemisphere.

ber, 1956]. We try to establish the direction of the prevailing winds, the location of hot and cold regions and the source of the energy that drives the winds. More precisely, we try to find out how the atmosphere manipulates heat energy, mass and momentum to keep everything in balance. Rather like the physician who examines a patient for the first time, we term these investigations diagnostic studies. When they have been completed, we hope we shall be able to explain why the atmosphere behaves as it does.

Our first step in the examination of these higher levels was to collect the meteorological observations made during the 18-month period of the IGY by some 250 observing stations spotted throughout the Northern Hemisphere. Each station launched about 1,000 balloons during the period (every day at midnight and midday Greenwich Mean Time) and recorded atmospheric conditions at various levels. By agreement all stations reported measurements at four levels in the atmosphere, corresponding roughly to heights of 16, 21, 25 and 30 kilometers. Two hundred and fifty stations, 1,000 balloons per station and four levels per balloon gave us a total of about a million observations each of pressure, temperature and wind, which we approached with some trepidation. We employed an electronic computer for many of the tedious calculations, but there was still much work to be done by hand. The study was started by Robert M. White (who was recently appointed chief of the U.S. Weather Bureau) when he was in the department of meteorology at M.I.T.



METEOROLOGICAL STATIONS that reported temperature, pressure and wind velocity in the upper atmosphere during the International Geophysical Year (18 months beginning in 1957) are identified by black dots. These stations launched balloons that were tracked to a height of 30 kilometers (about 19 miles). The 13 stations identified in color form a network created in 1959 to launch meteorological rockets to a height of 60 kilometers. Data collected by the two groups of stations are reviewed in this article.

Above 30 kilometers we had the results from about 850 successful meteorological rocket flights, mostly from stations across the North American continent. Although the picture obtained cannot yet be called hemispheric, isolated observations over Europe, the U.S.S.R. and Japan appear to be consistent with the North American findings. Most of the rocket flights gave good wind data, many up to heights of 60 kilometers, but temperature proved troublesome to measure. In fact, we supplemented our temperature data with the results from some experimental rockets fired by the U.S. Army Signal Corps during the IGY and by the National Aeronautics and Space Administration since 1959, which measured temperatures and winds rather well up to heights of 80 or 90 kilometers.

One of our first steps was to synthesize from all these observations a picture of the mean wind field and temperature from the surface up to a height of about 80 kilometers [*see illustrations on next page*]. Initially we have divided the year into two seasons, winter and summer, because the limited number of rocket firings to the higher altitudes do not provide enough data for a four-season analysis. We feel that the general features of wind and temperature are the same at all longitudes. In the lower part of both the winter and the summer systems there is a core of westerly winds with a mean height of about 12 kilometers; it meanders around the earth for the entire year but is somewhat stronger in winter than it is in summer. This wind system, which was discovered during World War II, is sometimes called the jet stream; it extends up to about 22 kilometers. Above this altitude in winter there is another westerly core in middle latitudes with its center at a height of 50 or 60 kilometers. There have not yet been enough observations made above 60 kilometers to define the top of this core precisely.

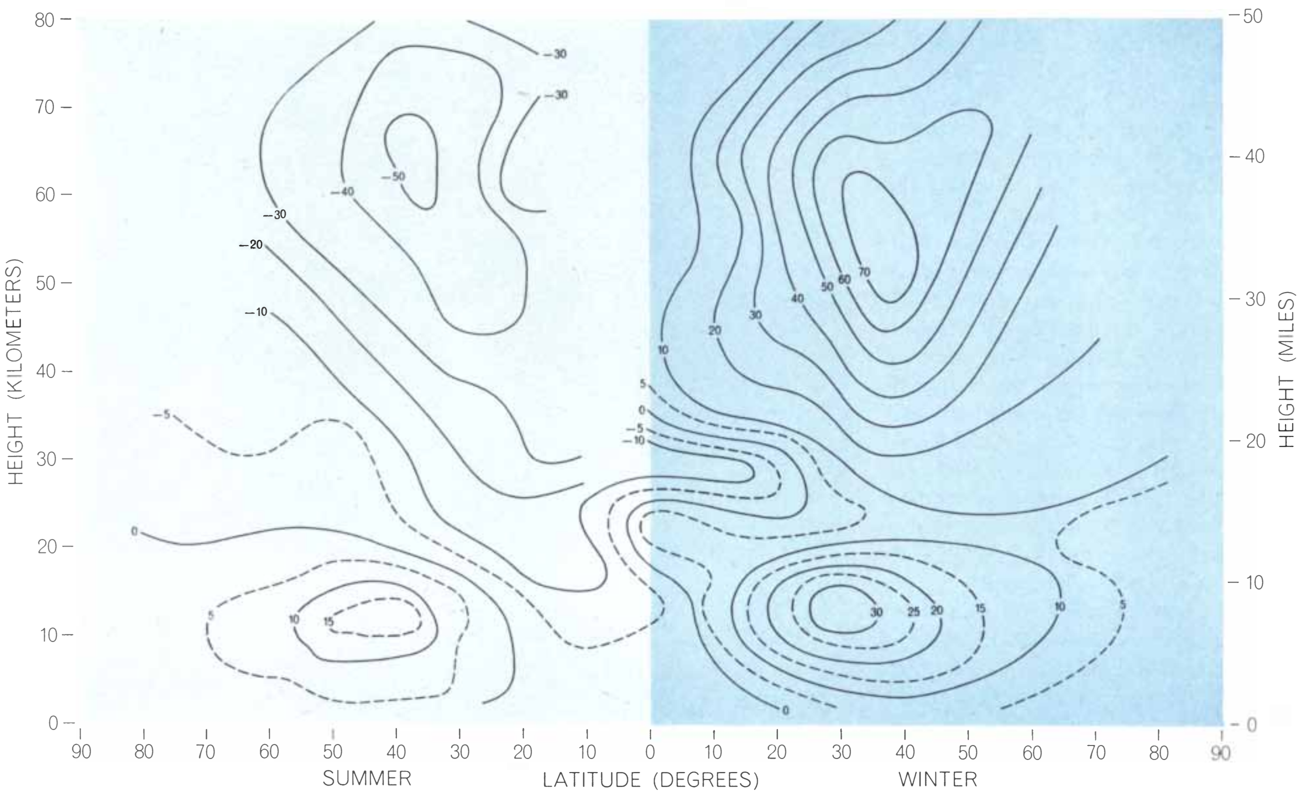
Wind speeds in the high-level core average about 70 meters per second (160 miles per hour), which is more than twice the wind speed in the lower core. Unlike the lower core, the upper one reverses its direction and blows from the east in summer. We do not have enough observations to say much about the circulation patterns over the Equator or over polar regions above 30 kilometers. Between 30 and 20 kilometers the balloon observations show that the winds just over the Equator blow from the west for about 13 months, then from the east for 13 months, and so on. Thus there are really three circulations

METEOROLOGICAL ROCKET ***Arcas*** **is fired at White Sands Missile Range in New Mexico. Such rockets reach an altitude of 50 to 60 kilometers and eject a target that can be tracked on its way down to provide wind data. On many flights temperature is also reported.**

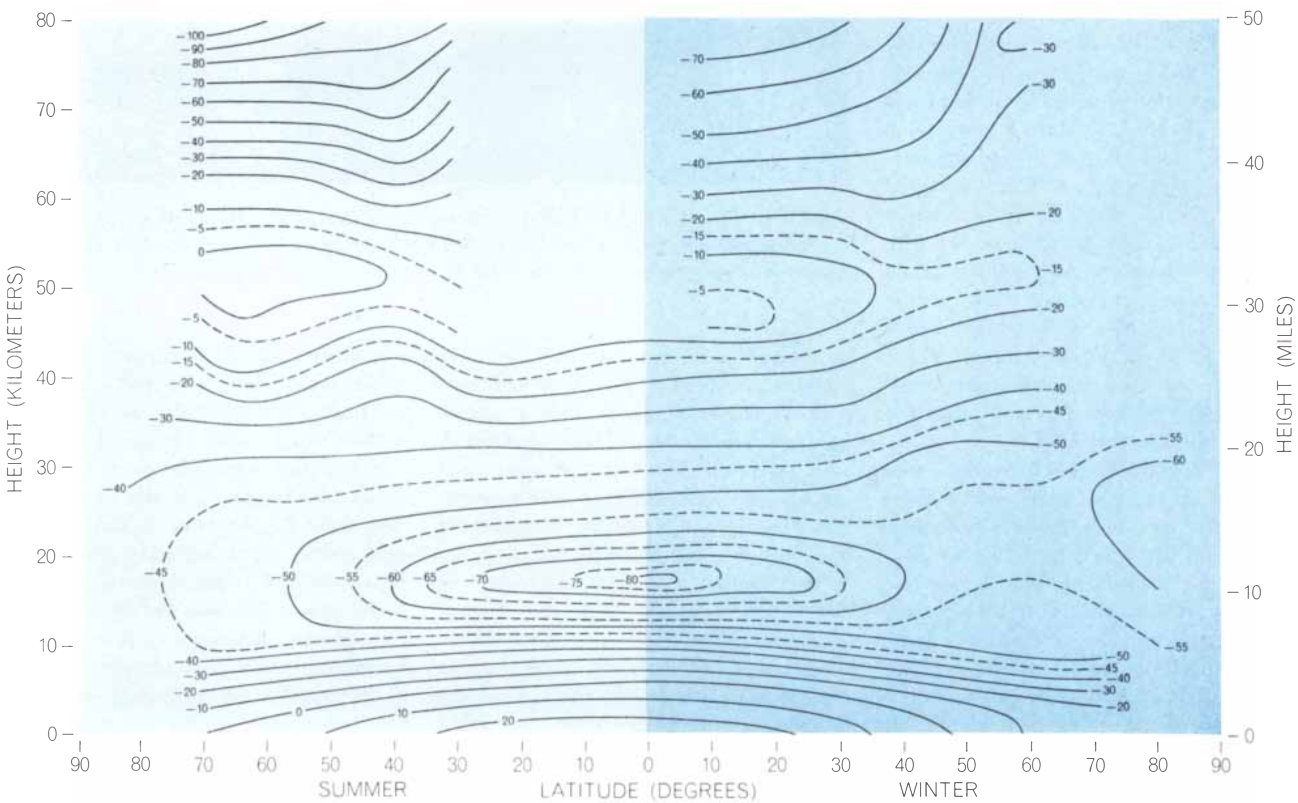
of interest: one, the low-level westerly core, is constant in direction; the second, the high-level core, changes from westerly to easterly and back again each year, and the third is the equatorial middle-level circulation. I shall not discuss the third any further because we still do not know much about it.

The temperature patterns show, as one might expect, that the largest changes take place in the vertical direction. A vertical profile of temperature in middle latitudes would show that the temperature decreases with increasing altitude up to about 15 kilometers [*see illustration on page* 67]. Above that height the temperature increases up to an altitude of about 50 kilometers, then falls again, and it is still falling at about 80 kilometers. (Somewhere around 90 kilometers the temperature starts to climb again.) This S-shaped pattern was originally inferred from an analysis of meteor tracks and confirmed by early rocket flights some 20 years ago.

The horizontal patterns of temperature from the Equator to the pole also exhibit striking peculiarities. (Again conditions in both hemispheres are assumed to be reasonably symmetrical, allowing for seasonal differences.) It is common knowledge that temperatures at the earth's surface decrease from the Equator to the pole, and a comparable decrease holds true for the bottom 10 kilometers of the atmosphere. At the 15-to-20-kilometer level, however, the situation is reversed and temperatures of about −80 degrees centigrade can be found over the Equator the year



WIND CROSS SECTION shows average zonal (west-to-east) wind velocities in meters per second over the Northern Hemisphere in summer (*left*) and in winter (*right*). Negative numbers indicate that the wind is from the east. The summer-winter pattern is the same as that depicted on a global scale on page 63. Contour lines up to 30 kilometers summarize about a million wind-speed measurements obtained with balloons. Data above 30 kilometers came from about 850 rocket flights, mostly over North America.



TEMPERATURE CROSS SECTION contrasts the summer and winter patterns over the Northern Hemisphere as determined by balloon- and rocket-borne instruments. The temperatures are in degrees centigrade. As in the case of the wind data, the contours can be regarded as showing the temperature distribution from pole to pole when it is summer in one hemisphere and winter in the other.

round, whereas temperatures over the Arctic vary from about — 40 degrees C. in summer to around — 60 degrees C. or less in winter.

Higher still, between 25 and 50 kilometers, temperatures decrease toward the winter pole and increase toward the summer pole. This is to be expected; the winter pole receives no solar radiation during the long polar night, and the summer pole is continuously heated by the sun. Paradoxically, in the next highest region, between 50 and 80 kilometers, recorded temperatures swing directly opposite to expectations. In the middle of winter temperatures high over the pole appear to be scarcely lower than at the polar surface: about — 30 degrees C. In summer, when the sun is shining steadily on the pole, the temperature at about 80 kilometers can plummet to as low as — 140 degrees C., the lowest temperature yet recorded in the earth's atmosphere.

It is clear that this is curious behavior and that it must be accounted for by processes that can move large quantities of heat energy from regions where it is available to regions where it is not. Indeed, one finds that the temperature distribution is inextricably linked to the wind distribution; the two must be considered together. But first let us consider the simpler problem of why there is in the atmosphere a vertical interleaving of two hot and two cold regions.

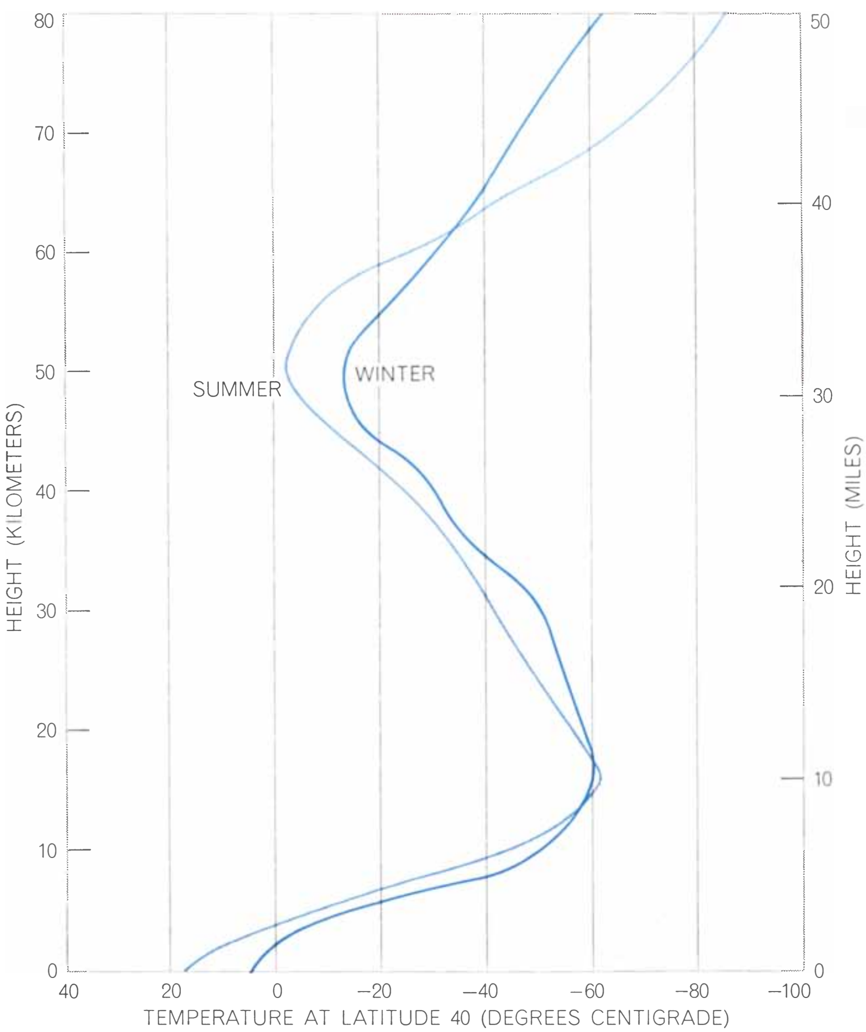
The Earth as a Radiator

The explanation involves the type of radiation received from the sun, the type of radiation directed back into space from the earth and the interaction of both types of radiation with the atmosphere. The radiation from the sun has its peak in the visible region of the spectrum at a wavelength of about .5 micron. At longer wavelengths the solar output decreases steadily; it is negligible beyond 7.5 microns [*see upper illustration on next page*]. The sun's ultraviolet output (lying roughly between .2 and .3 micron) is heavily absorbed by the ozone concentrated in the atmosphere between 15 and 60 kilometers. As ultraviolet energy is absorbed the atmosphere is heated, and it is found that the maximum heating rate occurs at a height of about 50 kilometers. Of the total incoming solar radiation a few per cent is absorbed in this way and never reaches the ground.

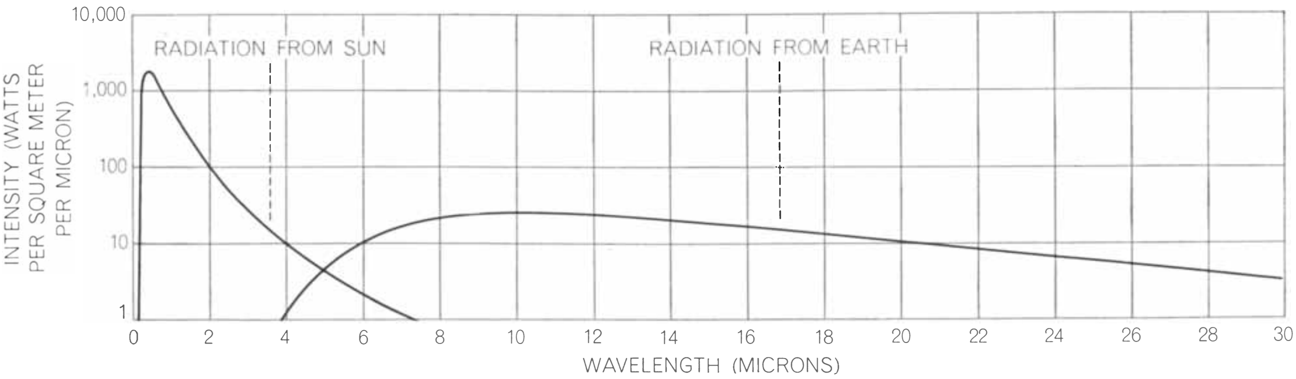
The remaining radiation penetrates to lower regions, where some is reflected back into space by clouds, some is absorbed by air molecules and some is simply scattered. At the ground a portion of the incoming radiation is immediately reflected, depending on the reflectivity of the surface, and the remainder is absorbed. On the average about 19 per cent of the total incoming solar radiation is absorbed in the atmosphere, 34 per cent is reflected into space and 47 per cent is absorbed at the ground. These figures are given in a study of the radiation budget by Henry G. Houghton of M.I.T.

Of the 47 per cent absorbed at the ground some goes to heat the air in direct contact with the surface, some goes to evaporate water and the rest is reradiated at wavelengths characteristic of a body whose average temperature is about 10 degrees C. Such wavelengths are much longer than those radiated by the sun, whose surface temperature is some 5,800 degrees C. The earth's radiation peaks at about 10 microns [*see upper illustration on next page*] and is strong well beyond 30 microns.

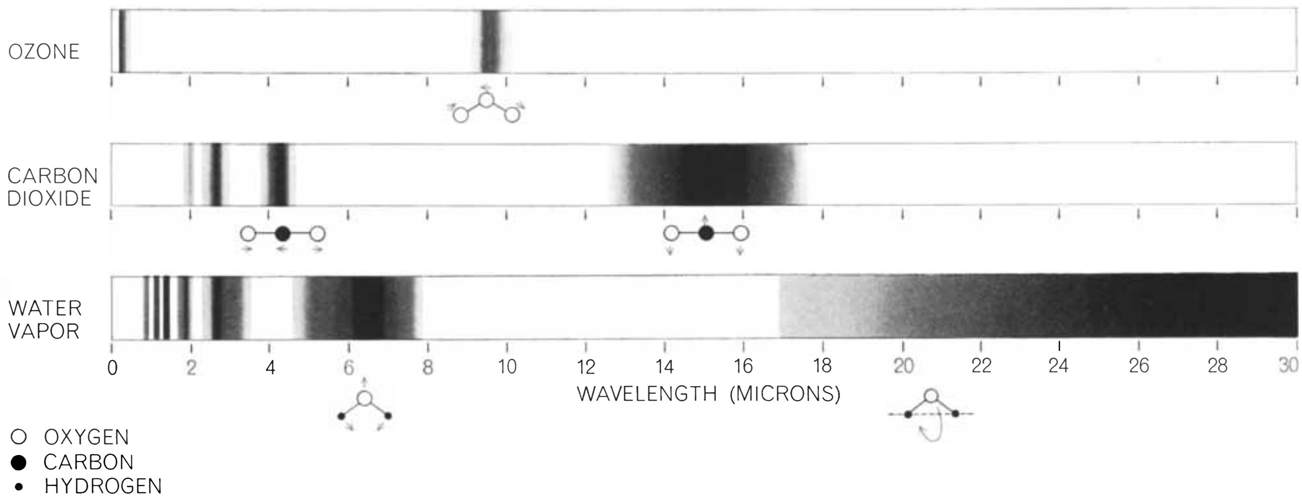
If the earth had no atmosphere, this long-wavelength radiation would simply be lost to space. At nightfall, even at the Equator, surface temperatures would fall far below 0 degrees C. Even an atmosphere consisting solely of nitrogen and oxygen would not present much of a barrier to the earth's loss of heat by radiation. Fortunately the atmosphere is adulterated with certain beneficent molecules, each consisting of three atoms, that can intercept the outgoing radiation. Those substances are ozone, carbon dioxide and water vapor. Molecules of these substances can vibrate and rotate in various ways, depending on their state of excitation. A molecule can go from one state to another only by the emission or absorption of a quantum



TEMPERATURE PROFILES at latitude 40 are derived from the cross-sectional data at the bottom of the opposite page. Temperatures drop with altitude for the first 15 kilometers, then climb to a maximum at about 50 kilometers before falling again. The S-shaped curve is roughly the same summer and winter. The heating at 50 kilometers identifies the region where the sun's ultraviolet radiation is most strongly absorbed by ozone in the atmosphere.



SOLAR AND EARTH RADIATION for the most part occupy different regions of the electromagnetic spectrum. Solar radiation has the short wavelength characteristic of a body that is at 5,800 degrees C. Earth radiation has the much longer wavelength of a body that is at about 10 degrees C. This is the temperature at which the earth radiates back into space as much energy as it receives.



RADIATION IS ABSORBED at specific wavelengths (*shaded regions*) by three kinds of molecule in the atmosphere: ozone, carbon dioxide and water vapor. When these molecules absorb or emit infrared radiation (which has a wavelength longer than .7 micron), a change is produced in their mode of vibration or rotation, or both. Certain near-ultraviolet wavelengths (radiation shorter than .3 micron) are absorbed when ozone is split into its constituents. It is created by still shorter wavelengths of ultraviolet radiation.

of energy. The energy can be in the form of either radiation or kinetic energy, which is received or expended in collisions with other molecules.

It happens that these triatomic molecules are very effective in absorbing particular wavelengths of the earth's radiation. Thus the earth's outgoing longwave radiation is absorbed and re-emitted countless times as it progresses upward through the atmosphere. At the low pressures prevailing at high altitudes absorption is less effective (because of a decrease in the width of the absorption bands) and the radiation is ultimately allowed to escape into space.

In the lower atmosphere the two molecules most involved in absorption and re-emission are carbon dioxide and water vapor; above 12 kilometers carbon dioxide and ozone play the chief role. Throughout most of the 25-to-60-kilometer region the net contribution of these molecules in the infrared part of the spectrum is to cool the air. Simultaneously ozone is absorbing solar ultraviolet energy and heating the air.

At all levels of the atmosphere the incoming and outgoing streams of radiation are approximately in balance and the equilibrium point is reflected in the temperature. At a height of about 50 kilometers ultraviolet absorption by ozone is at a maximum. As a result the air temperature rises until the heat lost by infrared radiation closely balances the heat gained by the absorption of ultraviolet. Above and below 50 kilometers the amount of ultraviolet absorption is smaller and the equilibrium temperature is correspondingly lower.

In the bottom 10 kilometers of the atmosphere temperatures tend to follow those of the earth's surface, so that the lowest-lying region is again warmer than the region midway between 10 and 50 kilometers. Thus the S-shaped curve of temperature between the surface and a height of 80 kilometers is accounted for.

Let us now consider the variations of temperature with latitude, that is, the Equator-to-pole variations. On a typical winter day surface temperatures range from 25 degrees C. (a pleasant 77 degrees Fahrenheit) at the Equator to — 25 degrees C. (— 13 degrees F.) at the pole. The incoming solar radiation strikes the equatorial regions nearly vertically, but at higher and higher latitudes the sun's rays strike the earth at a lower and lower angle. As a result the high latitudes receive less radiation per unit of area than lower latitudes do.

On the other hand, the long-wave dissipation of the earth's surface heat is proportional to the fourth power of the absolute temperature (obtained by adding 273 to the centigrade values) and therefore does not vary greatly with latitude. At the pole the mean annual loss is 390 calories per square centimeter per day, compared with 500 such units at the Equator. (It takes about 20,000 calories to raise a cup of water from room temperature to the boiling point.) In contrast the Equator receives almost five times more direct solar radiation annually than the pole: 580 calories per square centimeter per day, compared with 120 calories. These values, calculated by Houghton, apply to the bottom 12 kilometers of the atmosphere. As the chart on this page shows, there is a net excess of incoming radiation between 37 degrees north and south of the Equator and a net deficiency poleward of these two latitudes.

An Atmospheric Heat Engine

It is clear that heat must be carried in some fashion from the Tropics to the poles, otherwise the tropical regions would become steadily hotter and the polar regions steadily colder. A small fraction of this poleward transport of heat is accomplished by ocean currents, but the principal transporting agent is the atmosphere. The transport is achieved with high efficiency by the large-scale eddy circulations that show up on the weather map as high-pressure regions (anticyclones) and low-pressure regions (cyclones). These great weather systems carry warm air toward the poles and cold air toward the Equator.

So far the term "momentum" has been mentioned only in passing. It is perhaps evident that a mass of air turning with the earth at the Equator carries more angular momentum (an effect attributable to spinning) than the same mass of air turning with the earth near the pole. The eddies that carry heat northward also take momentum with them, thereby creating the prevailing westerly winds and the high-speed westerly core observed at about 12 kilometers.

The lower atmosphere can therefore be described as a simple heat engine heated at the Equator and cooled at the poles. The characteristic of such an engine is that heat energy flows down the temperature gradient from a heat source to a heat sink. Calculations of the poleward transport of heat based on wind and temperature observations show that its amount agrees closely with that needed to balance the earth's radiation budget.

Here it is pertinent to ask: How is the heat energy converted into kinetic energy of the winds? Imagine, if you will, two vertical columns of air, one at the Equator and the other at the pole; each column has the same cross-sectional area and contains the same mass of air. Because the hot column over the Equator is being heated by incoming radiation its center of gravity will tend to be higher than that of the column over the pole, which is being cooled by outgoing radiation. If the two columns are regarded as part of one system, it will be evident that the heating and cooling have created a certain amount of potential energy, and one measure of it can be found in the difference in height of the centers of gravity in the two columns.

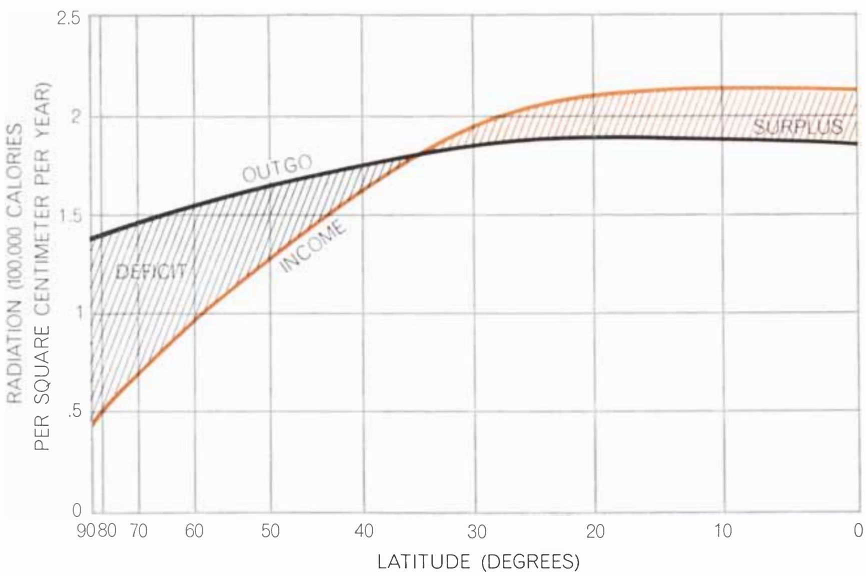
To convert the potential energy into kinetic energy the two columns must be connected. In the imagination this can be done by moving the columns together until they are side by side in a box, separated only by a partition. If the partition is removed, the cold air will slide under the warm air and the warm air will rise over the cold. Although it may not be intuitively obvious, the resulting center of gravity of the system will be lower than the mean center of gravity of the two columns before they came in contact. When the two columns are brought together, horizontal motion occurs and kinetic energy is released. This energy represents a conversion of potential energy into kinetic energy, as evidenced by the lowering of the center of gravity.

In the atmosphere warm equatorial air masses and cold polar air masses are brought together in cyclones. The warm air rises above the cold air, often producing rain as it ascends, and kinetic energy is poured into the resulting wind systems. In this way the lower atmosphere functions like a heat engine, producing kinetic energy from potential energy, which is derived in turn from radiation. Ultimately much of the kinetic energy is lost by friction between masses of air and between the air and the ground.

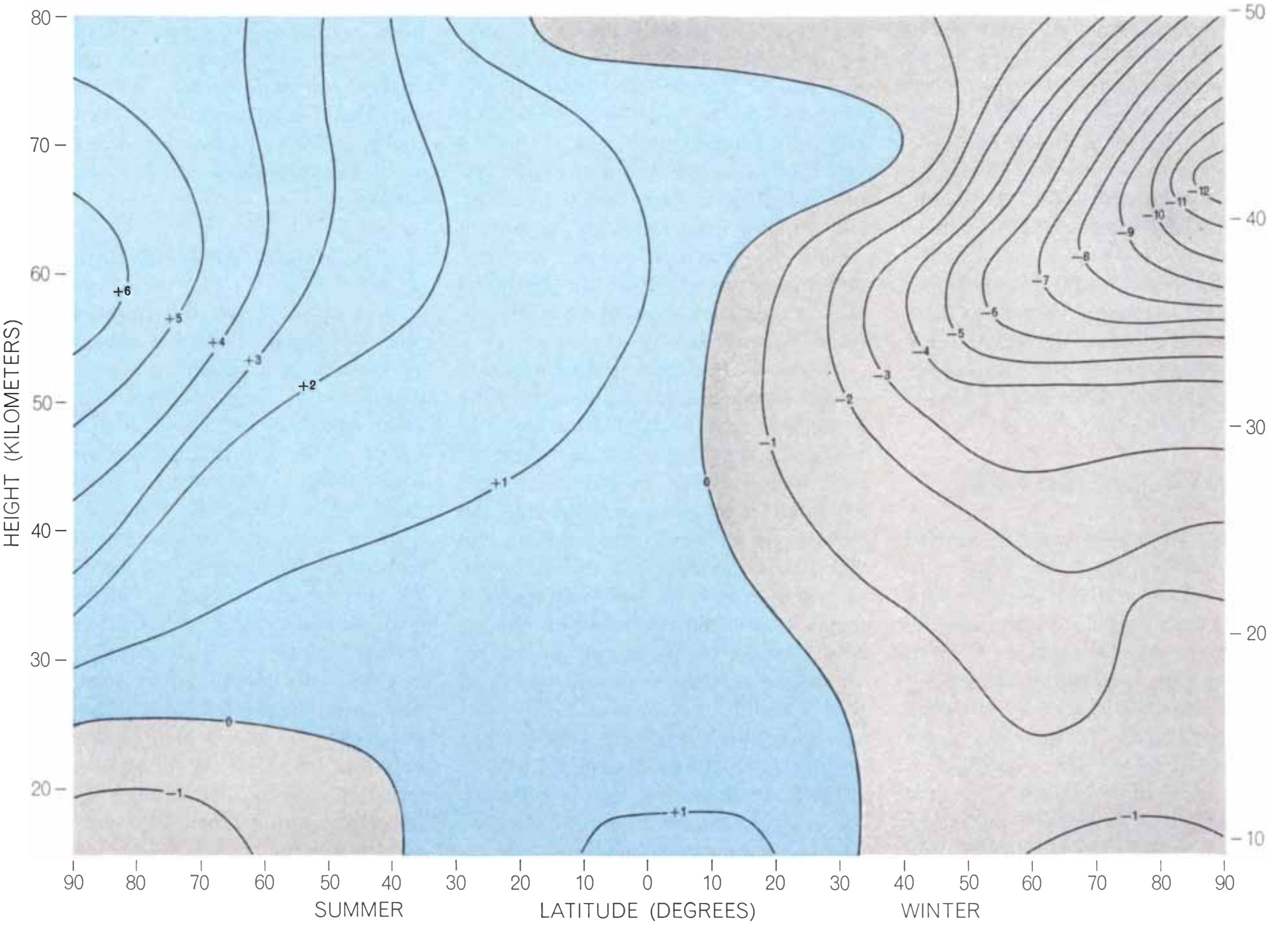
The 15-to-20-Kilometer Region

We can now ask the question: Do other atmospheric regions, those above 12 kilometers, also behave like heat engines? Let us first consider the 15-to-20-kilometer layer, which contains the upper section of the bottom westerly core. Here we observe that it is significantly colder over the Equator (– 80 degrees C.) than it is over the 60th parallel (– 55 degrees C.). This is just the reverse of what one would predict from considerations of radiation. The warmer northerly air should steadily lose heat by radiation into space, and the colder equatorial air should be heated by the excess of incoming solar radiation over the outgoing long-wave radiation. Yet the temperature differential, representing potential energy, lasts all year round.

Obviously this region of the atmosphere is not behaving like a heat engine. Some force is at work to preserve the potential energy that would otherwise tend to disappear. When Arnold Barnes and Abraham Oort were members of our group at M.I.T., they calculated the energy conversions in this region, using IGY data, and found that large-scale ed-



EARTH'S HEAT BUDGET requires a balance between incoming solar radiation and outgoing radiation from the earth. Between 37 degrees north and south of the Equator radiation income exceeds outgo. Poleward from these latitudes there is a heat deficit. The chart uses data of Henry G. Houghton of the Massachusetts Institute of Technology.



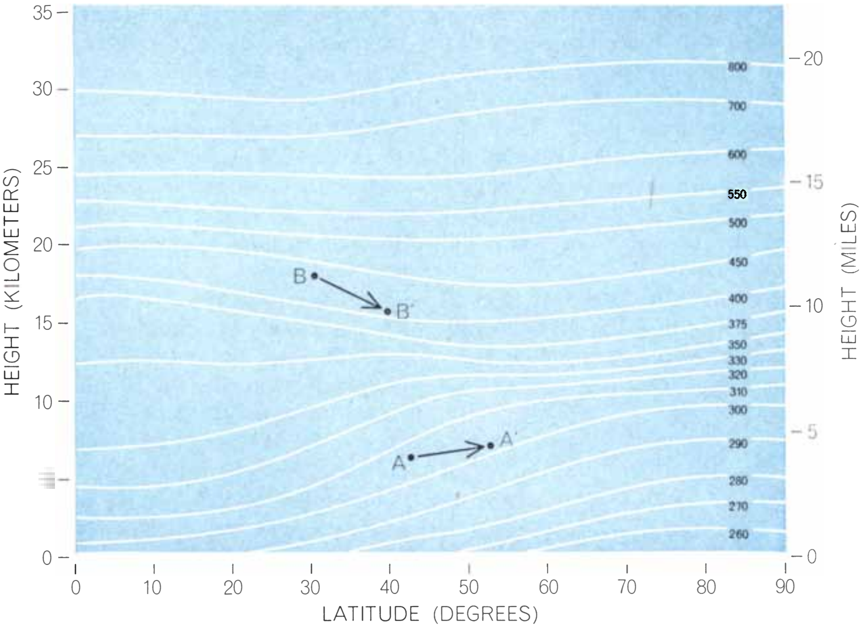
THEORETICAL TEMPERATURE CHANGES that would be produced in one day have been computed for a motionless atmosphere. In the winter radiation would sharply cool the upper atmosphere over the sunless pole. In the summer solar radiation would heat the same region. Temperature changes are in degrees C. This chart is based on the work of R. J. Murgatroyd and F. Singleton of the British Meteorological Office, R. M. Goody of Harvard University and George Ohring of the Geophysics Corporation of America.

dies convert kinetic energy into potential energy. Although this explains why the potential energy does not disappear, it leaves the source of the kinetic energy unaccounted for. On the basis of limited evidence it appears that the kinetic energy may be leaking upward from the lower portion of the westerly core, which is in the vicinity of 12 kilometers.

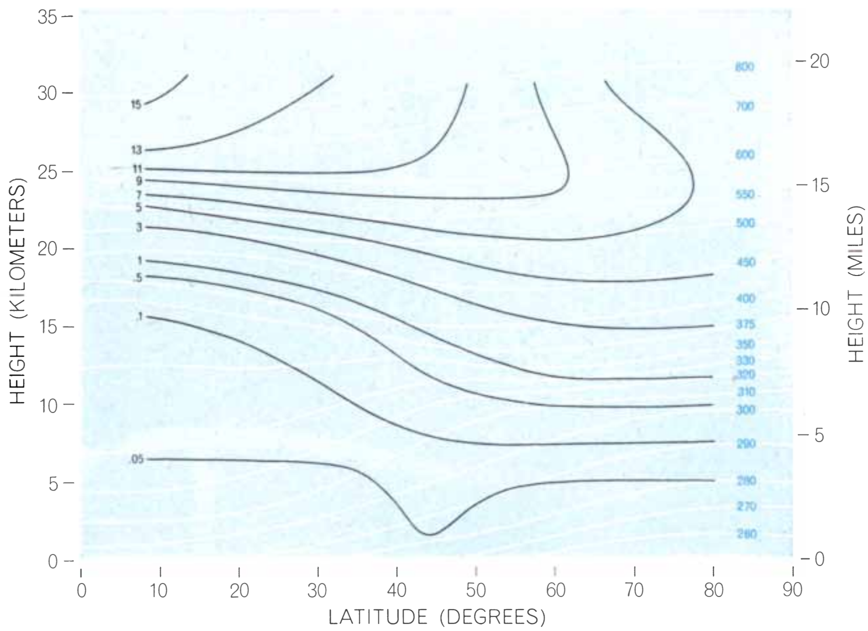
Three additional facts that must be explained in a satisfactory theory have emerged from observations in this same 15-to-20-kilometer region. First, the region contains a poleward flux of heat that is directed opposite to the temperature gradient. The observation, originally made some 10 years ago by Robert White, was confirmed during the IGY. Second, it has been found by C. J. Loisel and A. C. Molla, who are also in our M.I.T. group, that parcels of air moving poleward in this region sink and that parcels moving toward the Equator rise. Finally, when David Martin and I studied the way in which ozone is moved about in the region, we found that poleward-moving air parcels contained more ozone than those moving in the opposite direction. This would be the case if the poleward-moving parcels had descended from an altitude of 20 to 30 kilometers over the Tropics, where much of the ozone is formed. (When ozone descends below 25 kilometers, it is no longer subject to dissociation by ultraviolet radiation and can be used as a tracer.) Linking all three observations were some studies by Martin and Alan Brewer of the University of Oxford showing that air parcels that contained the most ozone were warmer than others at the same latitude and had moved up from the Tropics.

These various findings, reported by different people, were rather like the pieces of a jigsaw puzzle until about a year ago, when I visited the Imperial College of Science and Technology in London for several weeks. During a discussion over coffee after lunch, Percival A. Sheppard, head of the meteorology department, challenged me with some questions concerning the distribution of radioactivity and ozone in the atmosphere and their relation to the "Eady diagram," a concept developed 15 years ago by Eric T. Eady, a member of Sheppard's department. I was unable to provide complete answers at the time, but that evening the pieces of the puzzle fitted into one possible picture.

To explain the Eady diagram I must first describe how one can chart the distribution of "potential temperature" in the atmosphere instead of actual temperature [*see upper illustration on opposite page*]. The potential temperature is the temperature the air would have if it were brought down to the surface without any exchange of heat with the environment on the way. (This kind of movement is termed "adiabatic motion.") To accomplish this one can imagine lowering the air by placing it inside a perfectly insulated balloon. Naturally the balloon would decrease in volume as the air within it was compressed to match the density of the air at lower altitudes, and as the air was compressed it would be heated. One can see that rarefied air brought down from very



POTENTIAL TEMPERATURE SURFACES are shown for one hemisphere in late winter. Temperatures are given in degrees Kelvin (degrees C. above absolute zero). The potential temperature is that which the air would have if it were brought down to the surface without exchanging heat with the surrounding air. Actual air parcels flowing poleward at lower altitudes (*A,A'*) do not rise so steeply as the potential-temperature surfaces. At higher altitudes poleward-moving parcels (*B,B'*) descend more steeply than these surfaces do.



OZONE CONCENTRATION (*black lines*) shows that ozone formed high over the Equator is forced downward and poleward in January and February. The concentration is given in micrograms per gram of air. The data were collected by Wayne Hering and his associates at the Air Force Cambridge Research Laboratories, using instruments designed by Victor H. Regener of the University of New Mexico. White lines are potential-temperature surfaces.

high altitudes, even though cold at the outset, would be hotter on reaching the surface than initially warmer air brought down from lower altitudes. Hence these potential temperatures increase with altitude.

What Eady pointed out 15 years ago is that in the lower atmosphere actual air parcels move along paths whose slope is smaller than the slope of the mean potential-temperature surfaces. In the upper illustration on this page parcel *A* represents warm air being taken poleward and upward. At point *A'* if the motion is adiabatic, the parcel will still be warmer than its environment; therefore it will be buoyant and continue to rise. If the cold air that moves in to take its place travels equatorward and downward, the result will be a lowering of the center of gravity of the volume of atmosphere in which the exchange of air occurs. In the process potential energy is converted to kinetic energy.

In the next region higher up—the 15-to-20-kilometer level—events appear to be otherwise. Referring again to the upper illustration, one can see that if an air parcel such as *B* moves poleward and downward at a slope exceeding that of the potential-temperature surface, it will be warmer than its environment on arriving at *B'*. Consequently it will be buoyant and tend to go back up. Evidently, however, forces are available to keep this from happening; as a result the 15-to-20-kilometer region in the middle latitudes is warmer than might be expected. Similarly, if the air parcels moving toward the Tropics are forced upward rather than being allowed to descend, one can account for the very cold temperatures over the Equator.

How the forcing is accomplished is somewhat obscure. Evidently the kinetic energy of the motions themselves can do the job, provided that the energy is replaced by upward transport from the lower portions of the westerly core. Because the mass of air in the 15-to-20-kilometer region is so much less than that in the region below 15 kilometers, the upward leakage needs to be only a tiny fraction of the kinetic energy in the lower atmosphere.

Thus we see that Eady's fruitful concept can easily be extended to account for the three observations in the 15-to-20-kilometer region that had seemed so puzzling: the poleward flux of heat, the sinking of poleward-moving air parcels and the high concentration of ozone in poleward-moving air.

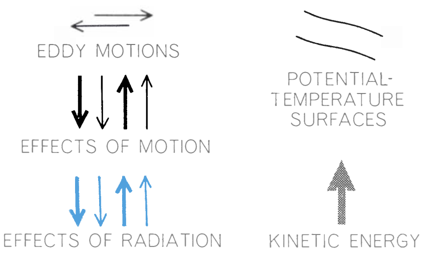
Is there any direct evidence that parcels of air moving poleward follow a downward slope? Actual air-parcel paths can be found by mapping the concentration of a trace substance that moves along unchanged with the air. One such substance is ozone, whose concentration lines do slope downward toward the pole more steeply than the potential-temperature surfaces [*see lower illustration on this page*]. Radioactive tungsten 185, which was injected into the region in some of the nuclear-bomb tests conducted in the Pacific in 1958, was also found to move poleward and downward. Debris produced in the bomb tests conducted by the U.S.S.R. in polar regions late in 1961 moved equatorward and upward. One can make rough estimates of the energy-conversion rates involved in these energy-consuming movements by determining the angles between the concentration lines and the potential-temperature surfaces. The conversion rates turn out to be quite close to those determined from wind and temperature data.

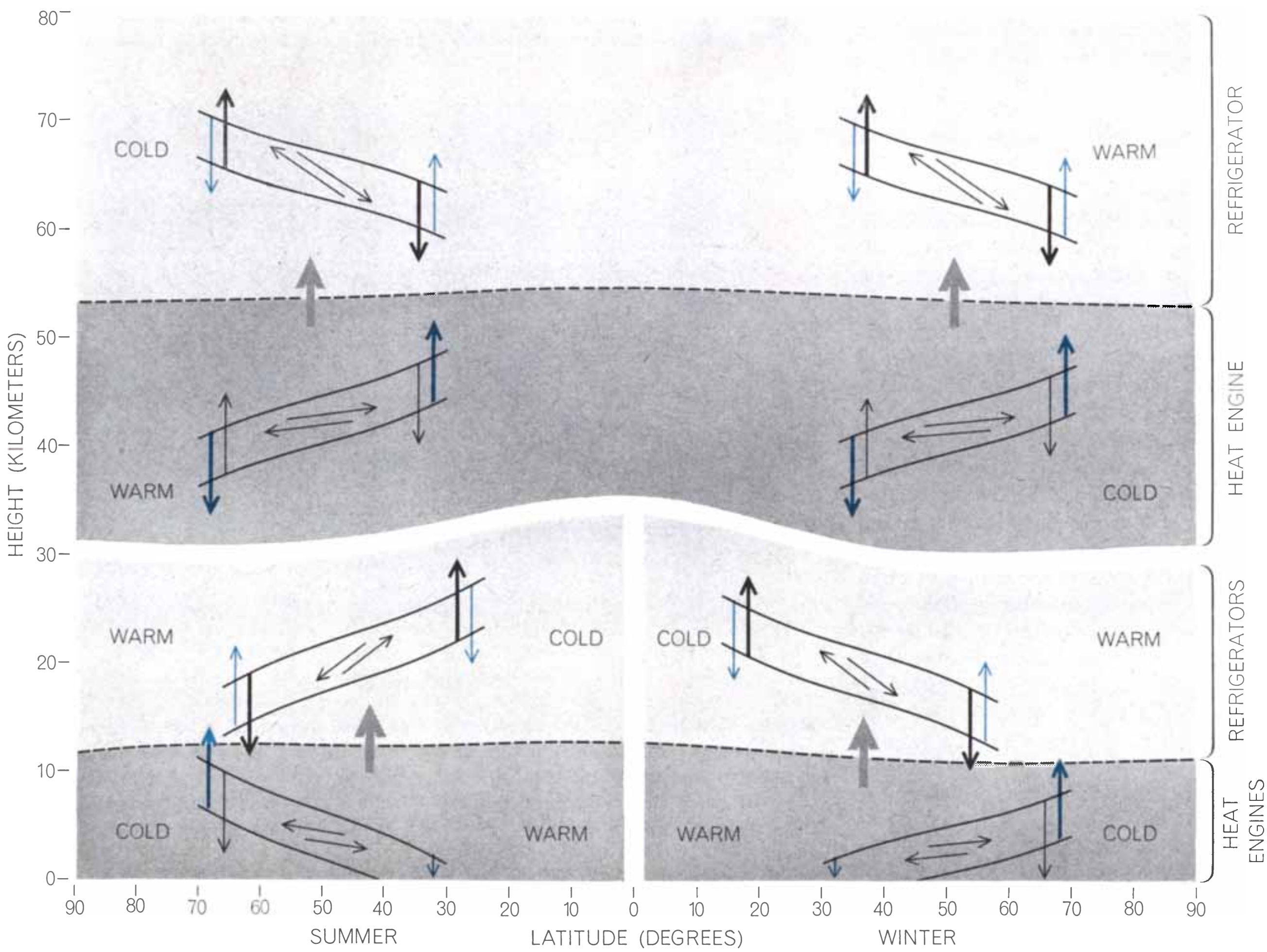
The conclusion to be drawn from all these studies is that the 15-to-20-kilometer region in the atmosphere functions not like a heat engine but like a refrigerator. A household refrigerator, by consuming power, is able to extract heat from a cold region and deposit it in a warmer one (the room outside the refrigerator). In the atmosphere between 15 and 20 kilometers the same process occurs. In this case the power needed to drive the refrigerator is obtained in the form of surplus kinetic energy from the heat engine in the lower atmosphere. The refrigerator in the 15-to-20-kilometer region pumps heat poleward from the Equator, leaving a large atmospheric mass over the Tropics refrigerated to temperatures of — 70 to — 80 degrees C., in spite of the intense solar radiation throughout the year. The heat pumped out of the Tropics is carried poleward and makes the year-round temperature over latitude 60 about 25 to 30 degrees C. higher than it is over the Equator.

Actually it can be assumed that there are two refrigerators in the 15-to-20-kilometer region, one in the Northern Hemisphere and one in the Southern Hemisphere, each coupled to its own heat engine. Rough calculations show that these atmospheric refrigerators are just about as efficient as their household counterparts.

Let us now inquire if regions still higher in the atmosphere, between 20 and 80 kilometers, exhibit the characteristics of a refrigerator or a heat engine or both. The striking fact about the wind core in this higher region is that it blows from the west in winter and from the east in summer. Or, if one considers the entire earth, there is a westerly core over the winter hemisphere and an easterly core over the summer hemisphere. (As noted above, the evidence for such a reversing core in the Southern Hemisphere is still limited.)

The explanation for this reversal of core direction is evidently to be found in the temperatures in the bottom por-





"HEAT ENGINES" AND "REFRIGERATORS" correspond to observed features of the upper atmosphere. The heat engines occupy regions where heat energy simply flows from a heat source to a heat sink. In the process kinetic energy is released in the form of eddy motions in the atmosphere. In the heat engines these motions tend to flatten the slope of the potential-temperature surfaces, which are basically determined by radiation. In the refrigerators the slope of these surfaces is determined by eddy motions rather than by the amount of radiation received or emitted. The refrigerators are driven by surplus kinetic energy from the heat engines.

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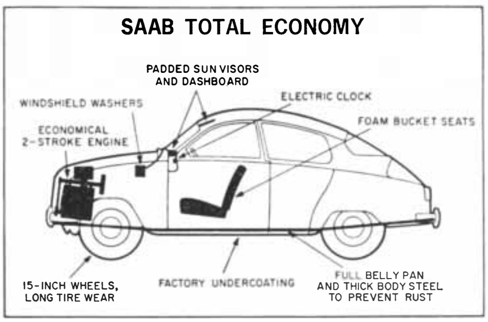

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tion of the 20-to-80-kilometer region. Between about 30 and 50 kilometers temperatures are some 20 degrees C. higher over the summer pole than over the winter pole. In other words, radiation is operating as expected: adding heat to the summer pole and removing it from the winter pole. And in the process potential energy is being created. One would therefore expect to find heat energy, and with it angular momentum, flowing toward the cold pole, representing another heat engine. Indeed, this appears to be the case. Energy and momentum flowing toward the cold pole would tend to produce westerly winds in the winter hemisphere and easterly winds in the summer hemisphere.

In the top portion of the 20-to-80-kilometer region, between 50 and 80 kilometers, there is another reversal of the temperature gradient. Here temperatures are *warmer* over the winter pole than over the summer pole, providing evidence for another refrigerator. Like the heat engine immediately below it, the refrigerator also seems to operate pole to pole. Evidently the pole-to-pole heat engine and the pole-to-pole refrigerator are coupled in the same fashion as the hemispheric heat engines and refrigerators in the lower reaches of the atmosphere [*see illustration on page 72*].

Our calculations show that the potential energy that can be stored in the pole-to-pole heat engine is very small, so that any change in heating rates can quickly lead to changes in circulation. In fact, it appears that winter in this region of the atmosphere is centered on the solstice (about December 22), which is not true lower down, where snow-covered land and heat stored in the oceans, plus a two-week supply of potential energy in the atmosphere, displace the center of winter into late January.

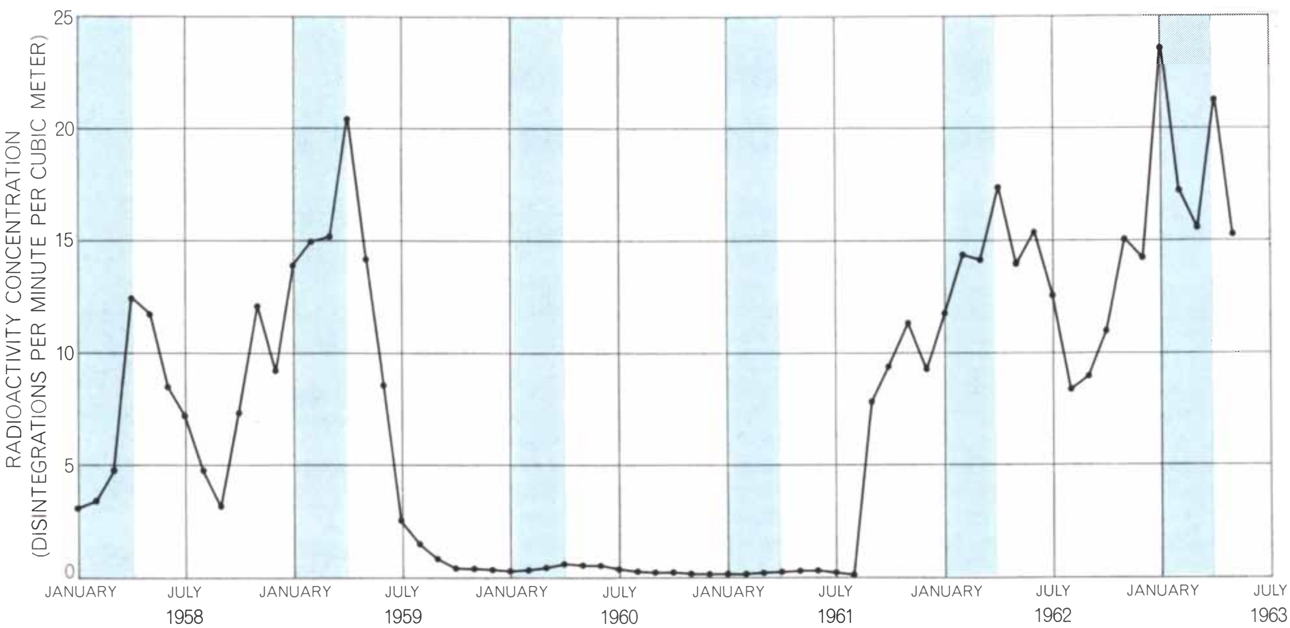
Evidence for Vertical Mixing

The picture I have sketched shows the atmosphere rather tidily stacked into heat engines and refrigerators. It is probable, however, that there are important connections from top to bottom in the atmosphere. For example, one could expect an interaction of the two superimposed wind cores. So far there are only enough observations to examine this possibility up to 30 kilometers, which includes only the lowest portion of the high-level core.

In early winter in the Northern Hemisphere the upper-level core intensifies, and at 30 kilometers vertical motions (northward and upward) are oppositely directed to those at 20 kilometers (northward and downward), leaving a fairly dead region in between at about 25 kilometers. After December 22 the radiational processes maintaining the higher core diminish; it seems that there is a period in late January when the upper core rides on top of the lower core, and the vertical motions, at least up to 30 kilometers, come into phase with those below. There is then a much deeper region of warm air associated with the northward and downward motions. Trace substances such as ozone, which are vigorously transported northward and downward in the 15-to-25-kilometer region throughout the winter, receive an extra northward and downward push in late January and thus produce peak ozone amounts in the region above 15 kilometers in middle and high latitudes in the spring.

These reinforced vertical motions between 15 and 30 kilometers mix the region more efficiently than at any other time of the year, with the result that any radioactive material that has been thrown into the upper atmosphere is carried down into the lower regions. Once down to about 15 kilometers the material quickly enters the well-mixed weather zone of the atmosphere and soon reaches the surface. Therefore at the surface there is a spring maximum in radioactivity as there is in ozone [*see illustration below*].

Little can yet be said about the behavior of the atmosphere above 80 kilometers. At very high altitudes tidal movements and other kinds of wave motion not as yet well understood become more important than at lower levels and the diagnostic problem becomes more complicated. There is some evidence that these tides and waves exist at the lower levels too, but the large-scale motions I have discussed here seem to be the dominant features below 80 kilometers.



ATMOSPHERIC RADIOACTIVITY, as measured near the surface in Washington, D.C., has shown an annual spring increase (*shaded areas*) every year since 1958. The increase indicates that high-altitude radioactivity is driven downward late in January.

Enlarged view of a memory core plane used in electronic computers.

"Brain Cells" Of A Billion-Fact Mind
—FROM RCA RESEARCH IN MAGNETICS

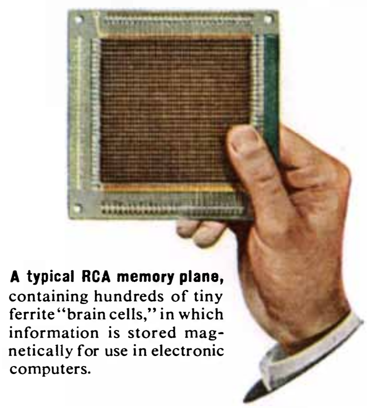
In a fraction of a second, determine the speed and trajectory of an intercontinental missile. Balance the day's books in a large bank. Confirm every leg of a round-the-world jet flight.

Impossible? A few years ago it would have been. But today it is routine, thanks to the incredible speed and accuracy of modern electronic computers.

Such lightning-fast performance is made possible by abacus-like arrays of RCA "memory cores" like those above—the "brain cells" of an electronic mind.

Much like the cells in a human brain, these tiny elements can remember and forget. Unlike human cells they work at millionths-of-a-second speed, translating the infinite calculus by which the computer . . . stores facts . . . responds to stimuli . . . discriminates . . . solves problems . . . all in the space of microseconds.

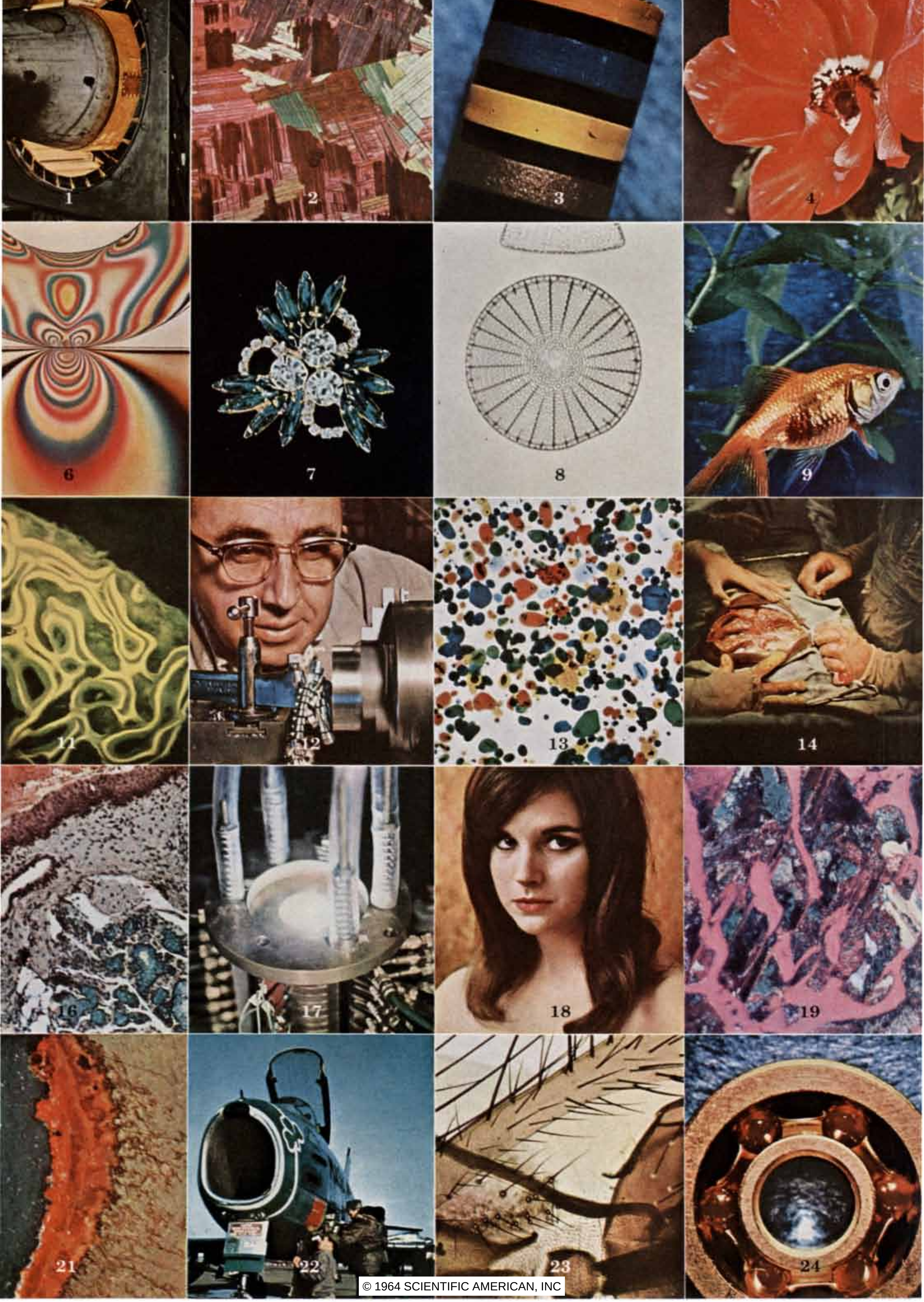
To make possible this speed and versatility, RCA has developed an entire new family of magnetic materials known as ferrites. Components incorporating these new materials are another unique contribution by RCA which is making possible smaller, speedier computers of greater capacity and capability—for business, science, industry, and government.



A typical RCA memory plane, containing hundreds of tiny ferrite "brain cells," in which information is stored magnetically for use in electronic computers.

RCA ELECTRONIC COMPONENTS AND DEVICES

The Most Trusted Name in Electronics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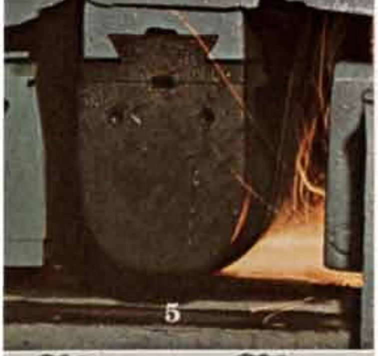
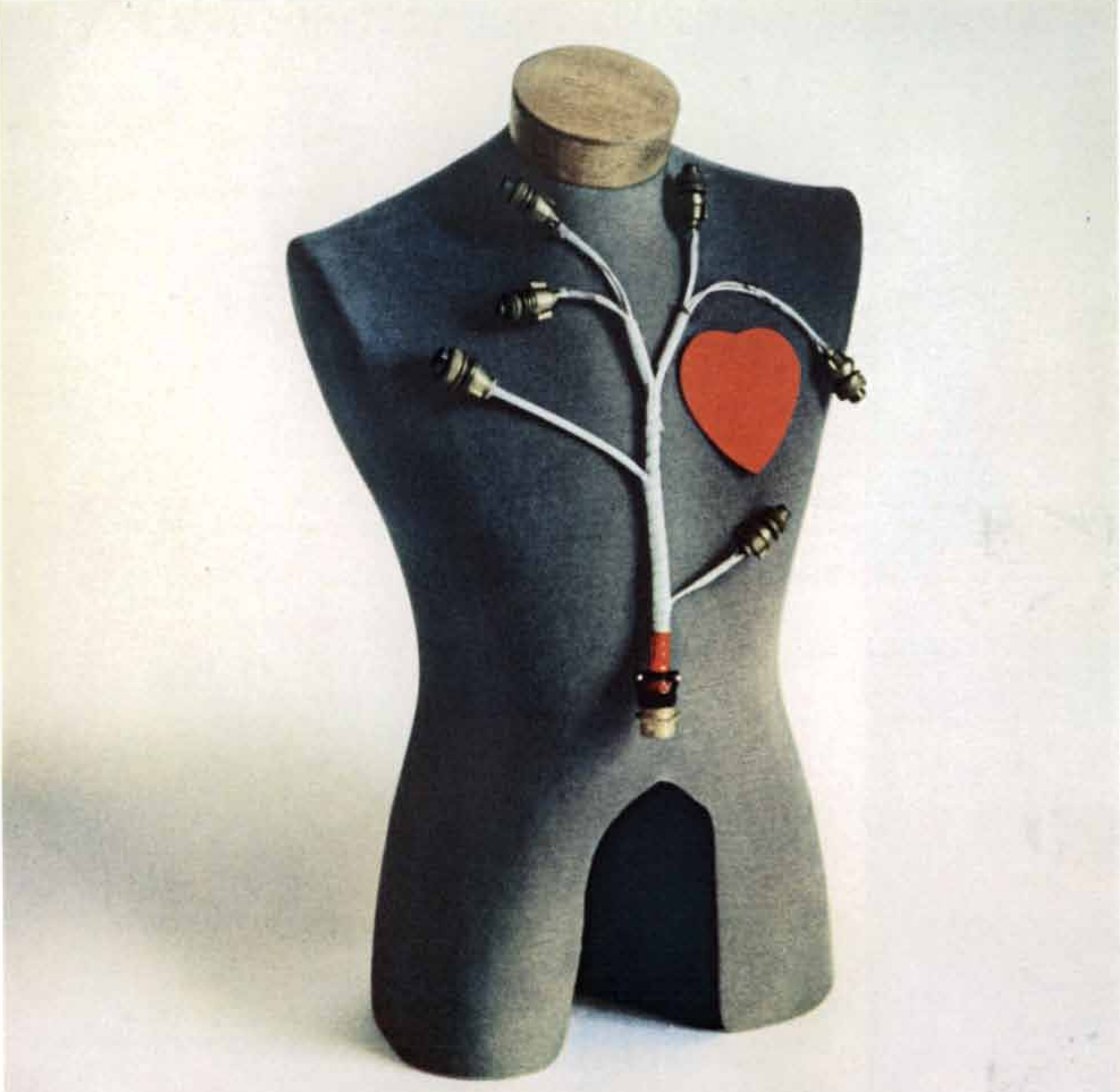


1. Static test of a jet engine at AVCO's Research and Advanced Development Division.
2. Titanium dioxide magnified 200X under polarized light.
3. 10X macrophotograph (of a resistor) used in quality-control tests.
4. Illustration of an anemone for a garden catalog.
5. Automatic butt welder joining bimetallic strips into a continuous length.
6. Stress-analysis picture of plastic models under 80 psi pressure photographed in polarized light.
7. Illustration for a costume jewelry advertisement.
8. A diatom from Oamaru, New Zealand, magnified 100X.
9. *Carassius auratus.*
10. Employee identification picture (one exposure) made with an Avant QUAD Camera.
11. Fluorescence photomicrograph of a cross section of canine tibia, showing the site of active bone growth (69X).
12. Hardinge Super-Precision high-speed lathe.
13. Photomicrograph (100X) of differential staining of starch grains with vegetable dyes.
14. Pectus excavatum operation performed at Andrews Air Force Base Hospital.
15. Preliminary bonding of ingots in the forming of bimetallic strips at Metals and Controls Division of Texas Instruments.
16. Human larynx section (Trichrome stain) at 100X by Leo Goodman, Mallory Institute of Pathology.
17. Plasma-jet experiment used in high-temperature research.
18. Magazine illustration by advertising photographer, Wingate Paine.
19. White iron photographed at 400X under polarized light.
20. Gross specimen of a human gall bladder photographed at the Free Hospital for Women, Boston.
21. Research photomicrograph of a corrosion pit in cast bronze (50X).
22. Pre-flight check on an F-86 Sabrejet, Massachusetts ANG, 102nd Tactical Fighter Wing.
23. Proboscis of a *Calliphora* blowfly at a magnification of 100X.
24. Frictionless ruby bearing (with a gold-plated race) for a missile, 10X macrophotograph by New Hampshire Ball Bearing Co.
25. Beta bromopropionic acid crystals viewed between crossed polarizers (70X).

Do you still think 60-second Polacolor film is just for snapshots?



Fast-Neutron Spectroscopy

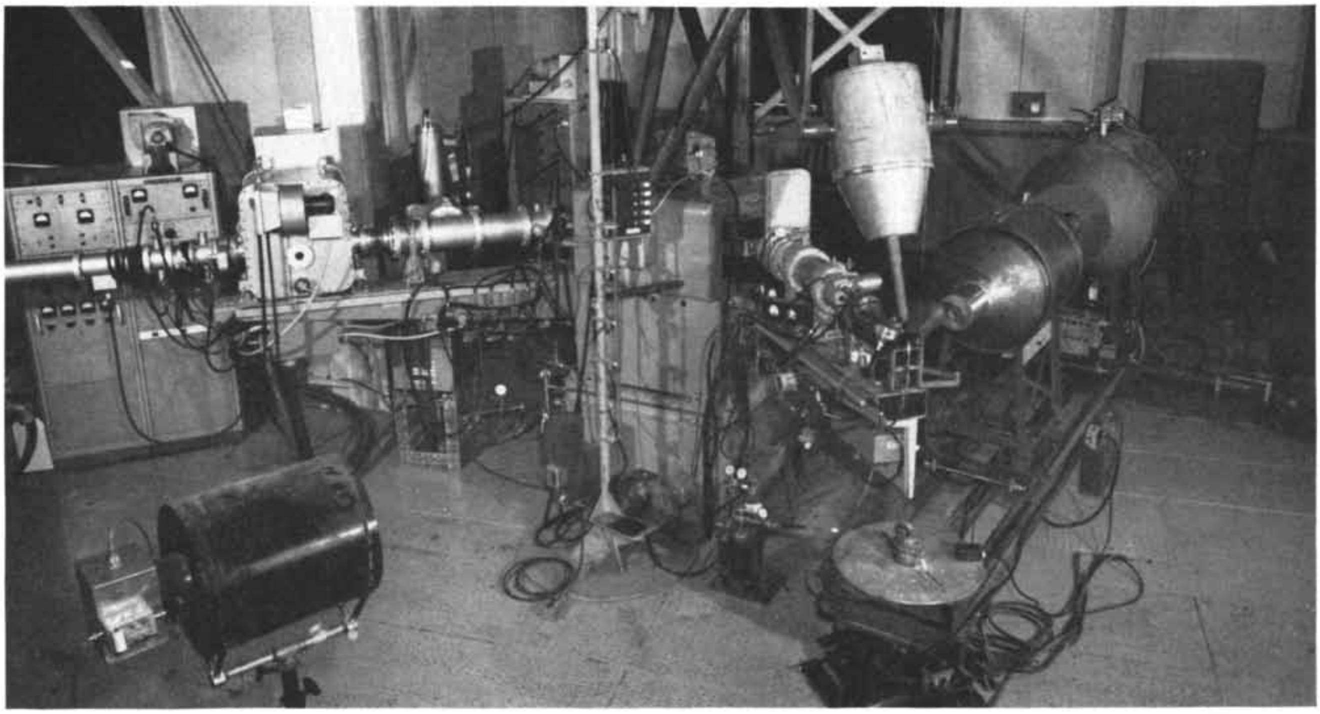
New systems for measuring the velocities of energetic neutrons have made it possible to extend the use of these particles as probes for investigating the structure of the atomic nucleus

by Lawrence Cranberg

As a probe for examining the structure of the atomic nucleus, the neutron offers several advantages. Since it has no electric charge, it is able to approach and penetrate even the heaviest and most highly charged nuclei. The neutron can either be absorbed by the nucleus, thus changing its species, or interact with it in a variety of ways that reveal its internal constitution and even its size and shape. (The absorption of a neutron by certain heavy nuclei gives rise to an unstable nucleus that fissions.) Neutrons are the preponderant particles of nuclear matter and are the by-product of many kinds of nuclear reaction, including, of course, fission.

In spite of these advantages, the use of energetic, or fast, neutrons as nuclear probes has been seriously limited by the difficulties inherent in detecting a fast-moving, electrically neutral particle and measuring its velocity. Unlike neutrons, electrically charged particles such as protons, electrons and nuclei themselves can be detected by a wake of disrupted atoms, or ions. Moreover, a beam of charged particles can be bent in an electrostatic or a magnetic field, whereas a neutron beam is oblivious of these constraints. Accordingly charged particles have been widely employed as nuclear probes and have provided many of the more important insights into nuclear structure.

Within the past decade, however, much progress has been made toward solving the problems associated with the measurement of fast-neutron ve-



PHOTOGRAPH OF APPARATUS at the Los Alamos Scientific Laboratory shows the main components of the system used for determining the energy states of atomic nuclei by bombarding them with energetic, or fast, neutrons. A beam of protons from an electrostatic generator enters through a pipe (*left*), is bent in an electromagnet (*center*) and strikes a neutron-producing target (*right*). The neutrons travel a few inches before colliding with nuclei in the sample whose neutron-scattering properties are being tested. The scattered neutrons are then detected by a scintillation counter buried inside the massive shielding in the right background. The device directly over the target area and the one in the left foreground are both used to take a background sampling of the neutrons not scattered toward the principal detector. A schematic drawing of the entire system appears on pages 80 and 81.

locities. New techniques have been devised for producing very short pulses of monoenergetic neutrons (neutrons whose velocities and hence energies are uniform). New instruments have been invented that are capable of recording the energy spectra of neutrons used to bombard atomic nuclei. It is now possible to construct a system in which the special qualities of the neutron as a nuclear probe can be exploited more fully. This article describes one such system recently put into operation at the Los Alamos Scientific Laboratory. The system is specifically designed to employ fast neutrons in the million-electron-volt region of the energy spectrum. Since many of the neutrons emitted in fission have energies in this region, our system can be expected to yield much-needed information about the ways in which fast neutrons interact with the materials in the environment of the fission process, such as the cores and shields of fission reactors. This new knowledge should find application in the design of power reactors and other devices for utilizing nuclear energy. And the use of fast neutrons as nuclear probes can be expected to lead to a richer understanding of nuclear structure.

Before describing the main elements of the new system, it may be illuminating to review briefly one of the several methods that have been employed for measuring the energy spectra of fast neutrons until now. In this method the neutrons to be measured are directed at a photographic emulsion that contains a substantial proportion of hydrogen atoms. When a hydrogen nucleus, or proton, is struck by one of the neutrons, it recoils in much the same way that a billiard ball recoils after being struck by another ball. As the recoiling proton slows down in the emulsion, it produces a microscopic track of ions that "exposes" a track of silver halide grains, which in turn can be made visible simply by developing the emulsion. By measuring the length and orientation of this visible track in relation to the direction from which the neutrons entered the emulsion, one can calculate the energy of the particular neutron that struck the proton producing the track. In order to arrive at the spectrum of energies for the large numbers of neutrons impinging on the emulsion, it is necessary to repeat this operation for each of the hundreds of minute tracks typically found in the developed plate. It is a good indication of the difficulty of the problem of measuring the energies of fast neutrons that until quite recently this laborious and time-consuming method was the main source of information about high-energy neutron spectra—and that for some purposes it is still unrivaled.

The new system of fast-neutron spectroscopy, which is currently replacing other methods wherever it can be applied, has a simple conceptual basis. It involves measuring rapidly and accurately the time it takes a neutron to traverse a fixed path.

It has been evident almost since the neutron was discovered by James Chadwick in 1932 that some sort of time-of-flight technique offers the most straightforward approach to the problem of measuring neutron velocities; indeed, this technique has for many years been used successfully to study the interactions of slow neutrons with nuclei. The practical limits of the technique extended to neutrons whose maximum velocities were on the order of a hundredth of the speed of light. In terms of energy this corresponds to a maximum of about 40,000 electron volts (ev).

Fast neutrons, however, travel at velocities on the order of a tenth of the speed of light, and their flight times must be measured in nanoseconds (billionths of a second). The energy spectrum for fast neutrons extends up to about 20 million electron volts (Mev). In spite of the familiarity of the timing methods developed for slow-neutron studies, it has required almost a decade of development to extend these methods into the fast-neutron region of the energy spectrum.

To get an idea of the magnitudes involved in measuring the flight time of a fast neutron over a fixed path, let us consider a neutron whose energy is representative of those produced in the fission process, that is, a neutron with an energy of about one Mev. Moving at a twentieth of the speed of light, this neutron would take only about 22 nanoseconds to traverse one foot. Over a flight path of, say, 10 feet, which is a reasonable distance to consider in view of the loss of intensity with distance, the total elapsed time would be only some 220 nanoseconds. To calculate the velocity of the neutron to an accuracy of 1 per cent, this total flight time must be determined within a tolerance of two nanoseconds. Therefore the time at which the neutron starts on its measured course and the time at which it arrives at the end of the course must each be measured to an accuracy of about one nanosecond. Obviously one must have a means of producing and detecting neutrons at times that are known with nanosecond precision. Furthermore, the apparatus that measures the time interval between production and detection, if it is to be efficient, must be capable of making many such measurements quickly—say hundreds of times per second—and must also be able to sort out and record a wide spectrum of elapsed times when neutrons of more than one energy are being examined.

The difficulty of producing substantial numbers of fast neutrons at precisely known times is further compounded if we are to apply the time-of-flight technique as a tool for probing atomic nuclei with neutrons whose velocity and energy are more or less uniform. By comparing the spectrum of energies obtained after bombarding the nucleus with the uniform energy of the incident neutrons we can determine the crucial exchanges of energy that have taken place during the neutron-nucleus interaction.

With these requirements in mind, let us examine some of the ways in which neutrons are produced in the laboratory. Nuclear reactors are prolific sources of neutrons, but these neutrons characteristically cover a continuous spectrum of energies and are therefore unsuitable for our purposes. The most convenient way to produce large numbers of monoenergetic neutrons is to bombard certain nuclei with a beam of charged particles in order to jar loose the neutrons from these nuclei. The isotope hydrogen 3, with one proton and two neutrons in its nucleus, is a particularly useful source of neutrons. When hydrogen 3 is bombarded with protons from a cyclotron or an electrostatic accelerator, large numbers of fast neutrons are produced. These neutrons can be made as monoenergetic as desired at various energies. Elementary calculations can then relate the energy of the neutrons to the energy of the bombarding protons and to the angle at which the neutrons are produced with respect

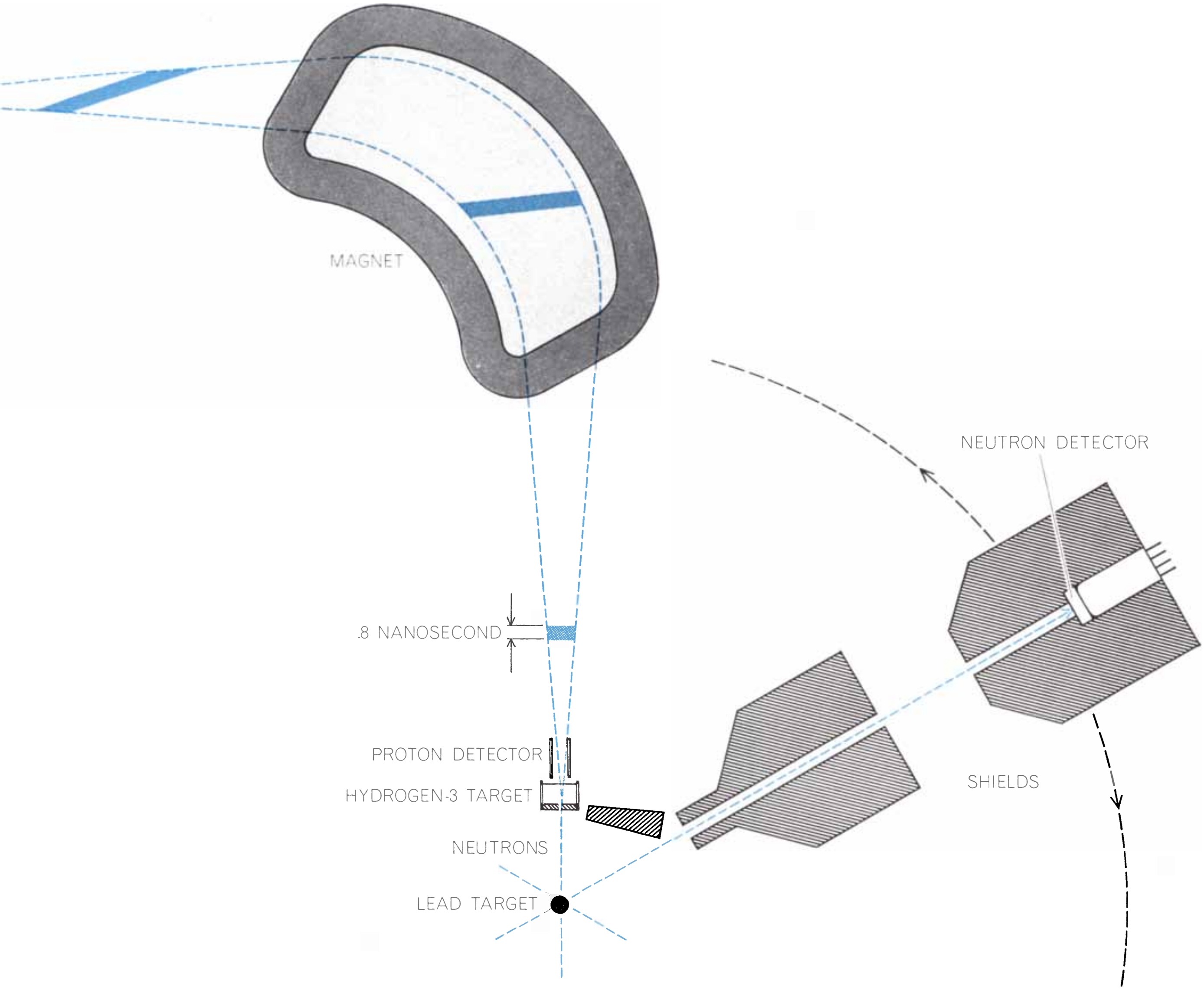


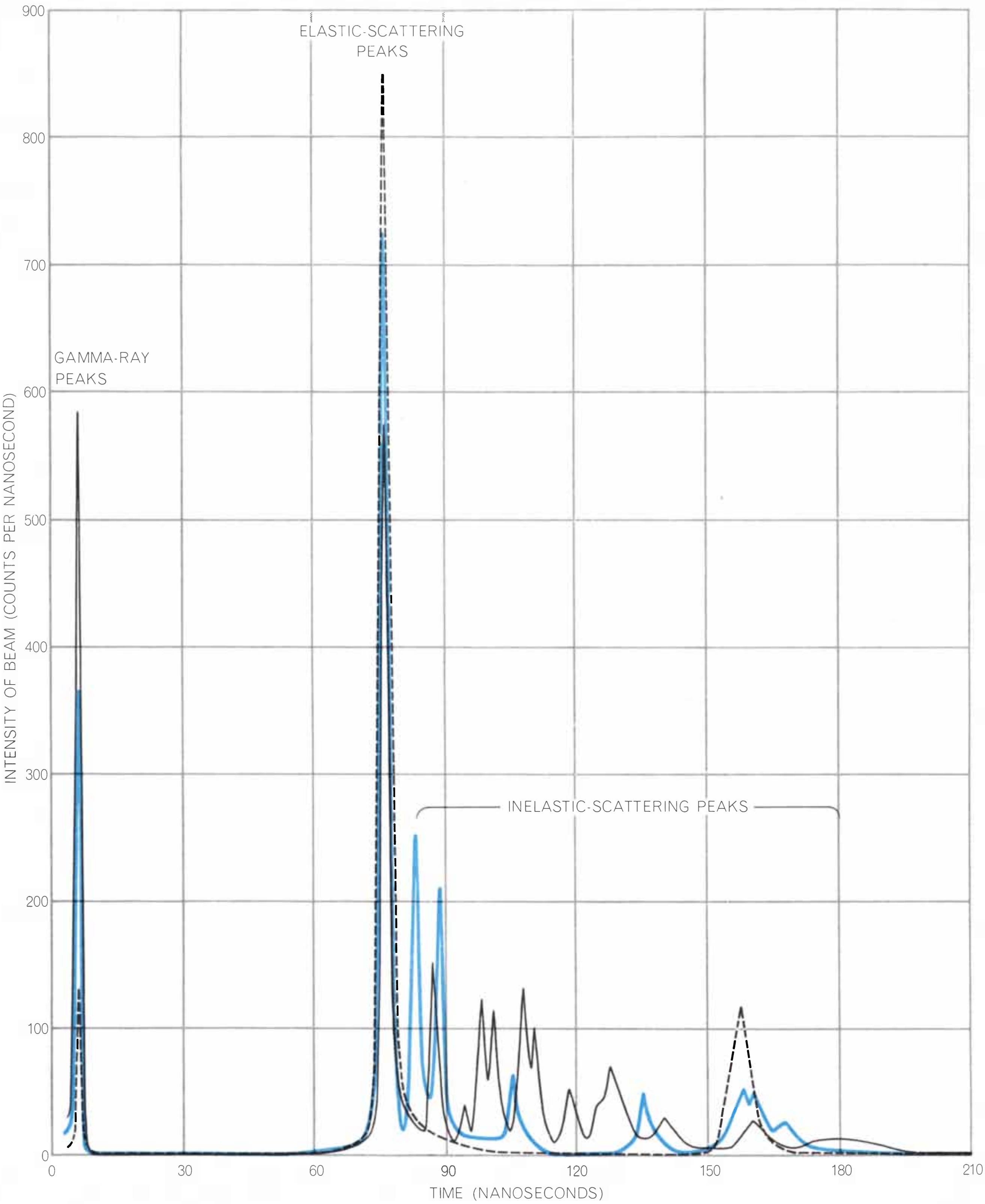
DIAGRAM OF APPARATUS shown in the photograph on page 79 traces the path of the proton beam from the electrostatic generator through the deflector plates (*top left*) and into the magnet (*top center*), where the long pulses of protons are condensed into a series of short bursts by turning them through an angle of 90 degrees. These bursts, which are only about one nanosecond (a billionth of a second) in duration, are focused by the magnet on a container of hydrogen-3 gas (*bottom center*), a radioactive isotope with two neutrons in each of its nuclei. The bombarded hydrogen-3 nuclei give off large numbers of fast neutrons, some of which are scattered in all directions by the nuclei of the sample being tested. The energy spectra of these neutrons are measured by computing the time interval between the arrival of the protons at the hydrogen-3 target and the detection of the neutrons by a scintillation counter (*right*). Angular distribution of the scattered neutrons is measured by rotating the detector around the scattering target.

to the direction of the beam of protons.

This mechanism of neutron production operates very rapidly: the interval between the collision of the proton and the hydrogen-3 nucleus and the ejection of a neutron is known to be far less than one nanosecond. By delivering protons at the hydrogen-3 target in bursts whose duration is about one nanosecond and by measuring the time of delivery accurately, it is possible to determine within the requisite one-nanosecond accuracy the time at which a fast neutron originating in the hydrogen-3 target is launched on its path.

The cyclotron produces protons in short bursts quite naturally; it is basically a device for accelerating charged particles by means of the repetitive application of an accelerating voltage, and its output normally consists of bursts of particles about one nanosecond in duration. Effective use has been made of the naturally pulsed beams produced by cyclotrons, but there are elements of inflexibility in the adjustment of conventional cyclotrons that make it preferable for our purposes to modify a continuous-current accelerator, such as an electrostatic generator, for pulsed operation.

Many techniques for converting a continuous beam of charged particles into a series of short bursts have been devised. The simplest of these involve merely "chopping" the beam by passing it between a pair of plates to which an alternating voltage is applied. This means, however, that the major portion of the beam is discarded. Since it is necessary not only to produce short bursts from a steady beam but also to do so with a minimum loss of intensity, this technique is too wasteful for general use in neutron spectroscopy. A satisfactory technique must be able to bunch as



SPECTRA obtained by bombarding the nuclei of three different isotopes of lead—lead 206 (*black curve*), lead 207 (*colored curve*) and lead 208 (*broken black curve*)—with fast neutrons are given in this graph. Zero on the time scale indicates the time at which the neutrons were produced in the hydrogen-3 target. With the exception of the three peaks at the extreme left, the curves show the rates at which the neutrons arrived at the detector two meters away after being scattered by the lead nuclei. These peaks are caused not by neutrons themselves but by gamma rays emitted by the scattering nuclei after they have been struck by the neutrons. The three highest peaks are caused by the arrival of neutrons that have lost no energy to the scattering lead nuclei except for the very small amount spent in the elastic recoil of the nuclei; the energy of these neutrons is about 3.5 million electron volts (Mev). All the other peaks are caused by neutrons that have experienced inelastic, or energy-exchanging, collisions of one kind or another with the lead nuclei; these peaks range from about .7 Mev to three Mev, reading from right to left. The energy of the incident neutrons was 3.5 Mev.

much of the beam as possible into a series of short, intense bursts.

One of the most ingenious and effective methods of condensing a continuous stream of charged particles into short pulses was proposed independently by Ralph C. Mobley, now at Oakland University in Michigan, and Robert J. Van de Graaff, now with the High Voltage Engineering Corporation. The essential principle of this method can best be visualized by imagining a single file of soldiers marching at a fixed speed past a given point. If the soldiers simultaneously perform a 90-degree turn, they will be marching in a line abreast and will then pass a given point in a much shorter time interval.

This elementary principle cannot be applied in its simplest form to a beam of protons because here an instantaneous change of direction is not possible. A file of soldiers or a stream of protons, however, can be brought into a line abreast by a somewhat more complex series of maneuvers that does not require an instantaneous turn or even a turn of 90 degrees. An adaptation of this basic system is shown in the illustration on pages 80 and 81.

Briefly, the system operates as follows: A proton beam from an electrostatic generator is first "rough-chopped" into a series of long pulses, which pass between a pair of deflector plates located near the entrance to a large electromagnet. By applying a rapidly increasing voltage to the deflector plates the protons, all of which are initially traveling in the same direction, will be fanned out just as they enter the magnet. The magnet is designed to act as a lens; it brings the fanned-out protons together at a focus, where the hydrogen 3 or some other neutron-producing target is located. The protons that arrive earlier at the deflector are pushed toward the outer edge of the magnet and consequently travel a greater distance to the target than the protons that arrive later and are pushed toward the inner edge of the magnet. By properly adjusting the voltage of the deflector plates it is possible to make the increase in the length of the flight path of the earlier protons just compensate for their earlier arrival at the deflector. Thus large numbers of protons initially spread out in time arrive in more or less precise step at the neutron-producing target.

This bunching technique has made it possible to convert a large fraction of the protons in a steady beam into short bursts less than a nanosecond long. Furthermore, the bursts are so intense they can be readily detected by simple electrical means as they approach the target. The detection signal is a sharp electric pulse, which is well suited for time-marking purposes. Therefore the time at which a neutron is launched from the hydrogen-3 nucleus can be measured within a nanosecond by the arrival on target of the proton burst.

At the other end of the flight path the arrival of the neutron can be timed rather easily by means of a conventional scintillation detector. Like the photographic emulsion mentioned earlier, the scintillator contains hydrogen atoms (essentially protons) that recoil when struck by neutrons. The recoiling protons excite the other atoms in the scintillator to emit light, which is in turn detected by a device called a secondary-emission photomultiplier. The output signal of the photomultiplier and the pulse produced by the arrival of the proton burst at the hydrogen-3 target respectively indicate the end and the beginning of the time interval to be determined. The only task remaining is to measure that interval.

For this purpose we employ a technique for measuring short time intervals that, in its essential elements, can be considered as going back at least to Galileo. He too was interested in measuring the flight time of electrically neutral particles—balls rolling down an inclined plane. In order to determine the relation between the distance traveled and the time elapsed Galileo used a water clock. By allowing a steady stream of water to pass through a valve, which was opened when the ball was launched and closed as soon as it reached the bottom of the inclined plane, he was able to measure the interval of elapsed time as a function of the weight of the water collected in a bucket.

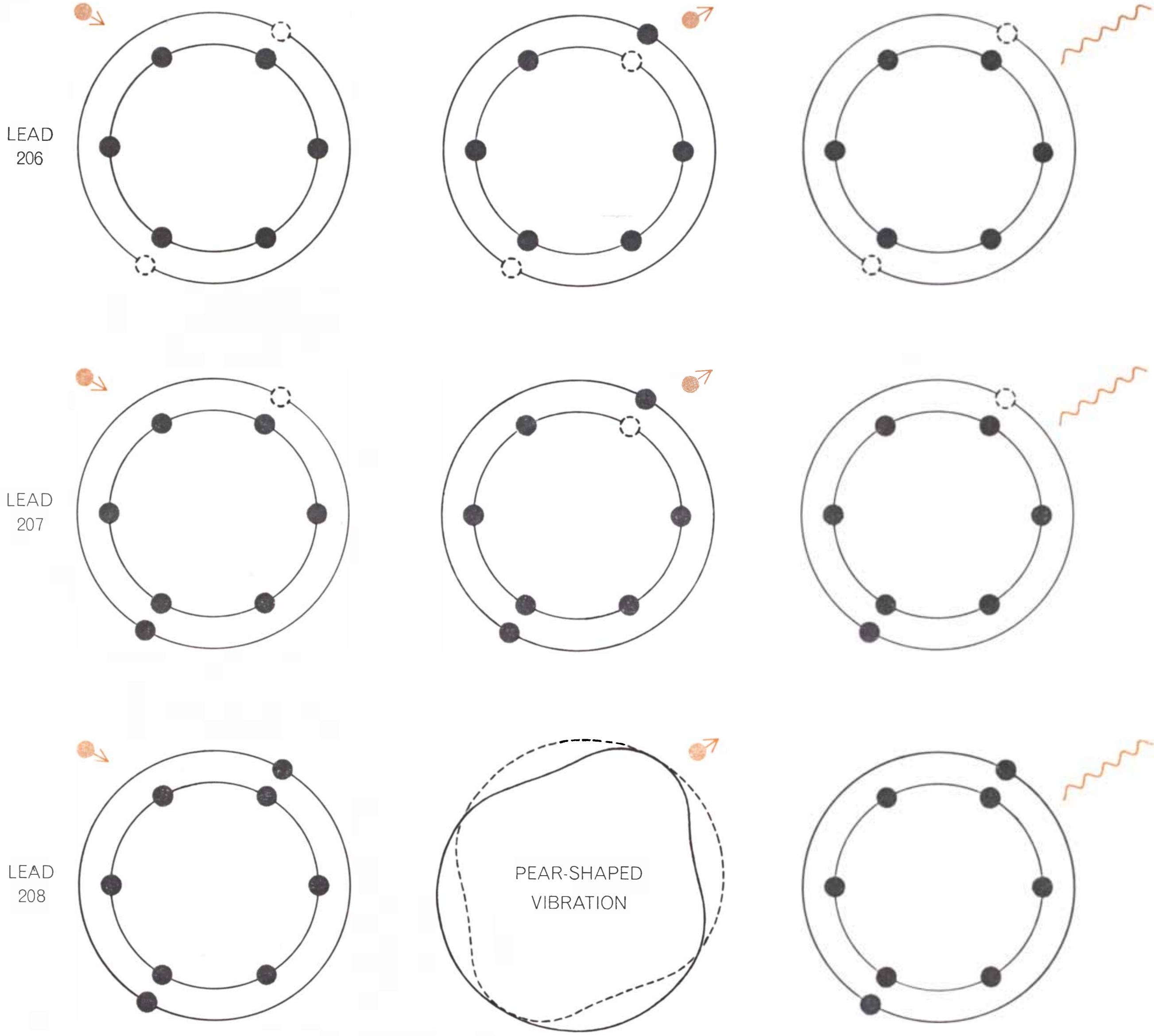
To make such a scheme applicable to the nanosecond scale, it is obvious that electrical devices must be substituted for hydraulic devices. Instead of a manually operated valve our system employs short electric pulses that trigger fast switching circuits; instead of a catch bucket it has an electrical capacitor, and instead of a weighing scale it has a charge-measuring device. These instruments are capable of instantaneously measuring, sorting and recording the flight times of several hundred neutrons per second.

We have, then, a complete system suitable for analyzing fast-neutron spectra in terms of the time it takes the various neutrons to travel from target to detector. To make use of this system as a tool for probing the structure of the nucleus we need only insert the sample to be examined in the path of the fast neutrons emitted by the hydrogen-3 source. In this case the detector does not view the neutron-producing target directly but rather the sample whose neutron-scattering properties are being investigated. The sample must be placed within a few inches of the neutron source in order to yield appreciable numbers of scattered neutrons. The proximity of the neutron source to the scatterer, and the fact that only about one neutron is scattered toward the detector for every million neutrons produced by the neutron source, make it essential to shield the detector carefully from the neutron source. The massive shielding enclosing the detector can be seen in the photograph on page 79. The detector inside its shield is mounted on a cart that pivots around the scattering object to facilitate observation of the scattered neutrons as a function of the scattering angle.

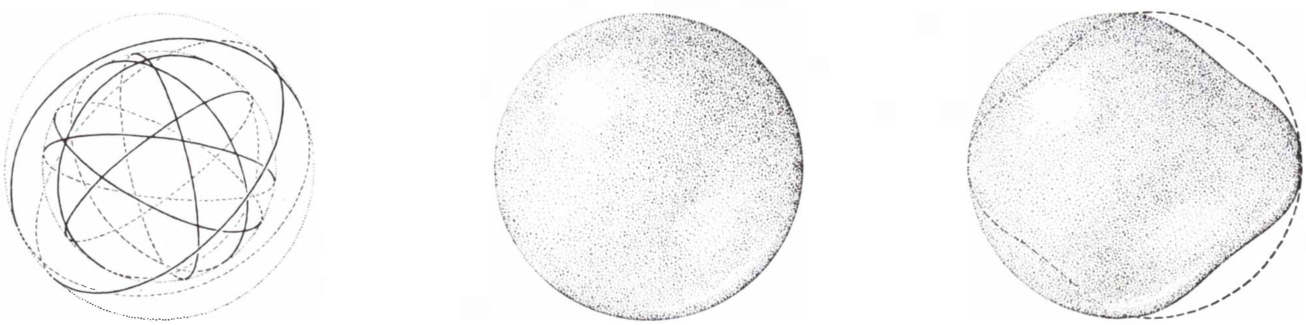
Let us now consider some of the results obtained recently with this system by Chris D. Zafiratos and Jules S. Levin in collaboration with the author. The graph on the opposite page shows the rate at which neutrons arrived at the detector after being scattered by the nuclei of three different isotopes of lead: lead 206, 207 and 208. Before striking the lead targets the neutrons all had an energy of about 3.5 Mev and a velocity of about a tenth of the speed of light. Each peak in the graph corresponds to a particular type of interaction between the incident neutrons and the lead nuclei.

In all three cases the peak at the extreme left is caused not by the neutrons themselves but by gamma rays emitted by the scattering nuclei after they have been struck by the neutrons. These gamma rays are exactly analogous to the light rays produced in a neon lamp. When electrons pass down such a lamp, the atoms of gas in the lamp absorb some of the energy of the electrons and are excited to higher energy states. These atoms subsequently return to their ground, or rest, states, emitting the excess energy in the form of visible light.

Nuclei can similarly be excited to higher energy states by bombardment with energetic particles such as fast neutrons. The neutrons are slowed down by the resulting collisions and give up some of their energy to the nuclei. When the nuclei return to their ground states, gamma rays are produced. This type of neutron-nucleus interaction, in which



NUCLEAR-SHELL DIAGRAMS for the three isotopes of lead indicate the neutron populations of the two outermost shells; in actuality there are 20 more neutron-containing shells inside these. When a fast neutron encounters a nucleus of lead 206 (*top left*), it can excite one or two neutrons from inside the nucleus to "jump up" and fill either of two neutron "holes," or vacancies, in the outermost shell (*top center*). When one of these neutrons returns to its ground, or rest, state (*top right*), the excess energy in the nucleus is emitted in the form of a gamma ray. Lead 207 (*middle*) is capable of only one such excitation, since it has only one hole in its outermost shell. Lead 208 (*bottom*) has a full complement of neutrons in its nucleus and all its shells are "closed." When a fast neutron encounters a nucleus of lead 208, the nucleus vibrates back and forth in a pearlike shape; this vibration, which also occurs in the other two isotopes of lead, accounts for the only inelastic scattering peak in the spectrum of lead 208 (*see illustration on page 82*).



PEAR-SHAPED VIBRATION of an excited lead nucleus (*right*) departs from the spherical by about 10 per cent of its diameter, or a little more than one fermi. (A fermi is 10^{-13} centimeter.) The normal lead nucleus (*center*) is portrayed in this case as a cloudy crystal ball, the surface of which owes its cloudiness to the nucleons (protons and neutrons) orbiting in its outermost shells (*left*).

the neutron loses energy to the nucleus, is known as inelastic scattering. Apparently the de-excitation process is so fast for lead nuclei, and the speed of the gamma rays is so much greater than that of the fastest neutrons in the experiment, that the gamma rays arrive at the detector well ahead of the neutrons that are responsible for exciting them.

The first neutrons to arrive at the detector are those that have been elastically scattered, that is, neutrons that have lost no energy to the scattering lead nuclei except for the very small amount spent in the elastic recoil of the nuclei, which are some 200 times heavier than the neutrons. The elastically scattered neutrons account for the highest peaks in the graph. All the neutrons that arrive later have experienced inelastic collisions of one kind or another with the lead nuclei. In each case the amount of energy the neutrons have lost is a direct measure of the energy of excitation imparted to the scattering nucleus. Thus the peaks in the graph are in a simple one-to-one correspondence to the spectrum of excited states of the nuclei in each lead isotope.

Since all three isotopes of lead have the same number of protons in their nuclei (82), the different spectra obtained for each by the foregoing method must be related to the slightly differing number of neutrons in the nuclei (respectively 124, 125 and 126). The significance of these differences can best be explained by referring to the shell model of the nucleus, which is closely analogous to the shell model of the atom [see "The Structure of the Nucleus," by Maria Goeppert Mayer; SCIENTIFIC AMERICAN, March, 1951]. According to this model lead 208 is considered the nuclear analogue of a "noble" gas such as argon. It has a full complement of 82 protons and 126 neutrons in its nucleus; its nuclear shells, made up of both protons and neutrons, are "closed." Apparently lead 207 has one "hole," or vacancy, in its outermost neutron shell and lead 206 has two holes. For lead 207 the inelastic peaks correspond to the excitation of one particle, whereas for lead 206 the peaks correspond to the excitation of one or two particles. Thus the increased number of possible inelastic interactions for lead 206 accounts for the greater complexity of its spectrum [*see top illustration on opposite page*].

One common feature shared by the energy spectra of all three of the lead isotopes is the excitation associated with the single inelastic peak in the lead-208 spectrum. Both lead 206 and 207 have close counterparts to this peak in their spectra. This similarity in the energy spectra of the lead isotopes was first emphasized by Bernard L. Cohen of the University of Pittsburgh, who employed charged particles as nuclear probes; it is probably caused by the so-called octopole vibration of the nucleus as a whole. As a result of an inelastic collision with a neutron or a charged particle, the nucleus is deformed from its normal spherical shape into a pearlike shape, with the base of the pear oscillating back and forth [*see bottom illustration on page 84*]. This is an example of "collective nuclear motion," the importance of which was first recognized by L. James Rainwater of Columbia University and which has been investigated intensively over the past decade by Aage Bohr and B. R. Mottelson of the Institute for Theoretical Physics in Copenhagen.

The new systems for fast-neutron spectroscopy get their most striking results, however, not from the spectrum obtained at a single scattering angle but from an analysis of the spectra obtained at many angles. By observing the variations in the spectral peaks with angle it is possible to arrive at the angular distributions of the neutrons associated with the various kinds of nuclear interactions and to infer from these angular distributions the actual size, shape and even the rate of spin of the scattering nucleus.

The importance of angular distribution in determining the size and shape of the nucleus can be best appreciated if one thinks of the neutron as a wave rather than as a particle. For example, a neutron whose energy is 3.5 Mev has an effective wavelength of about 15 fermis. (One fermi is 10^{-13} centimeter.) A lead nucleus has a diameter of about 15 fermis and can be visualized as a slightly cloudy crystal ball, which partially reflects, partially transmits and partially absorbs the incident neutron wave [see "A Model of the Nucleus," by Victor F. Weisskopf and E. P. Rosenbaum; SCIENTIFIC AMERICAN, December, 1955]. The part of the wave that is reflected will interfere with the part that is transmitted; the resulting intensity of the wave at any given angle will depend on the details of the shape of the nuclear surface and the optical properties of its interior. Thus the angular distribution of elastically scattered neutrons is essentially an optical diffraction pattern such as one observes when ordinary light is scattered by an object whose size is comparable to the wavelength of the light itself. By interpreting the diffraction pattern in terms of the scattering nuclei we are able to determine the optical properties of the nuclei.

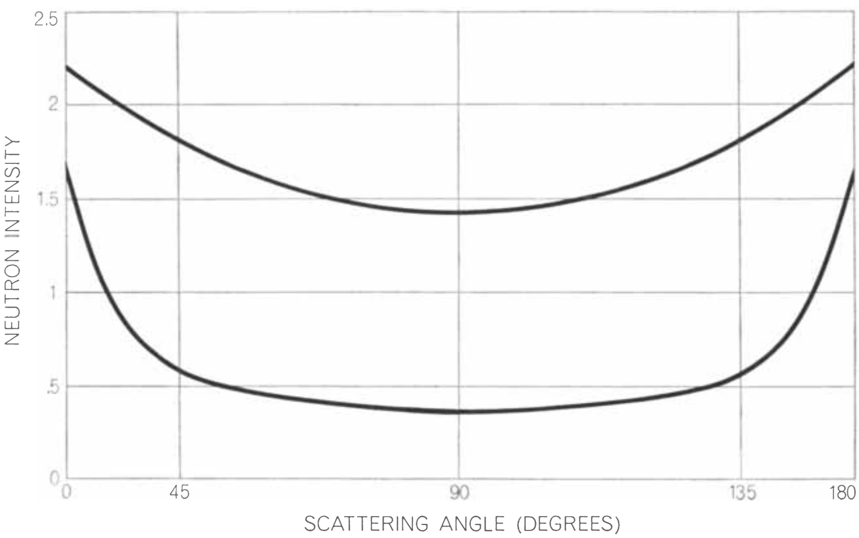
The results obtained recently also give an estimate of the magnitude of nuclear distortion in an excited state. It has been possible to infer that a lead nucleus in pear-shaped vibration as a result of being bombarded with energetic neutrons departs from the spherical by about 10 per cent of its diameter, or a little more than one fermi. It can be said that we "see" the nucleus with this sort of detail even though the wavelength of the neutron we use to look at the nucleus is comparable to the nuclear diameter.

The graph on this page presents some angular distributions recently obtained at Los Alamos corresponding to two inelastic interactions that are observed in the scattering of 2.5-Mev neutrons from lead 206. These distributions characteristically have the symmetrical shape of a dish. They are not so readily interpreted as diffraction patterns and suggest that a quite different model is required to describe them.

Elastic scattering is an example of a "direct" process that occurs in the very short time it takes a fast neutron to cross a nucleus—about 10^{-22} second. Inelastic scattering of the sort that produces the dish-shaped patterns shown in the graph can be explained if we assume the so-called compound-nucleus mechanism of nuclear reactions, which is based on a suggestion of Niels Bohr. On this model the incident neutron amalgamates with the target nucleus to form a compound nucleus that, after an interval of about 10^{-18} second, decays by emission of a neutron, leaving the original nucleus in one of its excited states. It should be noted that although we now have effective means of measuring short time intervals, it is entirely beyond our ability to distinguish between direct and compound-nucleus processes by time measurement alone.

To see how the compound nucleus gives rise to dish-shaped patterns we shall refer to a simplified particle model proposed by Torleif Ericson of the European Organization for Nuclear Research (CERN) in Geneva. On this model we make the further simplification that the target nucleus has no spin of its own, so that the spin of the compound nucleus is due entirely to the angular momentum brought in by the incident neutrons. Thus the compound nuclei produced by neutron bombardment from a given direction will all be set spinning with their axes of spin in a plane perpendicular to that direction. One can imagine these compound nuclei as being a collection of spinning wheels whose axes of spin point in many directions but are all confined to one plane.

The decay of the compound nucleus, which results in the emission of a neutron, leaves the original nucleus in one of its excited states (or, in special cases, in its ground state). The process of neutron emission can be visualized as being similar to the throwing off at a tangent



ANGULAR-DISTRIBUTION CURVES were obtained by bombarding a sample of lead 206 with 2.5-Mev neutrons. The energies of the emergent neutrons were about one Mev (*top curve*) and 1.3 Mev (*bottom curve*). The characteristic dishlike shapes of these curves are shallower for neutrons that have given up more angular momentum, or spin, to the scattering nuclei. Spin of excited nuclei is two units for top curve and zero for bottom curve.

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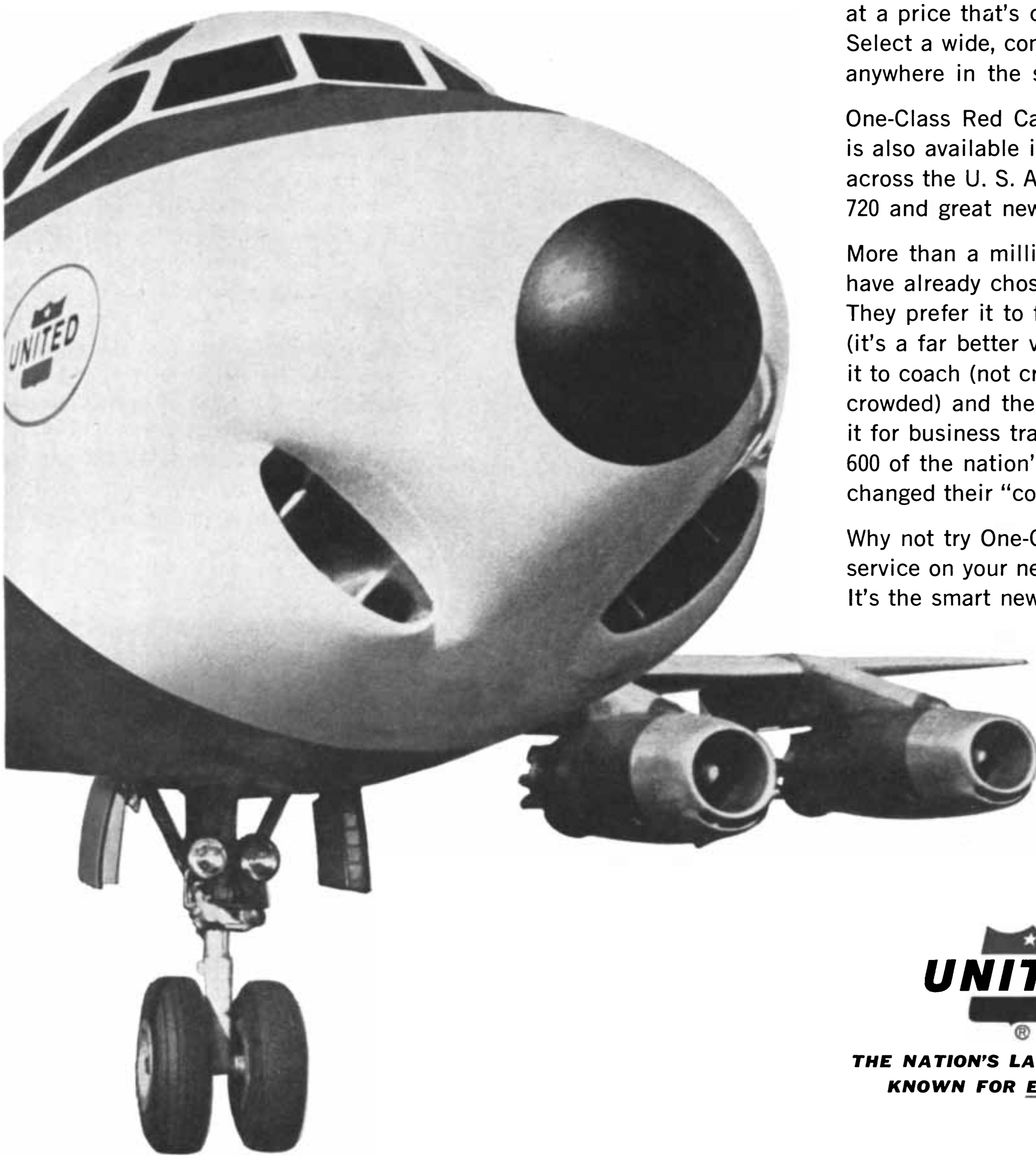

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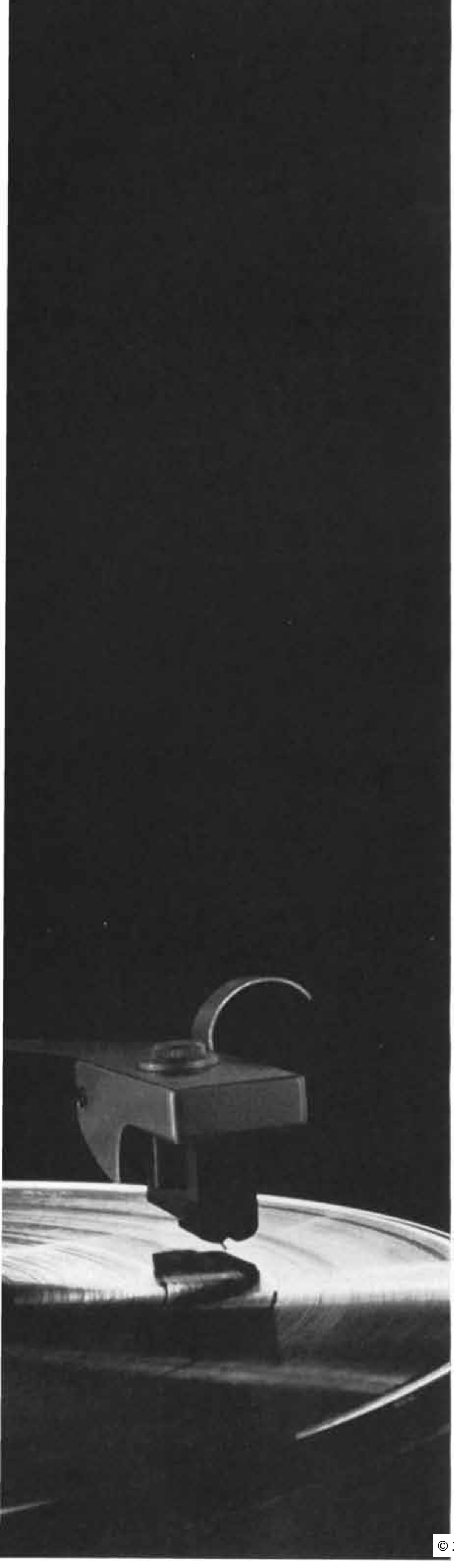
of a droplet of water from a spinning wheel.

The droplets in our spinning-wheel analogy would come off in all directions, but a little consideration shows that because the axes of spin are all confined to a plane there will be one direction to which each of the spinning wheels can make a contribution, and that is the original direction of the incoming neutron. It is clear that the forward and backward directions will be equally favored if the compound nucleus has spun around enough times to "forget" when it was created. Thus the compound-nucleus model does predict dish-shaped angular distributions.

Further consideration of this model shows that the dish will be deepest if the emitted neutron carries off all the angular momentum it brought in but will be shallower if it leaves some behind in the nucleus. The depth of the dish is an indication of the angular momentum, or spin, of the excited nucleus that is left behind, so that we have here a means of inferring the spins of excited states of nuclei to supplement the many other means that nuclear physicists have devised.

It is evident from the graph that the dish shape corresponding to excitation of a low-spin state is substantially deeper than that corresponding to a high-spin state. The detailed calculations whose results are given in the graph as solid lines are based on the quantum-mechanical theory of Walter Hauser of Boston University and Herman Feshbach of the Massachusetts Institute of Technology. Although they reproduce the main features of the results, there are discrepancies that remain to be resolved.

The foregoing discussion has focused primarily on use of fast neutrons as nuclear probes. Useful and interesting information about nuclei is also obtained by studying the complex spectra of neutrons that usually result from the bombardment of nuclei by other energetic projectiles, such as deuterons, protons and X-ray quanta. Pulsed-beam time-of-flight methods are also applicable to this sort of problem, and accelerators of many types have been adapted for such purposes. The greater intensities available in such work make it feasible frequently to use very long flight paths with substantial improvement in accuracy and resolution. As the techniques of nanosecond-time spectroscopy improve, we can expect to see many more applications of this relatively new art.



One of a series briefly describing GM's research in depth

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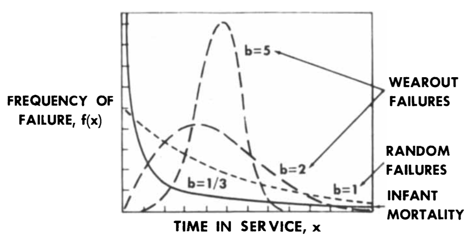


Varying one parameter (b) in the Weibull distribution function allows the characterization of many types of reliability phenomena.

FORGETTING

The ability to remember can be studied experimentally. Such studies point to some misconceptions about how different kinds of material are learned and what circumstances may produce lapses of the memory

by Benton J. Underwood

Rodin's sculpture "The Thinker," modified slightly by the addition of a wrinkled brow and a suggestion of anguish in the facial expression, could represent man in a more familiar aspect that might be labeled "The Forgetter." All of us spend more or less time in the mental activity known as trying to remember. Who has not had the experience of groping futilely for a name, a street number or the ending of a joke?

As an important property of the human mind, forgetting has received a not inconsiderable amount of research attention. From this has emerged a theory, strongly supported by recent experimental studies, that now provides us with a good start toward explaining some of the factors involved in remembering and forgetting.

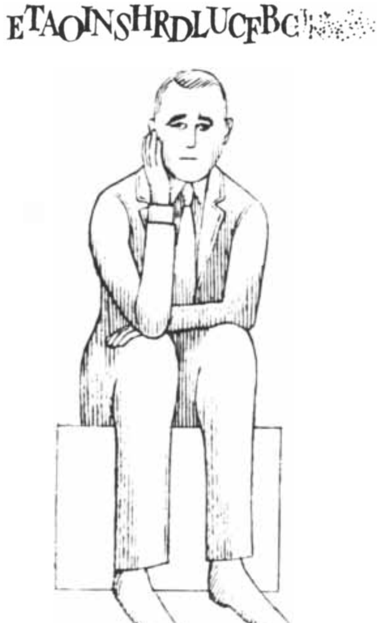
The experimental investigation of forgetting in psychological laboratories, which began with pioneering studies by the German psychologist Hermann Ebbinghaus in 1885, generally follows a standard procedure. The subjects (usually college students) are given a list of words or nonwords (for example, a combination of letters such as *QZR*) to remember. The list may consist merely of a sequence of items the subject is required to recall in the proper order or of a group of paired items (for example, *DAX—yellow*), in which case one member of each pair (*DAX*) is presented later and the subject is required to respond with the other (*yellow*). During the learning session the items are presented to the subject one at a time, each for a second or two, and after he has gone through the list in this way he is asked to give the full list; this procedure is repeated until he has mastered the list to a level fixed by the experimenter (100 per cent correctly, or 75 per cent or some other standard).

The subject is then tested after a certain interval (24 hours, a week, a month) to see how much of his learning he has forgotten in that interval. If he learned 10 items or pairs and is now able to recall only eight correctly, we say his forgetting score is 20 per cent. Obviously the amount of forgetting will increase with time; it will generally be substantially higher after a month than after a day.

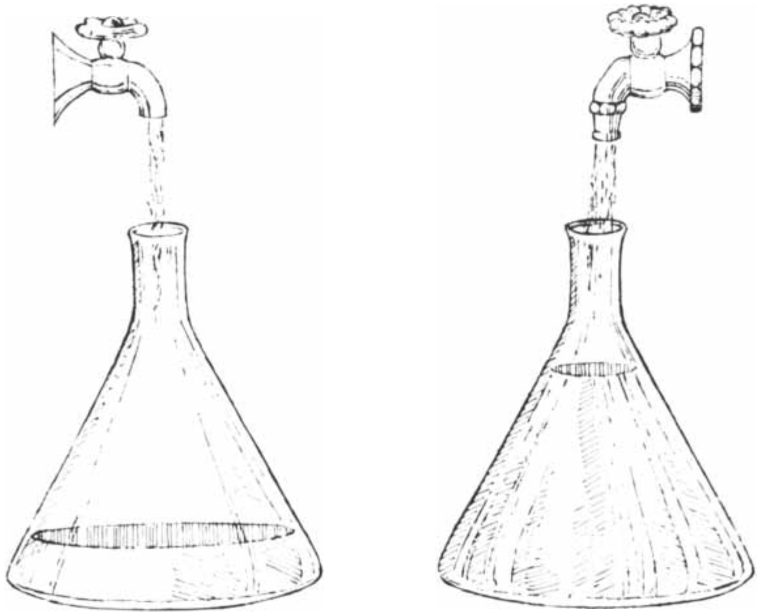
Now, this simple type of test quickly establishes several surprising facts that show that some of our notions about forgetting are misconceptions. One of these has to do with the nature of the material that is to be remembered.

If we examine only the learning phase itself, there are three important factors, three things that mainly determine the ease or speed with which one learns a list of items. First, of course, is the subject's learning ability; this varies considerably from individual to individual. We can disregard this variable for the moment and consider only the material. Here we find two decisive variables. In the first place, the speed of learning a list of items depends a great deal on how meaningful they are. A list of words such as *air, may, hot, cup, men* is easy to learn; many college students can master it by studying the items just once. On the other hand, it takes a number of study trials to learn a list of items of low meaningfulness such as *VKN, HXT, CGQ, MWS, BJP*. That is to say, it is much more difficult to plant nonwords than words in the memory storage system.

The other factor that powerfully influences the rate of learning is the degree of similarity or nonsimilarity between the items. The more alike the items of a list are, the harder it is to learn to repeat them. In the case of nonwords, the similarity may consist in the same letters being used in different combinations. Take a list such as *XQV, KHQ, VHX, VKQ, HVK*. It presents so much overlapping and opportunity for confusion that many college students are quite unable to learn it even in an hour of study. For those who do learn it, it may take as much as five times longer than the list of nonsense items in the paragraph above, which at least has the virtue of being composed of sharply different items. The rule that similarity makes for difficulty in mem-



FAMILIAR PLIGHT is represented by this figure of a man searching his mind for a fact that he knows is there and finding instead only a jumble of more or less related items soon trailing off into a total blank.



BEAKER ANALOGY indicates learning by level of water, forgetting by evaporation. As level rises, surface area decreases, so that there is less evaporation. Fast input (*right*) represents easy material or quick learner; but in time the slow input (*left*) will fill the beaker just as high. Similarly, remembering appears to depend on the degree of learning.

orizing applies to words as well as nonwords. It is difficult indeed, for example, to learn to give in order the words in a list such as *arctic, mammoth, huge, icy, cold, immense, frigid, giant.*

Now we can consider some paradoxes that emerge from tests of forgetting. To begin with, almost everybody supposes material that is easy to learn is also easy to remember. For instance, a list of meaningful words should be remembered better than a list of nonsense words, should it not? Surprisingly, the tests show that there is no difference: the rate of forgetting is no higher for items of low meaningfulness than it is for highly meaningful material. If the two kinds of material are learned equally well in the first place, the scores of remembering, or forgetting, are about the same for both after a lapse of time.

It is true that, given the same amount of time for study, the more meaningful material will be remembered better in the later test. For example, if one group of subjects is asked to learn a list of words and a second group is assigned a list of nonwords, and both groups are allowed just five minutes for learning their lists, the first group will score higher in the test of recall 24 hours later. A list of dissimilar items will be remembered better than one of similar items, again provided that the time allowed for learning is the same in both cases. But these results merely show that it takes longer to learn the one kind of material than the other. If we allot more time for learning the more difficult material, so that the group learning it reaches the same degree of proficiency as a group that has spent a shorter time mastering easier material, then the difficult list will be remembered later just about as well as the easy one. In short, when it comes to forgetting, or remembering, what counts is not the nature of the material but the degree of original learning.

We can illustrate the point neatly with a physical analogy. Suppose we liken the learning process to the pouring of water into a pyramid-shaped beaker [*see illustration above*]. The height of the water level represents the degree of learning. As the water level rises, the area of its surface decreases, as a result of the beaker's pyramid shape. We say that forgetting is represented by the evaporation of water from the surface. The higher the water level (that is, the degree of learning), the smaller the surface and therefore the slower the evaporation (that is, the rate of forgetting).

Now, when the learning is easy and the learner fast, the input of water into such a beaker will be much more rapid than it is when the material is difficult and the learner slow. In a given time (say five minutes) a fast input will produce a considerably higher water level in the beaker than a slow input would. But given time the slow input can fill the beaker to as high a level as the fast one, and the rate of evaporation (forgetting) will then be the same. The point of the analogy is that the ultimate degree of learning, rather than the rate of learning, is the critical factor in the rate of forgetting. If the degree of learning reaches a certain level, it makes no difference how long it took to reach that level. Given the same level of learning, nonsense material is not forgotten more rapidly than meaningful material, nor a high-similarity list more rapidly than a low-similarity list.

What about differences in the learner's ability? Surely a slow learner will forget more rapidly than a fast learner. Not at all: the experiments show conclusively that this too is a misconception. Allowed enough time to study a list so that he can reproduce it as readily as a fast learner, a slow learner will score as high as a fast one in later tests of remembering the list.

This suggests that a bright student does better on examinations than a dull one because he has learned the subject matter more effectively, not because his memory is superior. If both students spend an hour studying for a test the next day, the bright student will have mastered the lesson more fully; he will have filled his beaker to a higher level, so to speak. But the dull student may fill his to the same level by studying, say, three hours, and in that case he is likely to do equally well on the examination. Many students of average learning ability perform as well in school as those with greater ability simply because they spend more time studying.

Repeated tests of forgetting with various groups of subjects in various testing situations have disclosed a pattern that leads to a general theory. To summarize the findings, let us take the performances of a single representative individual.

We start with a "pure" situation: the subject is given a list to learn in the laboratory for the first time. Of course, the situation is not quite pure; the subject's performance will be affected by his previous learning of various kinds in other contexts, but it is pure enough for our purposes. The subject studies the list until he is just able to repeat it perfectly, and then he is tested 24 hours later. We find that he has forgotten 20 per cent of the items. This is a constant rate of forgetting; it holds for all kinds of items and all kinds of student subjects.

Next we give the subject a second list

to learn and test him on this list 24 hours later. This time his performance is not quite so good as it was in the pure situation: he forgets more than 20 per cent. We go on in the same way with a third list, a fourth, a fifth and so on up to 20 lists. Plotting his successive performances on a graph, we find a startlingly sharp rise in his rate of forgetting [*see illustration below*]. In the case of the 20th list, 24 hours after learning it he has forgotten 80 per cent of the items!

The experiment shows that the more lists a subject has learned, the more he forgets of the last list he studied. Somehow each list learned contributes to the forgetting of the following list or lists. But how? How can something learned 10 or 20 days ago influence the forgetting of new material? Let us explore the question with further experiments.

This time we ask a new subject to learn two lists, both of the paired-association type and related to each other. The first list is *DAX—neutral, VOH—pretty, PEL—hybrid, QUS—arctic.* (Usually we would use a longer list, but this shortened version will do for illustration.) After the subject has learned to say "Neutral" when he is shown *DAX* as the cue, "Pretty" in response to *VOH* and so on, he is given the second list to learn, this time with different words associated with the same cues: *DAX—yellow, VOH—agile, PEL—flashy, QUS—unclean.* Learning an item in the second list is like learning a new number for your home telephone or a new position for reverse in your car's gearshift. It takes the subject a little longer to learn the second list to the point where he can give the correct responses to all the items in a trial, but he does not have as much difficulty in learning as one might expect.

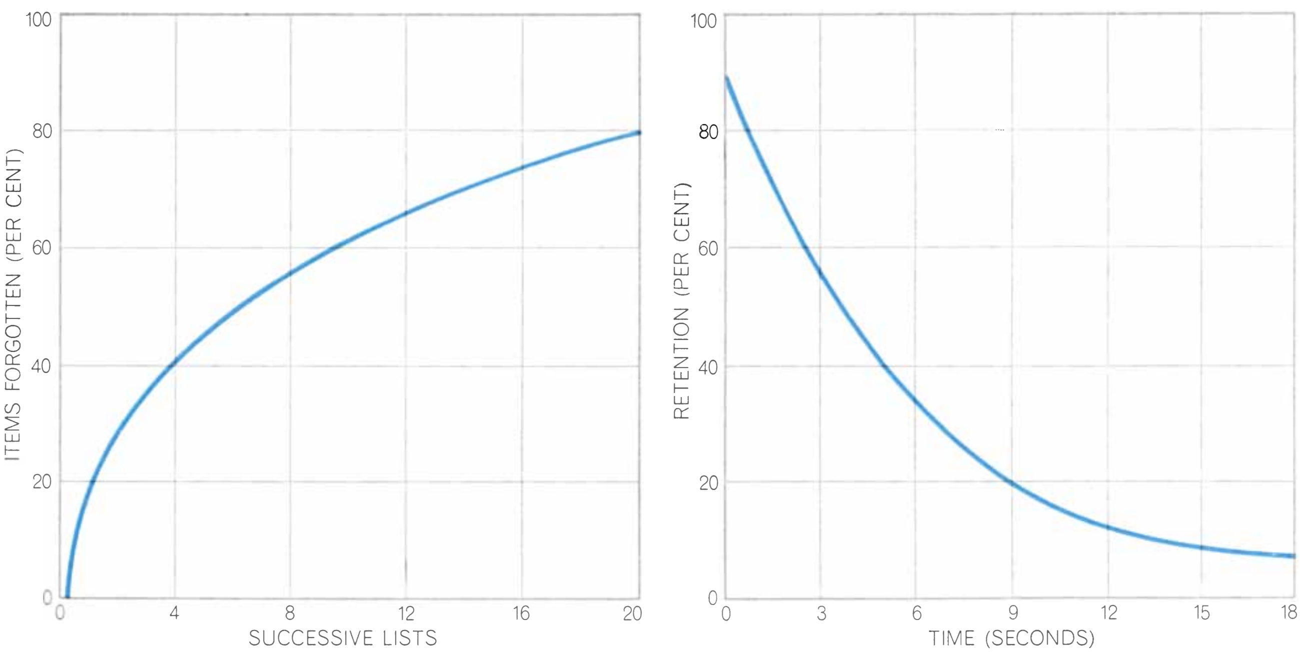
Twenty-four hours later we test the subject on each list. If he had been given only one list to learn, his forgetting score would have been 20 per cent. But now his forgetting, or failure, is 60 per cent on both lists. That is to say, his forgetting has been increased by 40 per cent, and we must conclude that the reason is *interference* of one list with the other. This interpretation is borne out by the fact that in trying to recall the associations in the first list the subject often gives a word or two from the second list and vice versa. It is as if the two learning batches had been poured into a single beaker and become mixed together by diffusion as time passes.

In the cases just described we can say List 2 exerted *retroactive* interference with the recollection of List 1, and List 1 caused *proactive* interference with the attempt to remember List 2. These experiments illustrate another important principle: The interference, and hence the forgetting, is most severe when the things to be remembered are very similar to each other. Here we had two lists in which the cues, to which different answers had to be given, were identical. We would get the same high rate of forgetting if the two lists were simply lists of words, one of which consisted of synonyms for the corresponding items in the other.

Summing up these observations in the form of a general theory, we can say that all forgetting results basically from interference between the associations a man carries in his memory storage system.

In our attempts to recall any given memory or bit of information, two kinds of interference are operating: proactive (by associations stored before this particular one) and retroactive (by others stored after it). And the amount of interference depends on certain other factors, the most obvious of which is the degree of similarity of interfering associations to the one we are trying to recall.

These principles have been demonstrated by a number of experiments in addition to those on remembering lists of words. For instance, Norman J. Slamecka of the University of Vermont has shown that proactive and retroactive interference occurs in experiments in remembering sentences. Jack Richardson of Harpur College of the State Uni-



RATES OF FORGETTING found experimentally are charted. Curve at left represents subjects who learned a list and tried after 24 hours to recall it, repeating the process through 20 lists; forgetting of any list was related to number of previous lists. Curve at right represents subjects who saw a nonsense syllable for one second and then were asked to recall it up to 18 seconds later.

versity of New York, using opposing concepts as the memory items, has demonstrated that retroactive interference operates to increase the rate of forgetting there also. Jacsue Kehoe of Brown University has found that retroactive interference operates even in pigeons, tending to destroy their memory for simple responses.

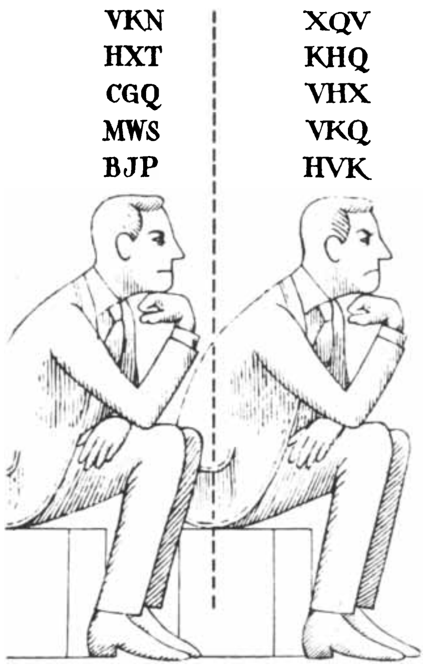
One of the most striking illustrations of the power of proactive interference has been given by an experiment in which a subject was asked to recall single items after a very short interval. This technique was initiated by a husband-and-wife team of psychologists, Lloyd R. and Margaret Jean Peterson of Indiana University. They displayed a nonsense syllable, such as *QRL,* for one second and then asked their students to recall the item at various short intervals afterward up to 18 seconds. The subjects' memory for the item declined in direct proportion to the lapse of time, and after 18 seconds 90 per cent of the students were unable to recall it correctly. This could be taken to mean that the memory trace merely decays in a simple fashion with the passage of time. But further experiments have made it almost certain that the forgetting is due to proactive interference. If one examines the retention of the very first item presented to the subjects, he finds little or no forgetting after 18 seconds. It is only after the subjects have been tested on several successive items that the rapid forgetting occurs. Clearly in this case the early items interfered with the recollection of later ones.

The demonstration brings us back to the finding that in the "pure" laboratory situation—learning the very first list of items—our subjects generally forget 20 per cent in 24 hours. We can now see more clearly that the situation is not strictly pure: there is proactive interference from the subjects' prior learning outside the laboratory. Almost any items we present to them will have earlier associations. For example, if we present the subject with the pair *table—duck,* requiring him to remember that to *table* he must respond with *duck,* his learning of this association will be complicated by other associations he has already formed with *table,* such as *chair* or *dinner.* By the same token, there is also a possibility of retroactive interference by associations with *table* formed during the 24 hours between the laboratory learning and the test of recall; the student may happen, for instance, to encounter the German word for "table" in a German class during that interval.

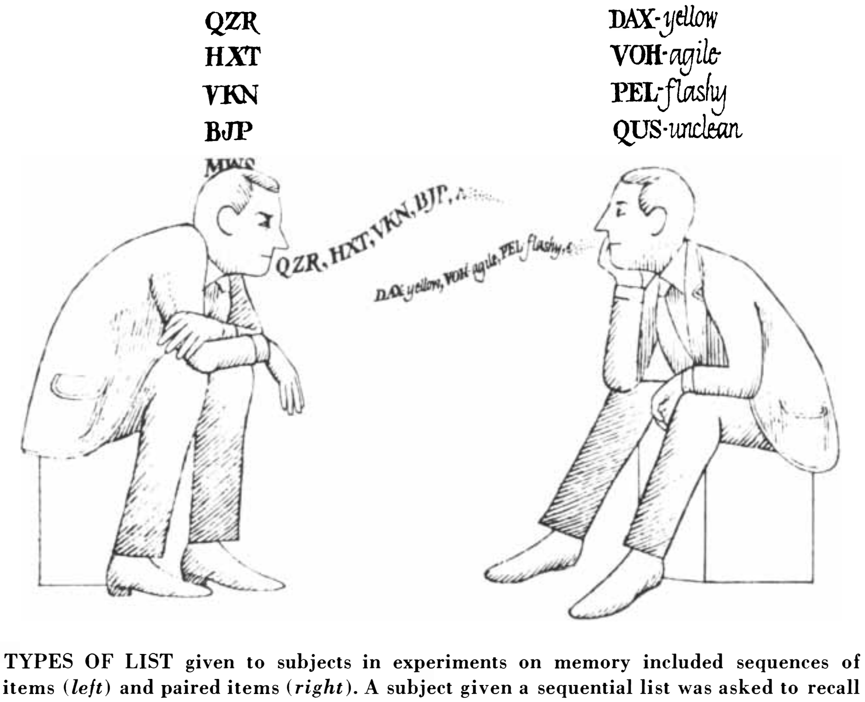
In an experiment with nonwords there is much less chance of such associations, of course, but even in that case the subjects are undoubtedly influenced by prior memories of combinations of letters, such as initials of names.

Earlier I noted that there is no evidence that slow learners forget either more or less rapidly than fast learners. This evidence, however, is based on the use of college students as subjects. If we consider much wider differences in learning ability than are present among college students, the interference theory suggests a conclusion that may seem to some a surprising paradox: a bright person should forget more rapidly than one who is mentally slower! Suppose we were to give the memory test to a bright child and a slow one. If the difference in their learning ability is great, we must suppose that the bright child has stored much more in his mind, both before and after the list-learning session, than the slow learner. Therefore his memory storage system must contain many more interfering associations; he will be beset by more proactive and retroactive interferences at the time of the test and as a result may not recall the particular list as well as the child who has less in his mind. This proposition has not yet been carefully tested, but it will not be surprising if experiments show it to be correct.

From the interference theory it also follows that a 20-year-old should forget a given list more rapidly than a 10-year-old because his greater experience makes



SIMILARITY OF ITEMS in a list appeared to make learning more difficult. A list of the type at left, with little similarity, was easier for subjects to memorize than a list of the type at right, with extensive overlapping. The same difficulty in learning appeared with lists of words relating to a single subject, such as the Arctic.

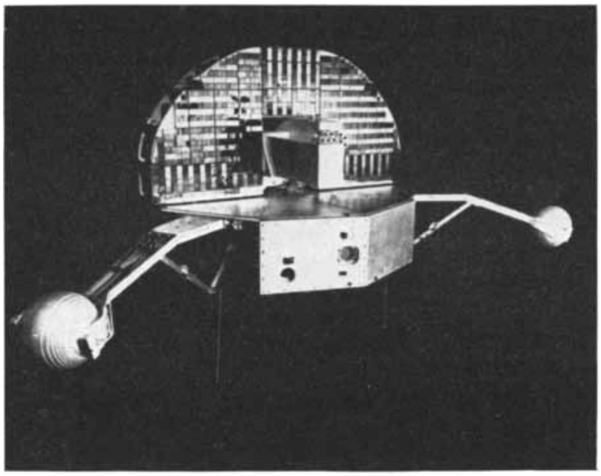


TYPES OF LIST given to subjects in experiments on memory included sequences of items (*left*) and paired items (*right*). A subject given a sequential list was asked to recall the items in same order at some subsequent time. Persons learning paired items were asked later to respond with one member of a pair (*yellow*) when given the other (*DAX*).

him more subject to proactive interference. Similarly, the theory may account for the fact that old people are notoriously forgetful of recent or current events although they show a remarkable memory of happenings of long ago. Here, however, proactive interference probably is only part of the answer, because deterioration in learning ability or concentration may help to weaken their memory of recent events as they grow older.

We must ask: If interference is so potent in making us forget things, how can we remember the enormous assortment of facts and items that all of us do manage to retain? The average 20-year-old has a great deal of information he can produce readily. He possesses a large vocabulary of words he can define on demand; he can recite a poem or two he learned many years ago; he can run off the Lord's Prayer and most of the Gettysburg Address; he carries with him, without having to look them up, the telephone numbers of several girls, the batting averages of many baseball players, perhaps the engine specifications of the new sports cars and similar items. He may even be able to talk with some sophistication about the subject matter of his college courses. How is it,

INTERFERENCE with memory may occur as a result of matter learned earlier or later. The former is proactive interference; the latter, retroactive. A man trying to remember a telephone number may have interference from other (and perhaps similar) numbers learned earlier or later, so that he jumbles the number he wants.



Orbiting Solar Observatory (OSO-1) for monitoring solar radiation—Official NASA Photo.

Detection of the 50-400A Region in NASA's S-16

A significant experiment designed by personnel of NASA's Goddard Space Flight Center as part of the first Orbiting Solar Observatory launched in early 1962 involved a study of solar X-rays, the probable source of which lies close to the base of the corona. Study of such radiation could not only lead to a theory for predicting solar flares but may also point the way for more accurate sun simulation in environmental testing. High resolution solar spectra in the 50 to 400 Angstrom region had never before been achieved. Hence, the OSO experiment.

The solar far vacuum ultraviolet soft X-ray spectrometer, utilizing a Bendix M-306 windowless photon detector, is mounted in an instrument housing in the upper portion of the satellite, the non-spinning section which remains oriented to the sun. In operation, solar radiation enters a slit and is diffracted by a curved grating, ruled 576 lines per mm. The resulting spectrum is focused along a circle according to wave length. The motor driven detector moves along this circle measuring radiation intensity throughout the desired wave length region.

The pulse output of the Bendix detector is then converted into binary wave form for telemetry to earth.

The particular Bendix detector, designed and fabricated for NASA's use in this experiment, differs significantly from conventional electron multipliers in that it uses a single dynode—formed of a continuous surface of high resistance semiconductor material—rather than many individual dynodes. In operation, electrons produced by impingement of photons on the cathode gain energy from the electric field produced by the potential drop along the highly resistive semiconductor surface.

A magnetic field, perpendicular to the electric field, forces the released electrons to travel in cycloidal paths, striking the strip "downstream" at regular intervals, each electron releasing additional secondary electrons. Eventually the swarm of electrons reaches the anode as a greatly amplified current.

The Bendix® Magnetic Electron Multiplier design permits current gains of over 10^7 without any activation to enhance secondary emission properties of the dynode surface. This type of multiplier is therefore particularly useful for applications where it must be periodically exposed to air.

The Bendix model M-306 photon detector used in the OSO-1, S-16 had a background counting rate of less than 1 count per 8 seconds. New and improved models, smaller in size and with special cathode materials, have been developed for future space experiments. Additional information on Bendix Electron Multipliers is available.

Bendix Research embraces a wide range of technology including acoustics, nuclear, solid state physics, quantum electronics, mass spectrometry, photoelectronics, electron beam and tube technology, measurement science, applied mechanics, energy conversion systems, dynamic controls, systems analysis and computation, navigation and guidance, microwaves, digital techniques, data processing and control systems. Motivation: to develop new techniques and hardware for The Bendix Corporation to produce new and better products and complete, integrated, advanced systems for aerospace, defense, industrial, aviation, and automotive applications. Inquiries are invited. We also invite engineers and scientists to discuss career position opportunities with us. An equal opportunity employer. Write Director, Bendix Research Laboratories Division, Southfield, Michigan.

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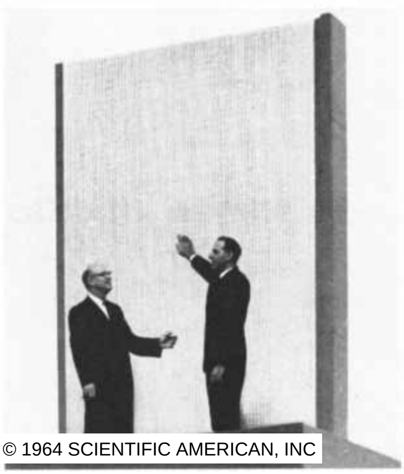
WHERE IDEAS UNLOCK THE FUTURE

This helicopter is air-lifting a new, compact 3-D radar which can be taken to trouble spots anywhere in the world at a moment's notice. It meets the need for systems which can snuff out threats to peace wherever they happen.

Packaged in two small shelter-boxes, this ruggedly-built radar can operate in the most remote areas. Setup and on the air "instantly" (in about 30 minutes), it will monitor hundreds of aircraft in its area without any human attendant.

Unlike conventional radar, the "picture" of air activity it presents is three-dimensional—simultaneously and accurately showing distance, direction and height of aircraft. Thus, it is equal to the difficult task of locating and tracking today's supersonic targets. And, it can provide the information necessary for commanders to take swift, decisive action.

This compact 3-D radar is the latest application of Hughes' invention of *frequency-scanning* (i.e., electronic positioning of radar beams). Conventional radars move in a "rocking" fashion—mechanically positioning its beams to determine the altitude of targets. Hughes 3-D radar,



Now in operation, this new compact, lightweight radar antenna is part of the Hughes air-transportable 3-D radar system. Hughes has tested and demonstrated this system before representatives of U. S. and tactical teams of our allies.

Creating a new world with electronics

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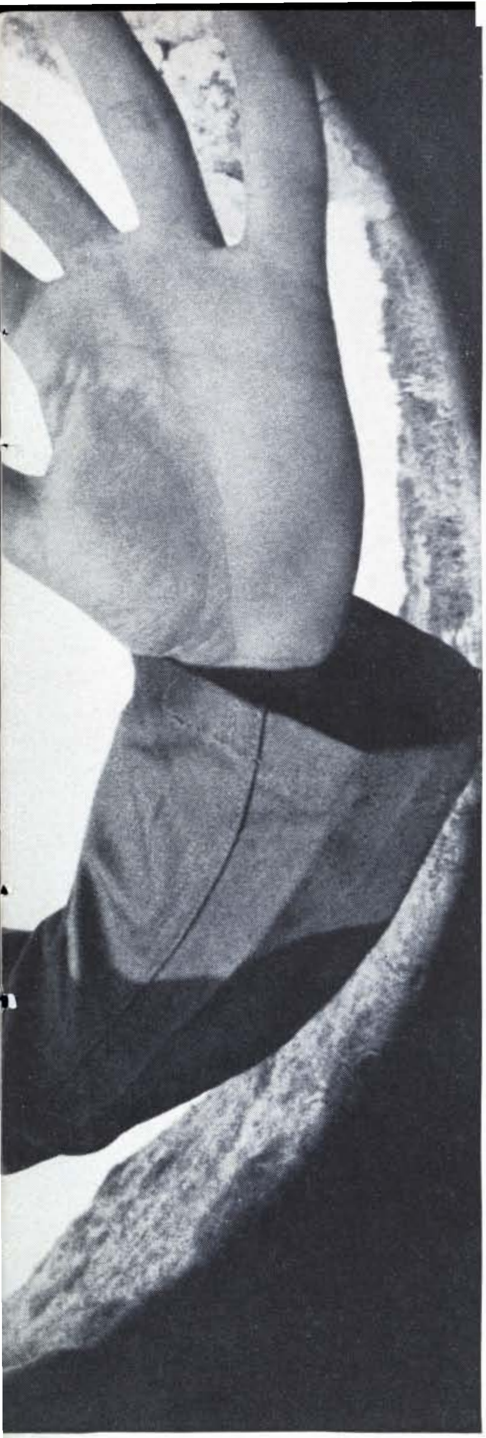
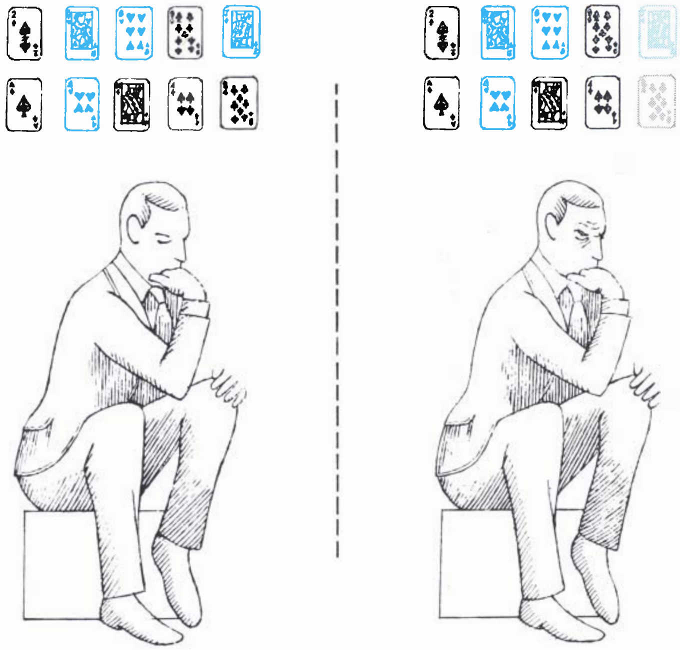




CONSISTENCY IN RATE of forgetting appeared in experiments. A subject who studied any kind of list long enough to repeat it perfectly was found usually to have forgotten 20 per cent of it 24 hours later. Here the list consists of 10 playing cards chosen at random.

after all, that so much sticks in our minds?

There seem to be two basic explanations. In the first place, learning and retention improve with practice. The more we use an item of information or an idea, the more firmly we establish it against interfering associations. Frequent reference to a telephone number, for example, removes it from the welter of less accustomed memories.

In the second place, our retention of some things is fortified by the circumstances under which we learn them. The schedule employed in learning has a strong effect in producing resistance to forgetting, as Geoffrey Keppel of the University of California at Berkeley has dramatically demonstrated. He tested two different schedules of learning a task complicated by strong proactive interference. The task required the subjects to learn four different sets of words paired to the same key words and then remember the fourth set in a later test. One schedule consisted in studying all four sets at a single sitting. In the other schedule Keppel had the subjects study the fourth set on a spaced-out basis over a period of four days, with two trials each day. This proved far more effective than the single-session system. Those who did all the studying in a single session had almost completely forgotten the fourth set of words at the end of a week, whereas those who learned the fourth list separately in the spaced schedule showed 34 per cent retention of it even after a month. Just how such a schedule reduces proactive interference is not yet clear, although a number of investigators are working on the question. Perhaps the results of the experiment are merely another illustration of the fact that periodic repetition or use of an item makes it resistant to forgetting. In any case, the experiment tended to bear out the well-established impression that cramming for an examination is apt to result in quick forgetting of the crammed material.

Now that we have a reasonable general theory of forgetting, it opens up many intriguing questions for both experimental and theoretical investigation. Why does a severe emotional trauma so often produce complete amnesia for the event with which it is associated? Why, on the other hand, are we sometimes unable to repress the memory of a very unpleasant experience and instead build it up to greater dimensions? Why does a name resist our most agonized efforts to recall it and then pop into our minds at a moment when we apparently have no interest in it? Questions such as these demand laboratory investigation, and the interference theory may be helpful in one way or another in pursuing the answers.

The Discovery of Stellar Aberration

This apparent displacement of starlight because of the velocity given an observer by the earth's orbital motion was explained in the 18th century by the English astronomer James Bradley

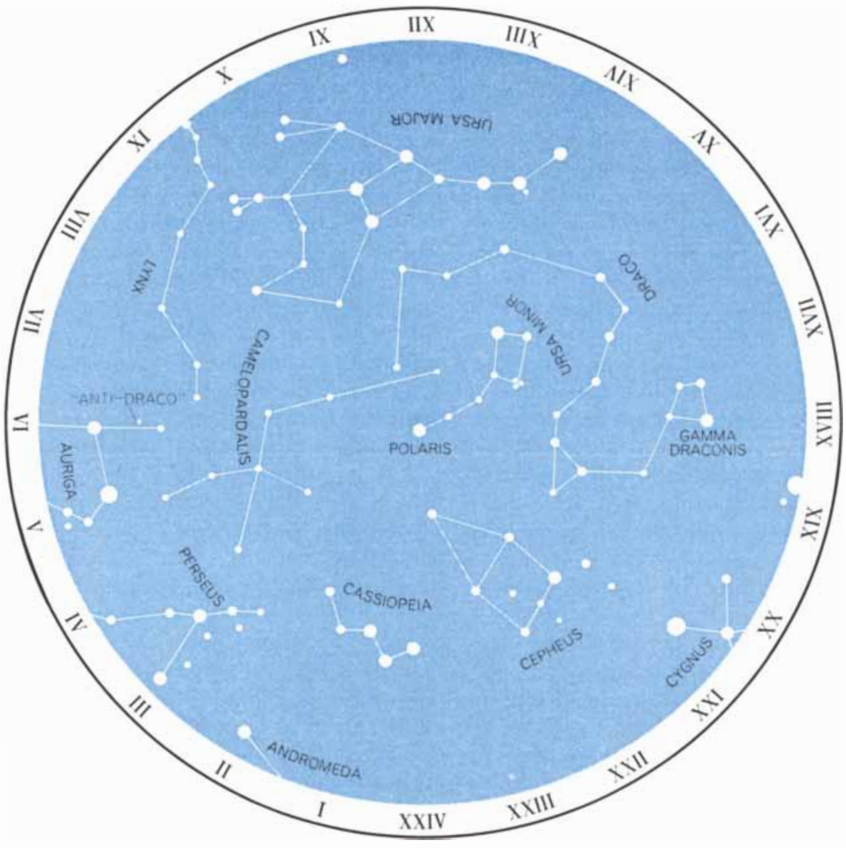
by Albert B. Stewart

When a man looks at a star, he sees the star not in its true position but in an apparent position. The reason is that the motion of the earth around the sun is carrying the observer through space at a speed of about 18.5 miles per second, so that the starlight he sees undergoes an apparent displacement resulting from the combined effect of his velocity and the velocity of the light. A similar phenomenon is observed by a man driving a car at a modest speed through a snowstorm at night; even though the snow may be falling vertically, it appears to be moving at an angle because of the combined effect of its velocity and the car's.

The displacement, or aberration, of starlight can be detected by direct observation because the earth is not always moving in the same direction. Since the earth's orbit is nearly circular, an observer who is being carried in one direction now will be moving in the opposite direction six months later. Owing to this change in direction, starlight that is displaced one way now will be displaced the opposite way six months from now. The actual displacement of starlight because of aberration cannot be directly observed, but the changes in this displacement can. It was through following the changes in the displacement of several stars that the English astronomer James Bradley discovered stellar aberration early in the 18th century. Bradley first assisted in and later extended observations by Samuel Molyneux, a wealthy amateur who like Bradley was a Fellow of the Royal Society. Both men were greatly aided by George Graham, whose mechanical skill enabled him to construct instruments of such precision that effects too small to be detected earlier were made accessible to astronomers.

The discovery of stellar aberration was of major significance in astronomy. It provided a convincing argument against die-hard anti-Copernicans who were still insisting that the sun revolved around the earth; it established a new standard of accuracy for astronomical measurements, and it proved in time to be an important piece of evidence for the principle of relativity. Yet, as is so often the case in the history of discovery, Molyneux and Bradley found stellar aberration when they were looking for something quite different. At first they did not know what they were observing. Molyneux may never have known; he died in 1728, about six months before Bradley arrived at his explanation of their observations.

A century after the observations by Molyneux and Bradley, S. P. Rigaud, a



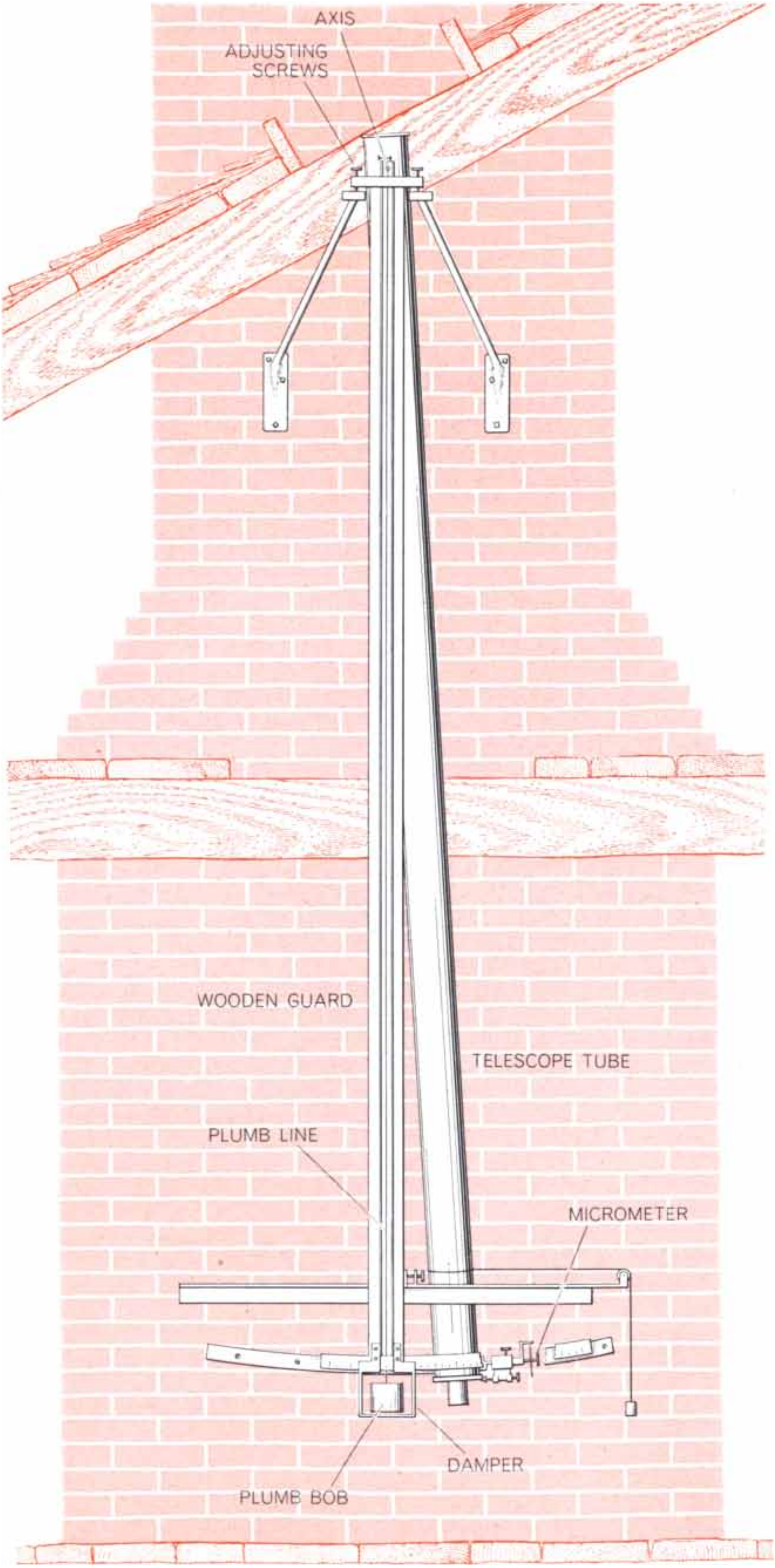
NORTHERN CONSTELLATIONS in the vicinity of Polaris, the pole star, are shown as they appear at midnight in mid-March. Observations by Samuel Molyneux and James Bradley of the star Gamma Draconis in Draco, checked when possible with observations of the small star in Auriga that they called "anti-Draco," led to the discovery of stellar aberration.

successor of Bradley's as Savilian Professor of Astronomy at the University of Oxford, assembled and published their data. Thus there exists an unusually complete record of a great discovery kept by the men who made it.

What Molyneux and Bradley had hoped to do was to detect and measure stellar parallax: the apparent displacement of a star resulting from changes in the point of observation as the earth moves through its orbit [*see illustration on next page*]. Since the Copernican doctrine asserted that an observer on the earth changes his point of observation as he and the earth proceed about the sun in the annual motion, the critics of the Copernican view had cited the failure to detect stellar parallax as evidence against a sun-centered system. Copernicus and his defenders had attributed the absence of an observable effect to the much greater distance between the earth and the stars than between the earth and the sun; in fact, the angles of stellar parallax are so small that the instruments of Bradley's time and earlier were unable to detect them. Stellar parallax was first measured by Friedrich Wilhelm Bessel in 1838; he found it to be .3 second of arc for the close star 61 Cygni.

A half-century before the observations by Molyneux and Bradley, Robert Hooke had reported detecting a change during a year in the position of Gamma Draconis, a bright star in the constellation Draco, and had called it the result of parallax. (It was, as Bradley was able to show, the result of using an inaccurate instrument.) Inasmuch as other observers had been unable to confirm Hooke's results, Molyneux and Bradley considered it highly desirable to repeat the work, with greater precision if possible. They chose the same star because its brightness made possible day as well as night observations and because it passed within .1 degree of their zenith, the point directly overhead, thereby minimizing the displacement of the star's rays by refraction on entering the earth's atmosphere.

So it was that at about noon on December 3, 1725, Molyneux lay back on a couch on the ground floor of his mansion on the western edge of Kew Green, near London, and peered through the eyepiece of a vertical telescope attached to the south side of the central chimneys and extending through two ceilings to the garret, where an opening in the roof made possible observations of the sky. At 18 minutes past noon Gamma Draconis entered his field of

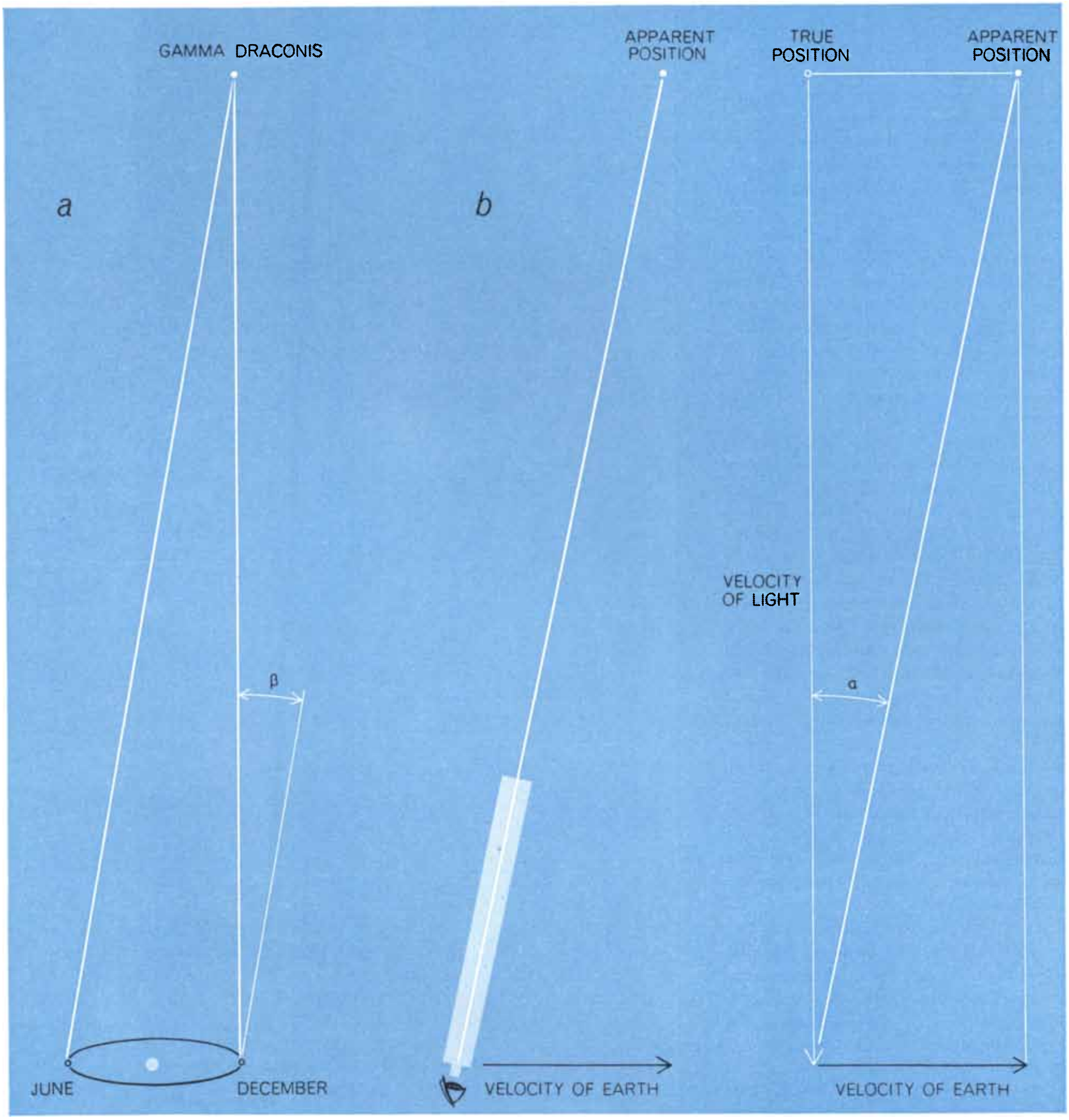


BRADLEY'S TELESCOPE, mounted in a house near London, was 12.5 feet long and could measure in quarter-seconds of arc any movement north or south by stars in its field.

view. By moving the tube of his telescope in a north-south direction he caused the cross hair to bisect the star [*see illustration on opposite page*]. He next adjusted a brass plate screwed to the telescope in such a way that the wire of a plumb bob attached to the upper end of the telescope mount "exactly bisected" a mark he and Bradley had made on the plate as a reference point. With these adjustments, completed at about 1:00 P.M., he was now prepared to measure changes in the star's position.

A measurement at any given time would consist of lining up the east-west cross hair of the telescope with the star, as it crossed the center of the field of view, by turning the wheel of a micrometer. The reading of the wheel could then be compared with the reading obtained when the telescope was lined up to make the plumb line bisect the mark on the brass plate; the difference between the two readings would give the angle by which Gamma Draconis had moved north or south since the initial alignment on December 3. Measurements could be read directly in seconds of arc, since Molyneux, Bradley and Graham had designed the thread of the micrometer screw and the divisions on the wheel so that one mark on the wheel corresponded to a change of one second of arc in the angle of the telescope.

The precision of the instrument de-

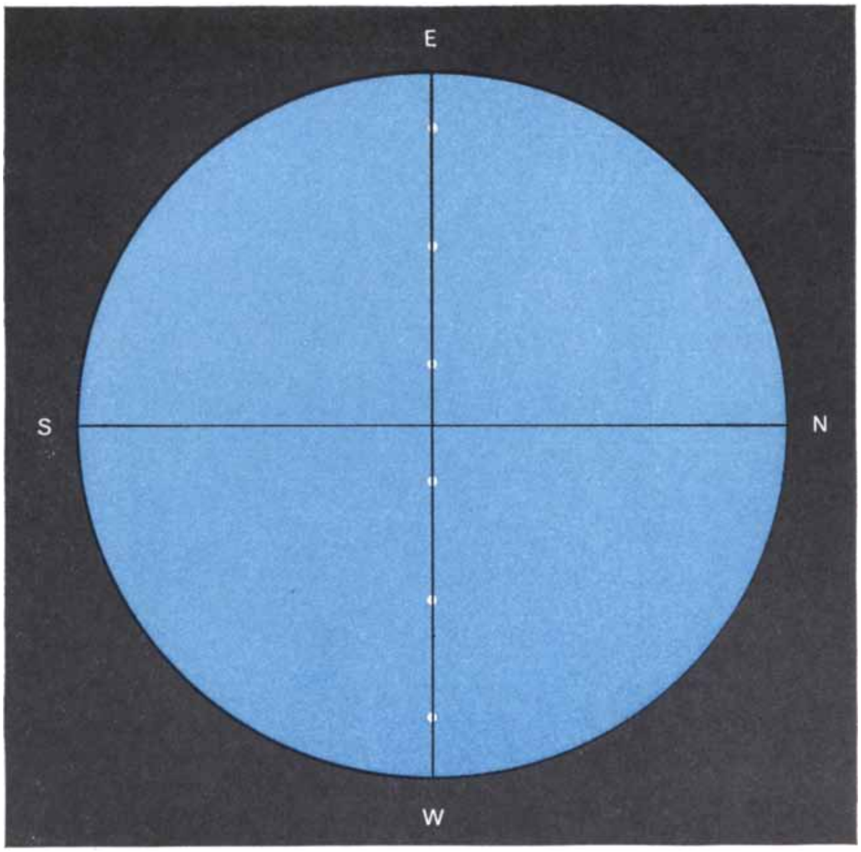


PARALLAX AND ABERRATION are differentiated. Because of parallax (*a*) a telescope pointed at a star in June will have to be adjusted southward through angle β to point at star in December. In aberration (*b*) earth's orbital motion at 18.5 miles per second combines with movement of light at 186,324 miles per second to make the star appear to be out of its true position.

pended critically on the stability of the chimneys and on the alignment of the plumb line with the vertical. Changes in the position of the bearing that supported the telescope, or any deflection of the plumb line, would alter the reference position from which all angular deflections were to be measured. The designers had eliminated the difficulty of the swaying of the plumb bob by damping the bob's motion in water and by surrounding the lower end of the plumb line with a wooden tube that protected it from air currents. (The tube also provided a support for spider webs, which often had to be removed before the instrument could be adjusted.) In a series of preliminary measurements Molyneux found to his delight that successive readings of the wheel when the telescope was adjusted to bring the plumb line on the index agreed to within one second of arc, which justified reading the wheel to a fraction of a second.

Bradley first came down to Kew on December 17 and established to his satisfaction that the instrument could be adjusted to .5 second by the plumb line. He had no particular reason to look at Gamma Draconis that day because observations on December 5, 11 and 12 had shown the star in essentially the same place and, as he wrote later, it was "a part of the year wherein no sensible alteration of parallax in this star could soon be expected." He added that "it was chiefly therefore curiosity that tempted me ... to prepare for observing the star on December 17th," at which time he "perceived that it passed a little more southerly." On December 21 Molyneux and Bradley again observed Gamma Draconis and found that it passed along the cross hair when the telescope pointed 3.5 seconds south of its December 3 setting. By March 6 the star was 21 seconds more southerly than it had been on December 3. It was first north of the mark on June 12. By December 26, 1726, it was 6.9 seconds south, agreeing to .5 second with the average of the December 21 and January 2 observations of the year before. During 1727 the observers recorded 18 more transits of the star, bringing their total to more than 80 before they stopped using the Kew instrument at the end of 1727.

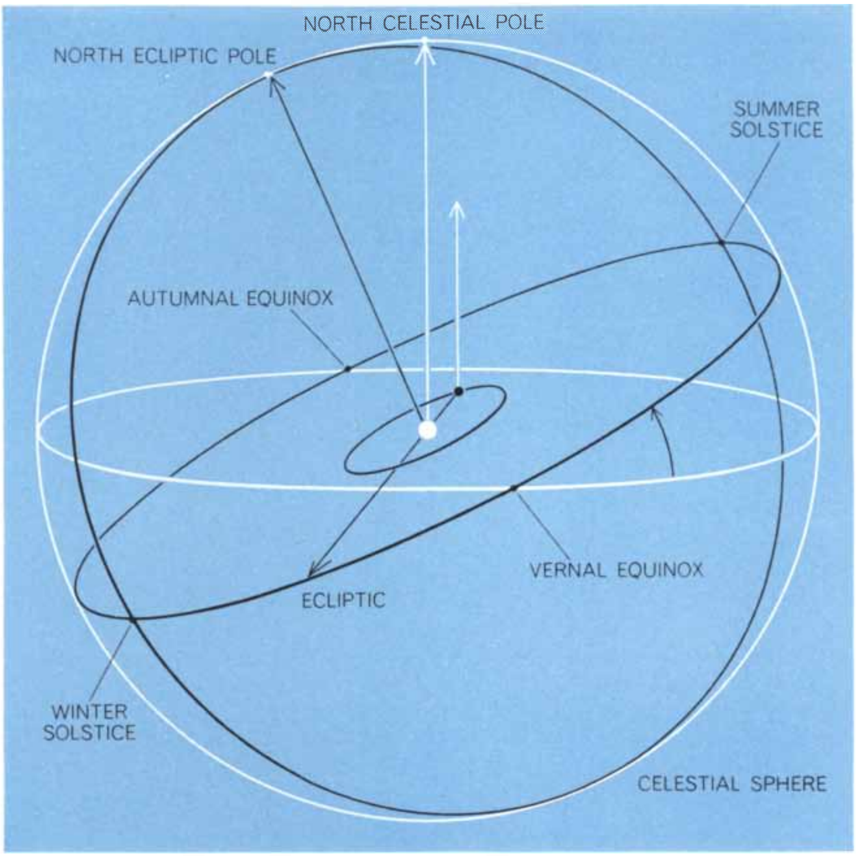
Throughout the two years Molyneux continually checked the stability of the chimneys. On one occasion he wrote in the notebook recording their observations: "This was a rainy, blowing tempestuous night; however this morning trying the instrument again we found the index as we left it last night at 5 and we were obliged to alter it only to 6; so that with this blowing, sudden change of weather, it alters but one second to bring it to the plumb line." And on another occasion: "There was a violent and very unusual hurricane, such as hath not been known in many years ... notwithstanding all which changes when we adjusted it this day the index stood at 11½, only 1/2 second different from what we left it."



FIELD OF VISION in the initial observations by Molyneux and Bradley with the former's telescope appeared as shown. Observer lay with head eastward; because of inversion by lens the star entered the field from bottom. It also described a barely detectable curved path. Aligning east-west cross hair with star gave movement north or south since first observation.

The notebook of the observations at Kew, with most of the entries made by Molyneux, is entirely lacking in speculation on the cause of the changing declination of Gamma Draconis. To reconstruct the way in which Bradley unraveled the mystery presented by the observations one must refer to a letter he addressed in 1729 to Edmund Halley, the Astronomer-Royal (a post to which Bradley succeeded on Halley's death in 1742), for inclusion in the *Philosophical Transactions of the Royal Society*.

From the letter it is apparent that the rapid change of declination in December, amounting to 3.5 seconds in 18 days, was a complete surprise to Bradley. He realized for two reasons that the cause was not parallax. The effect of parallax would be greatest in March and September, when the change from one day to the next in the earth's position along the north-south direction is greatest; but (as is now realized) because an observer's velocity is at right angles to the north-south plane when Gamma Draconis is overhead in December and June, the change in the angle of aberration from one day to the next is greatest at those times. Moreover, the direction of the star's motion was to the south, whereas any observable motion that was due to parallax at that time of year should have been to the north. Rigaud wrote in his memoirs of Bradley that the time when the first readings were made "happened to be most favorable." Three months earlier "the star by the effect of aberration would have been moving southward; but that is the direction in which [at that time] it would then have been carried by parallax." Rigaud expressed confidence that Bradley "would have disentangled the clew, but it was fortunate that this trouble was spared him, and



CELESTIAL SPHERE, shown in white, is the imaginary sphere that has as its equator an infinite extension of the earth's equator. The ecliptic is the plane of the sun's apparent movement around the earth. Equinoctial points to which Bradley referred are at intersections of ecliptic with celestial equator; solstices are 90 degrees away on the ecliptic.

that the first step to his great discovery presented itself clearly and decidedly to his view."

Bradley's first reaction to the unexpected observations was to doubt the accuracy of the instrument. But as the weeks passed and the index remained staunchly fixed in relation to the plumb line, his respect for the telescope and the chimneys to which it was attached gradually overcame these doubts. He became convinced that there was a real effect, whatever it might be.

After parallax the next possibility that Bradley considered was a nutation, or wobble, of the earth's axis. Beginning a month after the first observations, Molyneux, Bradley or Graham observed whenever possible a star in Auriga that crossed the field about 12 hours after Gamma Draconis. While Gamma Draconis moved southward, "anti-Draco," as they dubbed the other star, moved northward—but only five seconds of arc during the time that Gamma Draconis moved 9.1 seconds. Because of this difference of 4.1 seconds when nutation presumably would have produced little or no difference, Bradley looked for another explanation of the phenomena they were observing. He did not abandon the idea that nutation might be a partial cause, however, and some 20 years later he was able to make a convincing demonstration that this much smaller effect did indeed exist.

At about the same time that they investigated the possibility of nutation Molyneux and Bradley considered whether or not the bending of light rays from the star on entering the earth's atmosphere might produce the deviations they were observing. If the atmosphere were deformed into a spheroid by some resisting medium through which the earth was steadily passing, then the rays would not strike the surface of the atmosphere at right angles and would undergo a small refraction toward the perpendicular. The refraction hypothesis coincided fairly well with the readings Molyneux and Bradley were obtaining from their telescope, but it required detailed assumptions about the shape of the earth's atmosphere that were unsupported by other observations. The two men seem to have abandoned the hypothesis when they were able to make further measurements on "anti-Draco" and discovered that the magnitude of the deviations depended on the angle that a star made with the plane of the earth's orbit.

With this discovery, made about a year after observations began, Bradley realized that he needed observations on more stars than entered the field of the Kew instrument. As he reported to the Royal Society:

"Not being able to frame any hypothesis at that time sufficient to solve all the phaenomena, and being very desirous to search a little farther into this matter; I began to think of erecting an instrument for myself at Wansted [Wanstead, near London], that, having it always at hand, I might with the more ease and certainty inquire into the laws of this new motion. The consideration likewise of being able by another instrument to confirm the truth of the observations hitherto made with Mr. Molyneux's was no small inducement to me; but the chief of all was, the opportunity I should thereby have of trying in what manner other stars were affected by the same cause, whatever it was. For Mr. Molyneux's instrument, being originally designed for observing γ Draconis, (in order, as I said before, to try whether it had any sensible parallax,) was so contrived as to be capable of but little alteration in its direction, not above seven or eight minutes of a degree: and there being few stars within half that distance from the zenith of Kew bright enough to be well observed, he could not, with his instrument, throughly examine how this cause affected stars differently situated with respect to the equinoctial and solstitial points of the ecliptic" [*see illustration on this page*].

The instrument that Bradley had Graham construct for him, and which he mounted in his aunt's house at Wanstead, was only half the length of Molyneux's—12.5 feet instead of 24.25 feet—but it could be adjusted to a quarter of a second, about twice the precision of the Kew instrument. The general design closely resembled that of the Molyneux instrument, with the smallest division of the micrometer screw corresponding to a little less than .5 second. The new instrument could be extended to observe 6.25 degrees on each side of the zenith, giving it 100 times the range of the old. Bradley could now observe 200 stars, 12 of which were bright enough to be seen at all seasons of the year, even when nearest the sun.

He began his observations on August

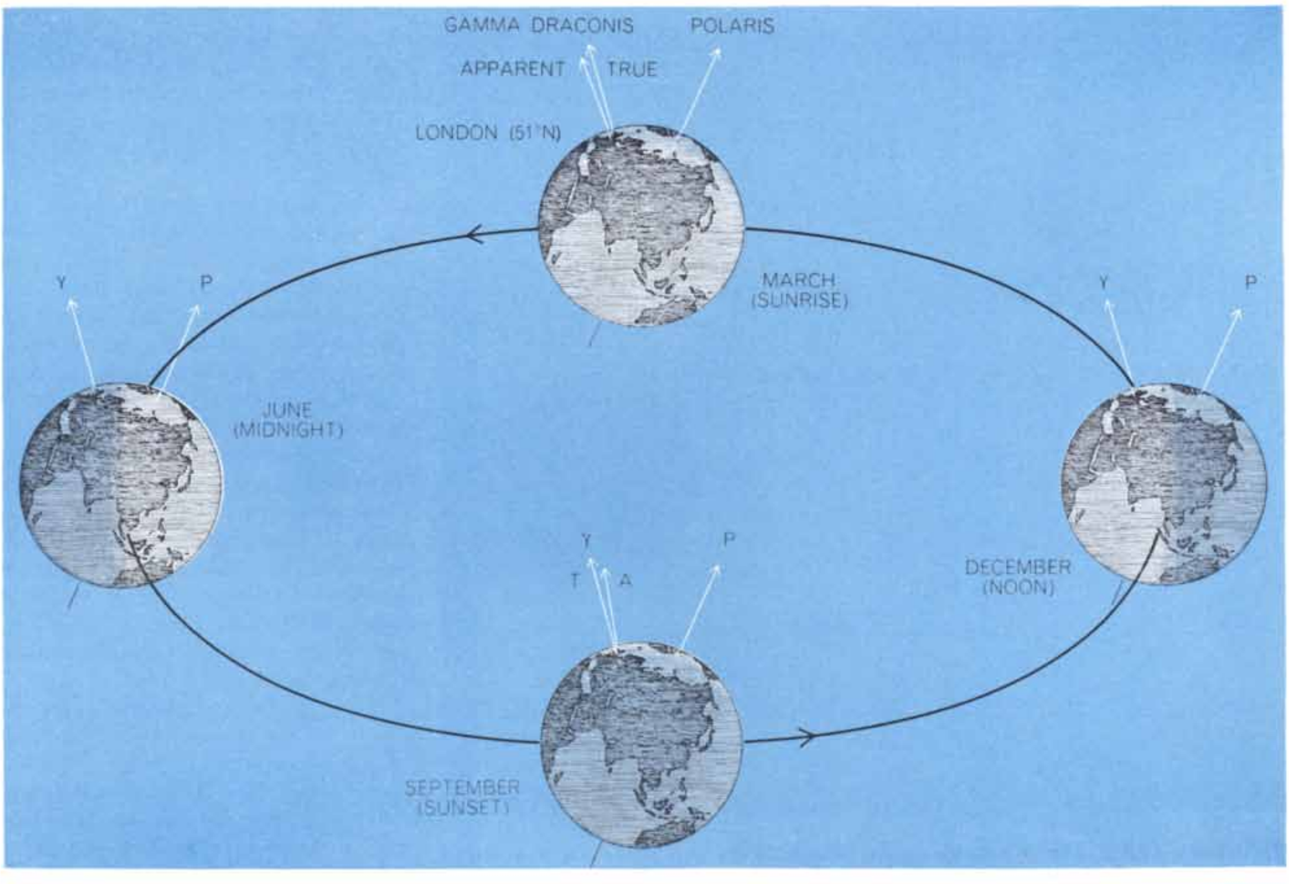
19, 1727, and within a few months had collected enough data to realize the insupportability of an earlier hypothesis he had advanced that the changing declination of the stars was determined by the position of the earth with respect to the solstice. Rather, he wrote: "I discovered what I then apprehended to be a general law, observed by all the stars, viz. that each of them became stationary, or was farthest north or south, when they passed over my zenith at six of the clock, either in the morning or evening. I perceived likewise, that whatever situation the stars were in with respect to the cardinal points of the ecliptic, the apparent motion of every one tended the same way, when they passed my instrument about the same hour of the day or night; for they all moved southward, while they passed in the day, and northward in the night; so that each was farthest north when it came about six of the clock in the evening, and farthest south when it came about six in the morning."

Not all the stars showed the same range of variation in declination, and Bradley sought to find what rule was operating to determine the range. By September, 1727, he thought it was proportional to the sine of the angle between a line drawn from the star to the earth and a line in the plane of the earth's orbit; in other words, to the sine of the latitude of the star. But because his observations did not "perfectly correspond with such an hypothesis," Bradley resolved to abandon speculation until he had followed the motion of the stars for a full year.

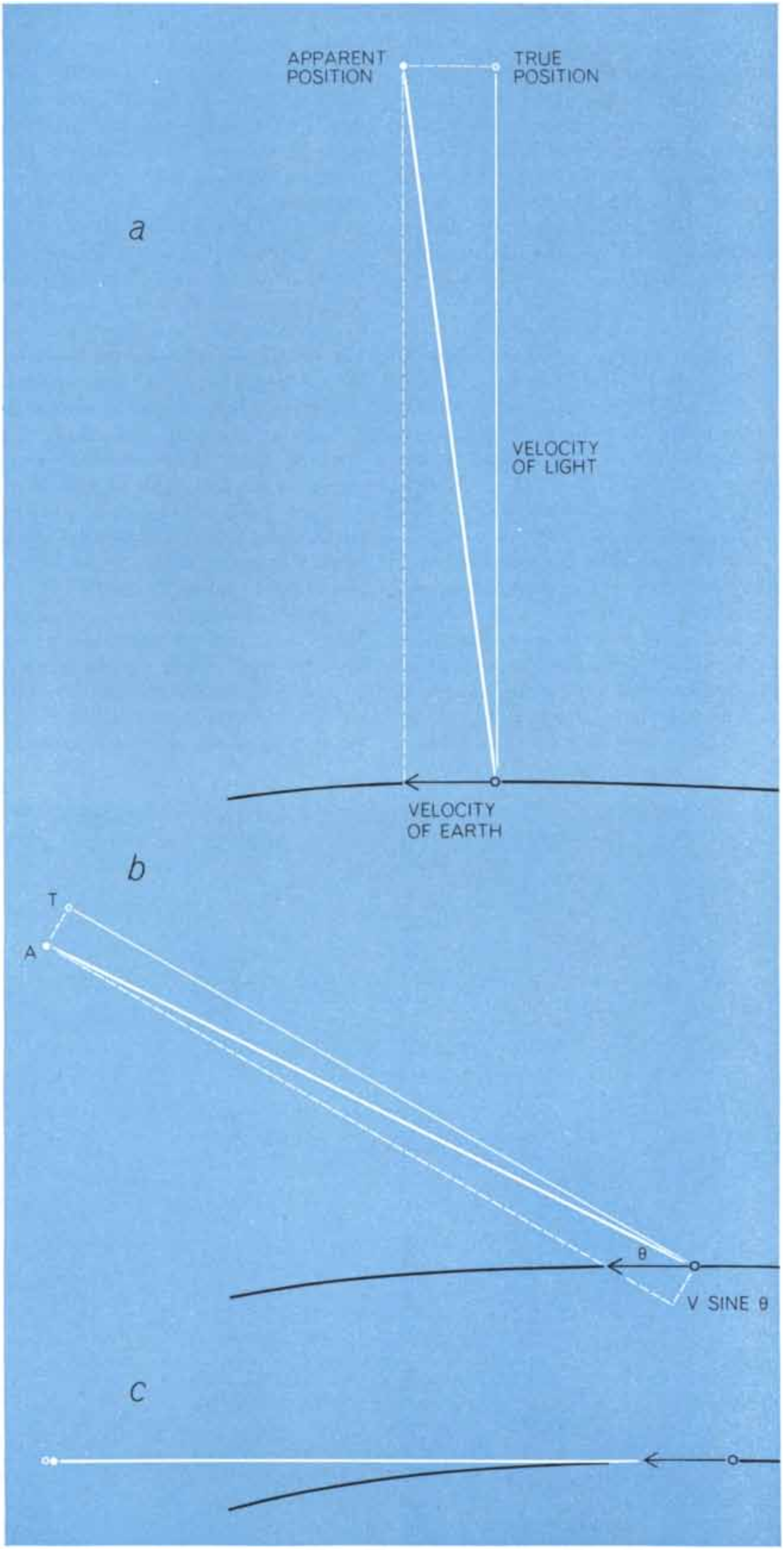
Just when Bradley arrived at the correct explanation of all the phenomena he had been observing is not known, but Rigaud sets the time early in the fall of 1728 and locates the place of the inspiration as a sailboat in the Thames. Thomas Thomson in his *History of the Royal Society,* published in 1812, gives this account:

"At last, when he despaired of being able to account for the phenomena which he had observed, a satisfactory explanation of it occurred to him all at once, when he was not in search of it. He accompanied a pleasure party in a sail upon the river Thames. The boat in which they were was provided with a mast, which had a vane at the top of it. It blew a moderate wind, and the party sailed up and down the river for a considerable time. Dr. Bradley remarked, that every time the boat put about, the vane at the top of the boat's mast shifted a little, as if there had been a slight change in the direction of the wind. He observed this three or four times without speaking; at last he mentioned it to the sailors, and expressed his surprise that the wind should shift so regularly every time they put about. The sailors told him that the wind had not shifted, but that the apparent change was owing to the change in the direction of the boat, and assured him that the same thing invariably happened in all cases. This accidental observation led him to conclude, that the phenomenon which had puzzled him so much was owing to the combined motion of light and of the earth."

Rigaud, relating the story, explained that when Bradley's boat was at rest, the vane would point directly opposite to the wind. As the boat moved, however, its velocity would combine with the velocity of the wind and make the



EFFECT OF ABERRATION varies during the year. Gamma Draconis appears to move toward the south from September to March, when it is seen by day. During the rest of the year, when it is seen by night, it appears to move northward. It reaches its most southerly position in March, most northerly in September. Its greatest apparent daily movement occurs in December and June, when earth's orbital velocity is at right angles to north-south plane. Parenthetical words indicate time of day star is visible.



RANGE OF ABERRATION depends on the latitude of the star. If the star is overhead (*a*), the velocity of the earth is at right angles to the line of sight to the star and the aberration is at a maximum. At a lower latitude (*b*) the effect of the earth's orbital velocity is diminished: aberration will be equivalent to the earth's velocity multiplied by the sine of the angle θ. A star in the direction of the earth's motion (*c*) will show no aberration.

vane "incline from its former direction towards the stern of the boat." In like manner, Rigaud wrote, the earth in its orbit "successively meeting the rays of light from any one of the heavenly bodies, modifies the direction in which they enter the eye, and the star ... must appear to be at some distance from its true place." He remarked that "this deviation will always be on the side to which the earth's relative motion shall be at the particular moment directed, and the quantity of it will depend on the ratio which the velocity of that motion shall bear to the velocity of light."

Although Bradley said nothing about a sailboat incident in his letter to Halley, which was read to the Royal Society on January 9 and 16, 1729, his failure to mention it does not necessarily prove the story false. His recital of his conclusions about aberration was brief:

"At last I conjectured that all the phaenomena hitherto mentioned proceeded from the progressive motion of the light and the earth's annual motion in its orbit. For I perceived that, if light was propagated in time, the apparent place of a fixed object would not be the same when the eye is at rest, as when it is moving in any other direction than that of the line passing through the eye and object; and that when the eye is moving in different directions, the apparent place of the object would be different."

This hypothesis perfectly accounted for the movements Bradley had noted. The star Gamma Draconis appears farthest south in March, when observed at sunrise, because at that time of year the earth's motion about the sun gives the telescope its maximum velocity in a southerly direction [*see illustration on preceding page*]. The star appears farthest north in September, when observed at twilight, because at that time of year the earth's orbital motion gives the telescope its maximum velocity in a northerly direction. When the star "passes by day," from September to March, it moves southward; when it "passes by night," between March and September, it moves northward.

The hypothesis of aberration also accounts for the dependence of the range of a star's apparent motion on the latitude of the star. The maximum range will occur for a star that lies on a line perpendicular to the plane of the earth's orbit; for such a star the orbital velocity of the earth is always directed at right angles to the line of sight. For stars at lower latitudes the velocity component perpendicular to the line of sight is reduced in proportion to the sine of the angle of latitude [*see illustration on opposite page*]. For a star in the direction of the earth's motion no change in north-south declination would be expected.

Bradley, using the observations on the eight stars most satisfactorily observed with the Wanstead instrument, computed an average value of 20.25 seconds of arc for the angle of aberration that occurs when the earth is moving at right angles to the line drawn from the star to the earth. The accepted value for this aberration constant today is 20.47 seconds of arc; Bradley's value differs from the presently accepted value by less than the .5 second uncertainty he assigned to his measurements.

In another calculation Bradley computed the tangent of the angle of aberration—that is to say, the ratio of the earth's velocity past the star to the velocity of light—to be 1/10,210. From this figure and the value of the earth-sun distance he computed that it takes light 16 minutes 26 seconds to travel the diameter of the earth's orbit about the sun. Since this figure was between the 22 minutes computed earlier by the Danish astronomer Ole Roemer and the 14 minutes 10 seconds computed by Jean Dominique Cassini, both of whom calculated from observations of the eclipses of Jupiter's moons, Bradley's results for the velocity of light were consistent with earlier measurements. He concluded, quite correctly, that his observations gave the most precise value for the velocity of light obtained up to that time.

With respect to the original quest, Bradley decided that the parallax could not have been greater than two seconds of arc for any of the eight stars he followed most closely and must have been less than one second for Gamma Draconis. Bradley's results showed that the figures on which Hooke had based his claim for the discovery of stellar parallax were in error by as much as 30 seconds of arc.

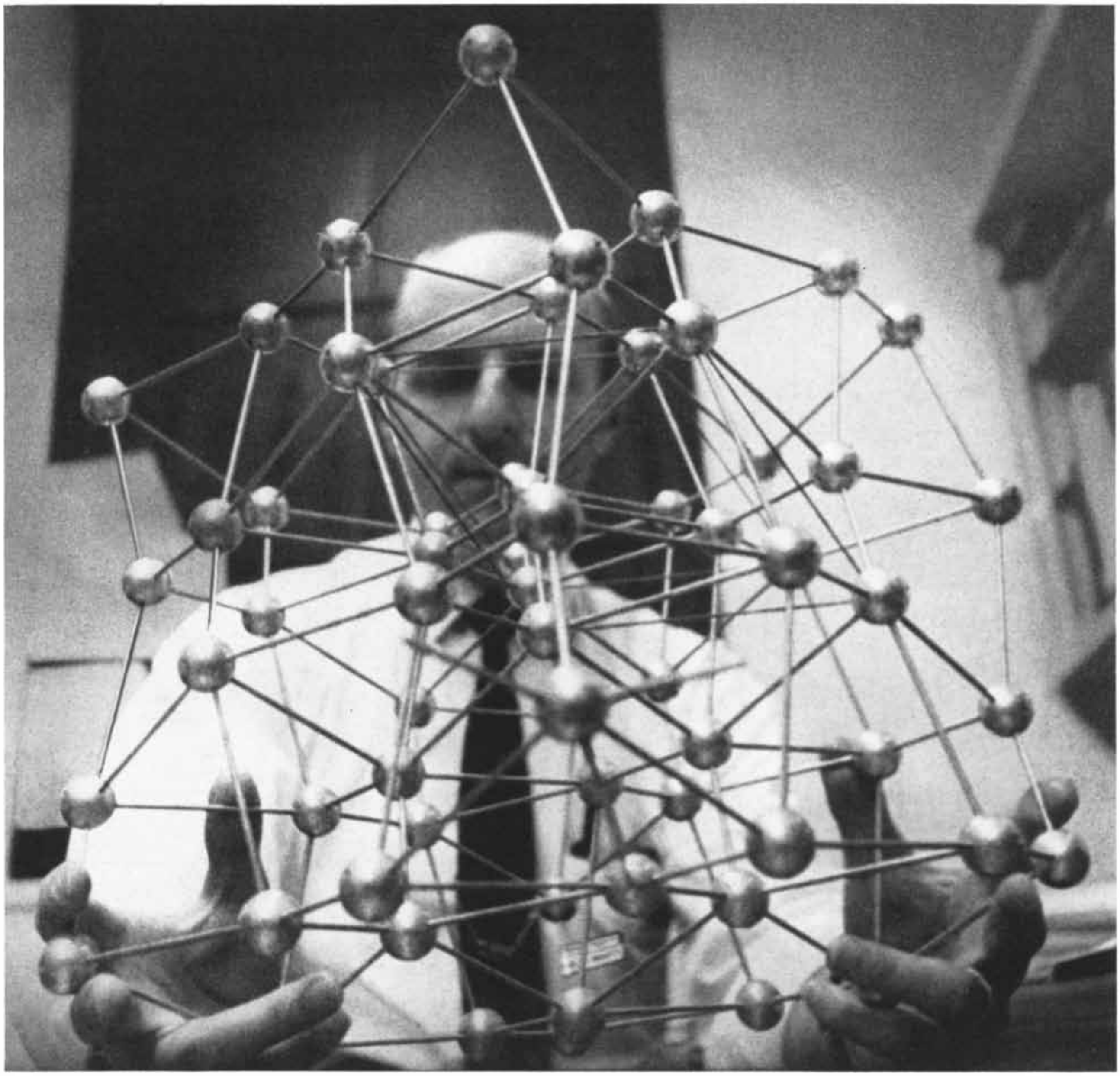
It is difficult now to appreciate fully the degree of brilliance and patience required for Bradley to work out his theory of aberration. Rigaud wrote that arriving at the correct solution "must have cost much thought and trouble," and the English astrophysicist Sir Arthur Eddington remarked that "it was only by extraordinary perseverance and perspicuity that Bradley was able to explain" the phenomenon.

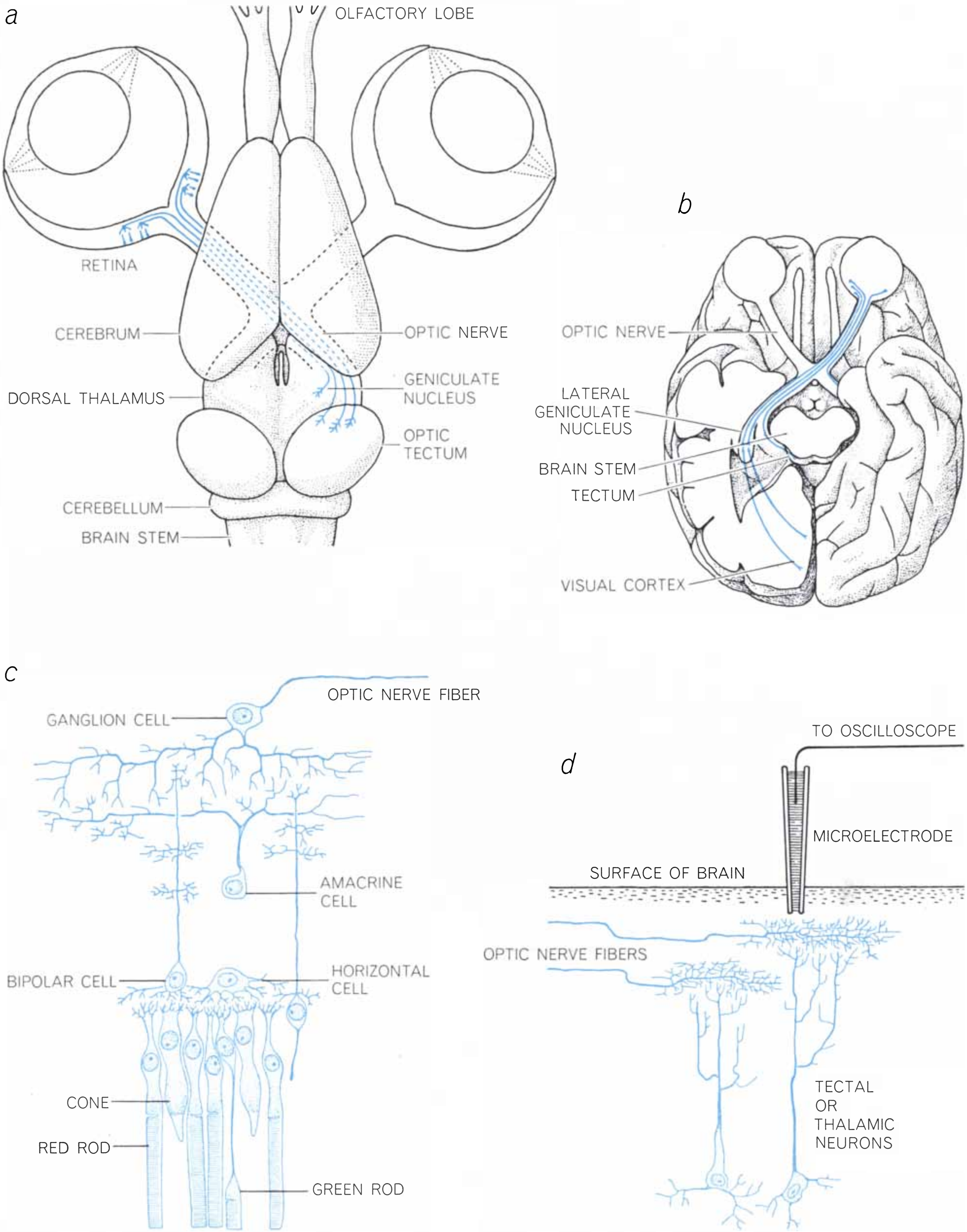
Bradley's discovery was a significant

step in the development of physical ideas in three ways. First, the additional quantitative evidence he obtained for the progressive motion of the earth about the sun was a blow to the dying cause of geocentrism. Bradley concluded his report to the Royal Society with a dig at those who still doubted the Copernican doctrine. "There appearing therefore after all no sensible parallax in the fixed stars," he wrote, "the Anti-Copernicans have still room on that account to object against the motion of the earth; and they may have (if they please) a much greater objection against the hypothesis by which I have endeavoured to solve the forementioned phaenomena, by denying the progressive motion of light, as well as that of the earth."

Second, Bradley's work set a new standard for precision in astronomical observation, thereby producing a great stimulus for further accurate measurements of the stars. Stellar aberration is still used to ascertain the orbital velocity of the earth; knowing the angle of aberration and the velocity of light, one can readily compute the third factor, the velocity of the earth.

Finally, the phenomenon Bradley discovered pointed the way to interpretations of the way light is propagated and eventually to the theory of relativity. Early in the 19th century the French physicist Augustin Jean Fresnel showed that a theory viewing light as undulations in an all-pervading luminiferous ether was consistent with the observed aberration provided that the earth and the telescope move through the surrounding ether with the earth's full velocity around the sun. Thus Bradley's work was interpreted as proving that if there is an ether, the earth is moving through it. Then A. A. Michelson and E. W. Morley found in their famous interferometer experiment of 1887 that there was no detectable effect of an ether on the speed of light, thereby demonstrating that if there is an ether, it moves with the earth, so that in effect the earth is at rest in it. The dilemma presented by these two pieces of evidence remained unsolved for nearly 20 years until Albert Einstein recognized that the relative character of simultaneity gave the key to the resolution of the dilemma. It is ironical that Bradley's work, which at first supported the Copernican doctrine of the absolute motion of the earth, later provided a critical piece of evidence for the relativity of all motions.





VISUAL PATHWAYS are traced in color in these drawings. In the frog (*a*) an image of the visual world formed on the retina is transmitted by optic nerve fibers to the optic tectum and, to a lesser extent, to the geniculate nucleus in the dorsal thalamus. In man (*b*) the tectum is unimportant; most of the fibers go, via the geniculate nucleus, to the visual cortex. The frog retina (*c*) contains about a million receptors (rods and cones), three million connecting cells (bipolar, amacrine and horizontal) and 500,000 ganglion cells leading to optic nerve fibers. In the brain (*d*) these fibers end as small branches that intermingle with the neurons of the optic tectum and dorsal thalamus. A microelectrode records impulses from these terminal arbors of the optic nerve fibers.

VISION IN FROGS

Certain fibers in the frog's optic nerve respond mainly to blue light. This fact supports the idea that the retina is not a mere photographic plate that transmits a picture to the brain but is an analyzing device

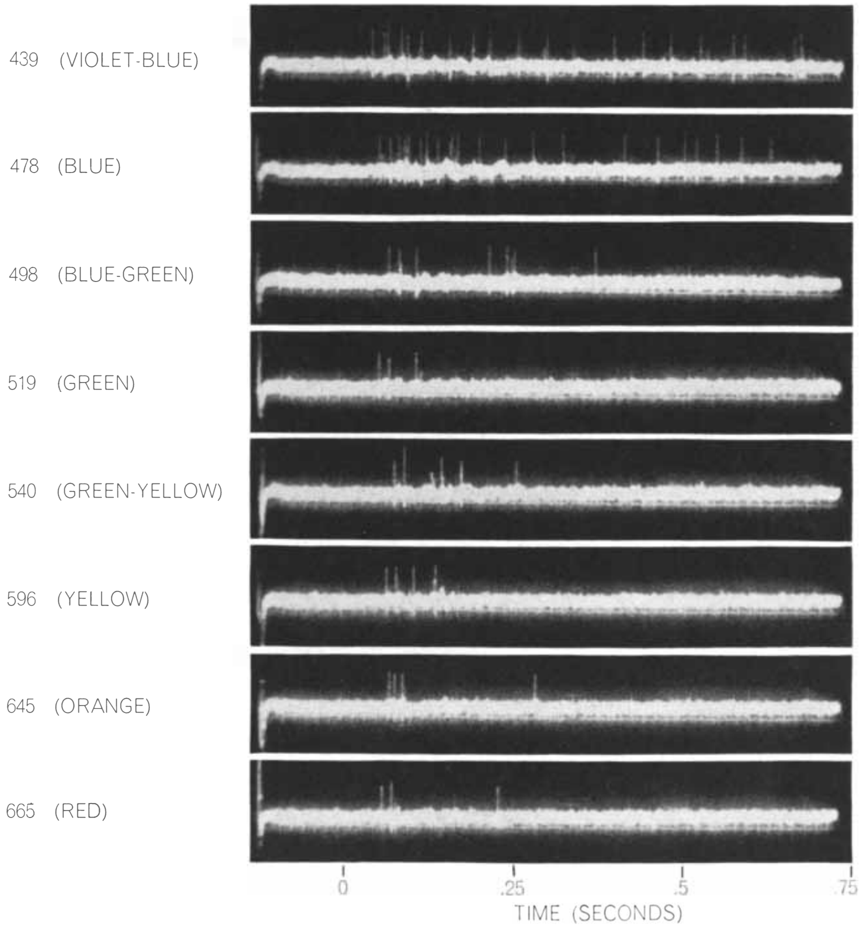
by W. R. A. Muntz

The analogy between the eye and the camera has helped to clarify the process by which the lens of the eye, its aperture regulated by the iris, casts an image on the light-sensitive screen of the retina. On this basis the optic nerve connects the retina to the central nervous system in such a way that a map of the retina is formed on the surface of the brain. The analogy can be carried too far. Students of the visual system came to assume that the retina was like a photographic film, its individual receptor cells responding to light and its absence like the grains of silver salt in a photographic emulsion; that the whole function of the eye and the optic nerve was to form and then transmit a mosaic of the visual world to the brain, there to form the basis of visual perception.

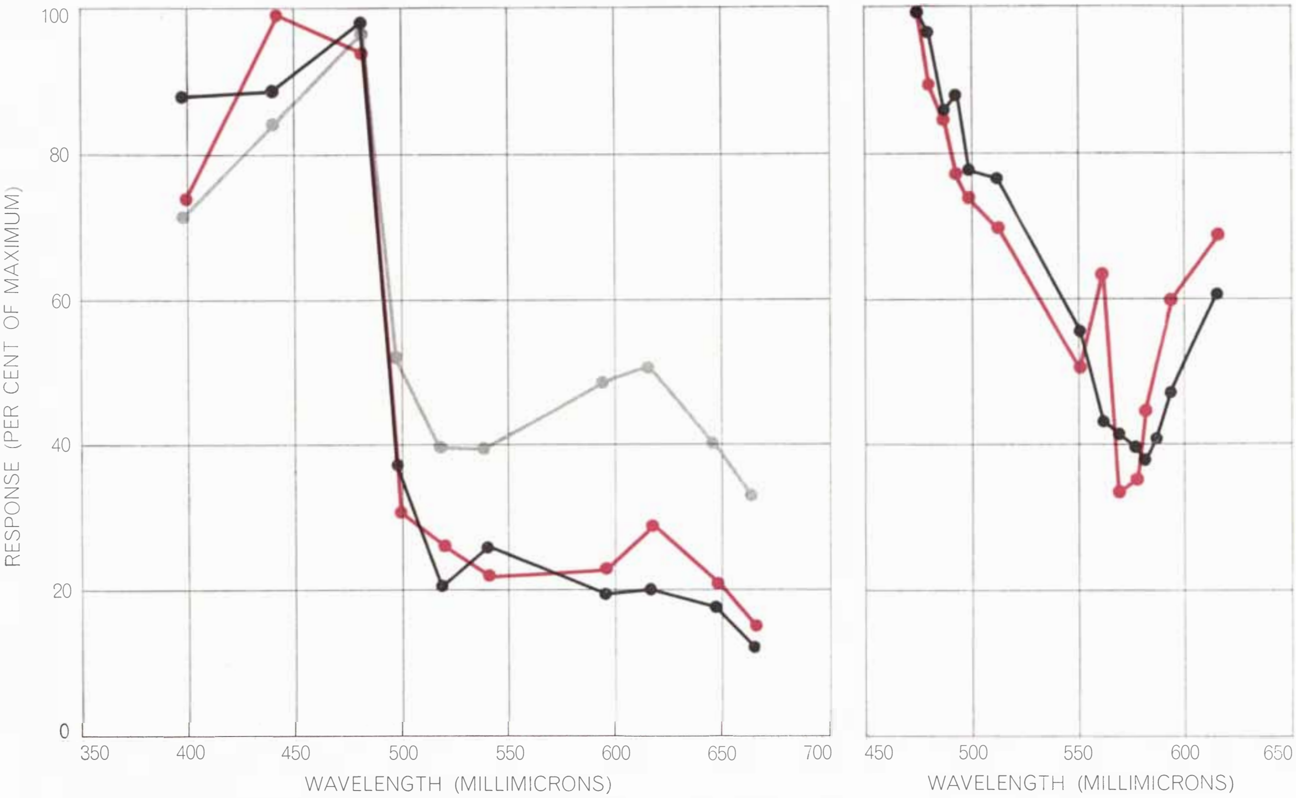
Anatomical investigations have shown, however, that there are many more receptor cells in the retina than there are fibers in the optic nerve. It is thus impossible for every receptor cell to send a separate message to the brain, and the concept that the array of receptor cells is equivalent to the grain of a photographic emulsion must be abandoned. The very intricacy of the retina, the cells of which are variously specialized and richly interconnected, hints at a role more complex than the mere relaying of a visual map. The fact is that the retina is more filter than film. It discriminates: it sends on to the brain only the most useful information.

What is useful varies from animal to animal. Consider, for example, the frog. From the frog's point of view the most relevant objects are the insects on which it feeds. Any small moving object is therefore likely to be important and calls for a specific set of fast responses; no such responses are required by small stationary objects such as pebbles. According to the earlier theories an image of the object—whether moving or stationary, important or unimportant—was sent to the brain, where the meaningful distinctions were made at some later stage.

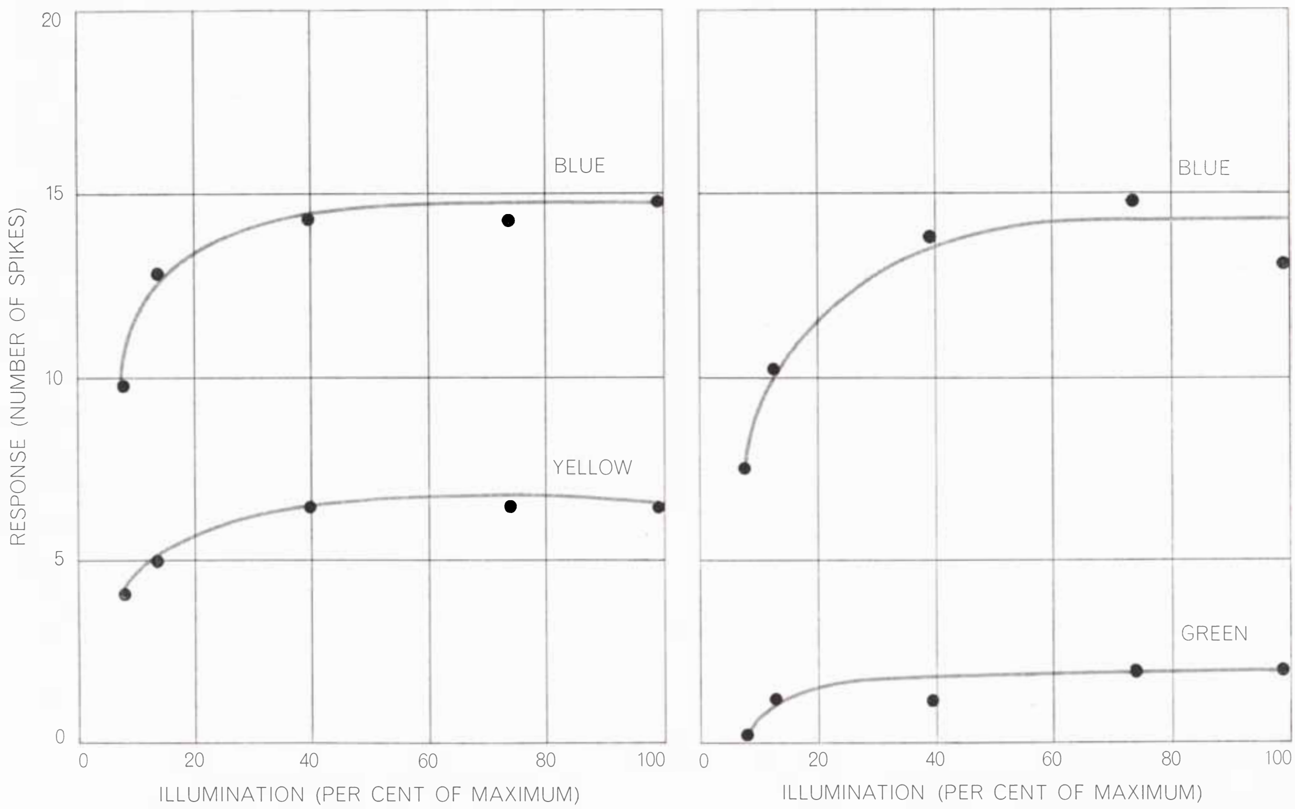
It now appears that the retina itself makes the distinctions. Certain nerve fibers leaving the retina have been found to respond specifically to small moving objects and not to stationary objects or even to large moving ones. Such "bug-detectors" can be disadvan-



IMPULSES from an "on" fiber are picked up by a microelectrode and recorded on an oscilloscope. Each spike represents response by fiber to stimulation by light of various wavelengths (*shown in millimicrons*). Fibers responded strongly to blue and weakly to green.



RESPONSES of three on-fibers to 10 different colored lights are compared in the curves at left. The "maximum response" was the largest number of spikes counted in a 1/2-second period. These colors, obtained from interference filters, were quite pure. Unsaturated, or impure, colors had about the same effect, however, as shown by the responses of two fibers to 14 colored papers (*right*).



INTENSITY of the stimulating light was not a major factor. The curves at left are for light reflected from colored papers, those at right for filtered light. In both instances blue brought a greater response than yellow or green even when only a tenth as bright.

tageous under unusual conditions: a frog will starve to death surrounded by dead flies. In the ordinary circumstances of a frog's life, however, the early filtering of significant information by the retina makes for efficient utilization of the limited number of optic nerve fibers.

Each fiber, then, reports not whether illumination is present but whether some rather complex situation—such as the approach of a bug—exists in a given part of the visual field. The eye is not a physical instrument like a camera but a biological instrument adapted to meet the animal's needs; to understand the function of the frog's eye it is necessary to consider the frog's point of view. To this end several investigators have studied the nature of some of the messages sent by the frog's eye to the frog's brain and have undertaken to correlate the properties of individual optic nerve fibers with the behavior of the whole animal.

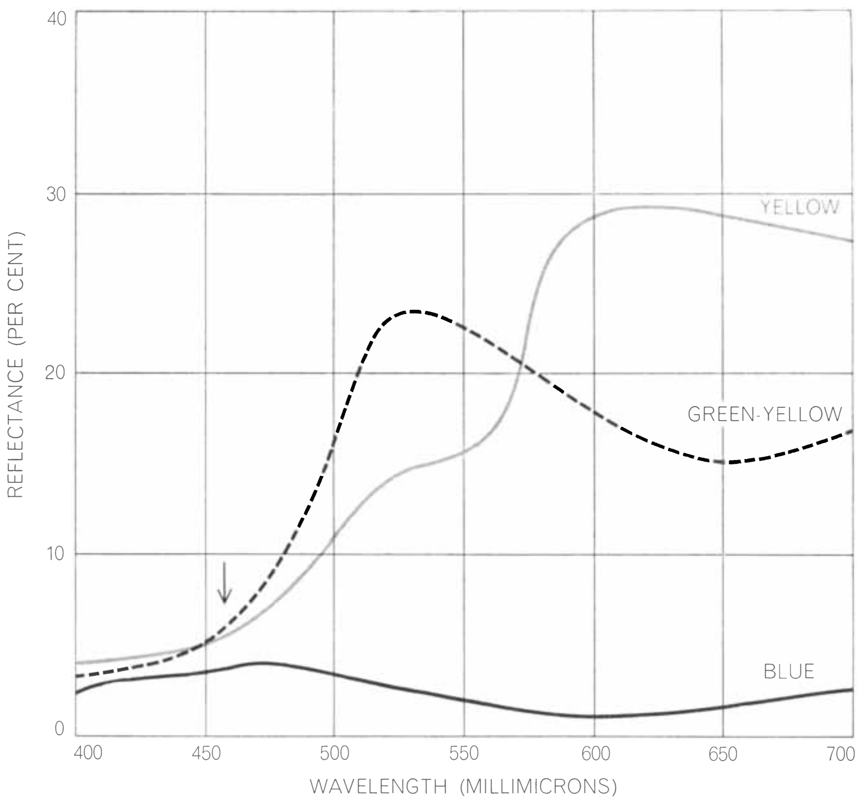
The first recordings of the activity of single optic nerve fibers in the retina of a vertebrate were made by H. K. Hartline at Johns Hopkins University in 1938. Under the microscope he teased a single fiber out of the inner surface of the retina of a frog, placed an electrode under the fiber and then amplified and displayed on an oscilloscope the nerve impulses that resulted when the eye was stimulated by various visual events. Hartline found three types of fiber in the frog's retina: those responding only to the onset of illumination, which he called "on" fibers, those responding only to the end of illumination ("off" fibers), and "on-off" fibers, which responded to both events. The subsequent perfection of microelectrodes made it possible to confirm and extend Hartline's findings without dissecting out the individual fibers; this was done by H. B. Barlow of the University of Cambridge and Ragnar A. Granit of the Royal Caroline Medico-Surgical Institute in Sweden. Their experiments, like Hartline's, were performed on the isolated retina of the frog and therefore demonstrated the retina's analytical capabilities.

From the retina most of the optic nerve fibers pass to the optic tectum, the chief visual center in the frog, where they project a map—not a one-to-one reproduction of the visual world as it appears on the retina but a selective map. At the Massachusetts Institute of Technology Jerome Y. Lettvin, Humberto R. Maturana, Warren S. McCulloch and W. H. Pitts were able to determine that four specific attributes of the visual field elicit responses in four specific types of fiber and are emphasized in the map projected on the optic tectum. Each fiber ends in a dense mass of small branches that makes contact with the cells of the tectum; Lettvin and his colleagues, recording nerve impulses in these "terminal arbors" with a special microelectrode, located each type of fiber at a different level.

Fibers ending in the surface layers of the tectum responded to the presence of any sharp edge in the visual field whether the edge was moving or stationary. Fibers ending slightly deeper proved to be the bug-detectors: they responded to small, dark moving objects but not to large or stationary objects. Neither of these groups reacted to a change in general illumination: switching a light on or off did not affect them. They had probably eluded discovery by earlier investigators of isolated retinas because they lack the fatty myelin sheathing of most nerve fibers and are hard to isolate by dissection.

Probing deeper into the optic tectum, the investigators found the myelinated fibers detected earlier by Hartline. The first of these responded to either the onset or the end of illumination, and they fitted his category of on-off fibers. They responded even more markedly to the movement of a linear shape, however, and therefore they are called "moving-edge detectors." Deeper still Lettvin came on fibers that responded to the cessation of illumination: Hartline's off-fibers.

The M.I.T. workers, to sum up, identified in the tectum four different kinds of optic nerve fiber, each carrying information about an attribute of the visual world that the animal requires in its daily life. They did not find a tectal projection of Hartline's on-fibers. Anatomical studies had shown that not all the frog's optic nerve fibers pass to the tectum; some go instead to a secondary visual center in the dorsal thalamus. This thalamic system is of particular interest because it is the forerunner of the visual system in higher animals, including man. In the human brain the tectal network is small



DIM BLUE LIGHT in an experiment such as the one graphed at bottom left on the opposite page had the characteristics of the bottom curve in this graph. It is compared with a green and a yellow light 10 times brighter and has less energy in the blue region (*arrow*) than either. It nevertheless stimulated a greater response. This demonstrates that the sensitivity of the thalamic fibers to blue cannot be due to any single visual pigment in the retina.

and relatively unimportant; most of the fibers carry signals from the retina, by way of the lateral geniculate nucleus in the dorsal thalamus, to the visual area of the cerebral cortex [see "The Visual Cortex of the Brain," by David H. Hubel; SCIENTIFIC AMERICAN, November, 1963].

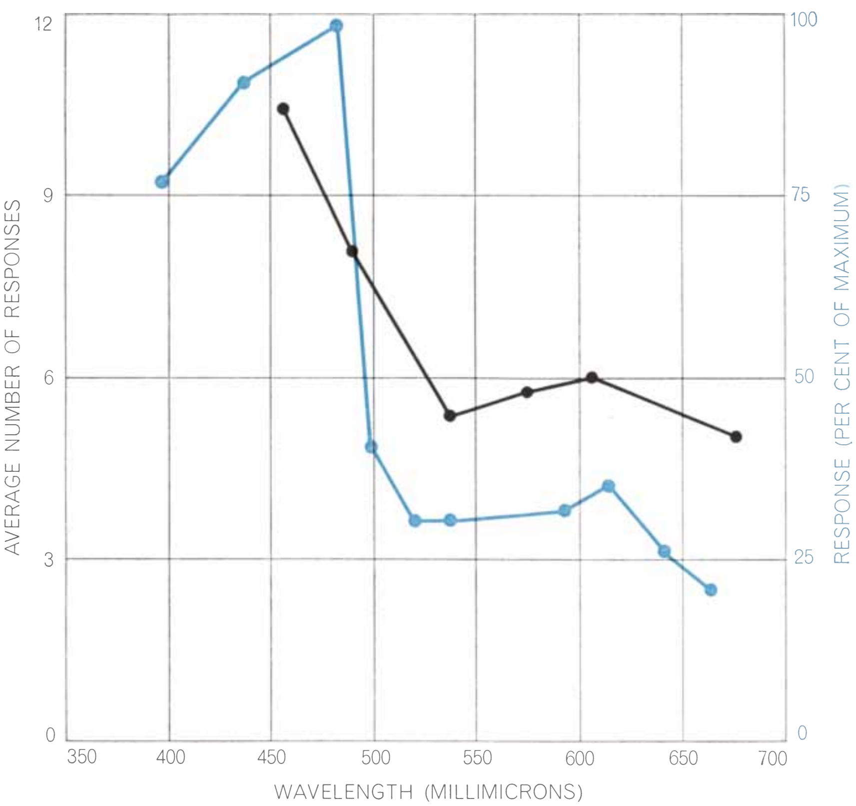
In Lettvin's laboratory at M.I.T. I applied his microelectrode methods to an exploration of the optic nerve endings in the dorsal thalamus of the frog. When I displayed various targets in the visual field of a frog, the record of responses showed that all the optic fibers running to the thalamus were sensitive to the onset of illumination and to no other stimulus; they are the on-fibers. Clearly the frog's eye transmits messages about objects primarily to the tectum and sends information from light-detectors primarily to the dorsal thalamus. The information does not become mixed, since four kinds of optic nerve fibers go only to the tectum and one kind only to the thalamus. There are opportunities for interaction at a subsequent stage, however, through a rich network of nerve fibers that connects the optic tectum and the dorsal thalamus.

The light-detectors of the dorsal thalamus proved to be sensitive not only to the presence or absence of light but also to the color of the light. Every fiber I tested in this area responded much more strongly to blue light than to light of any other color. Exposure to blue light brought a rapid burst of nerve impulses that often lasted for several seconds, but in response to green, yellow or red light there was only a brief burst of a few impulses [*see illustration on page 111*].

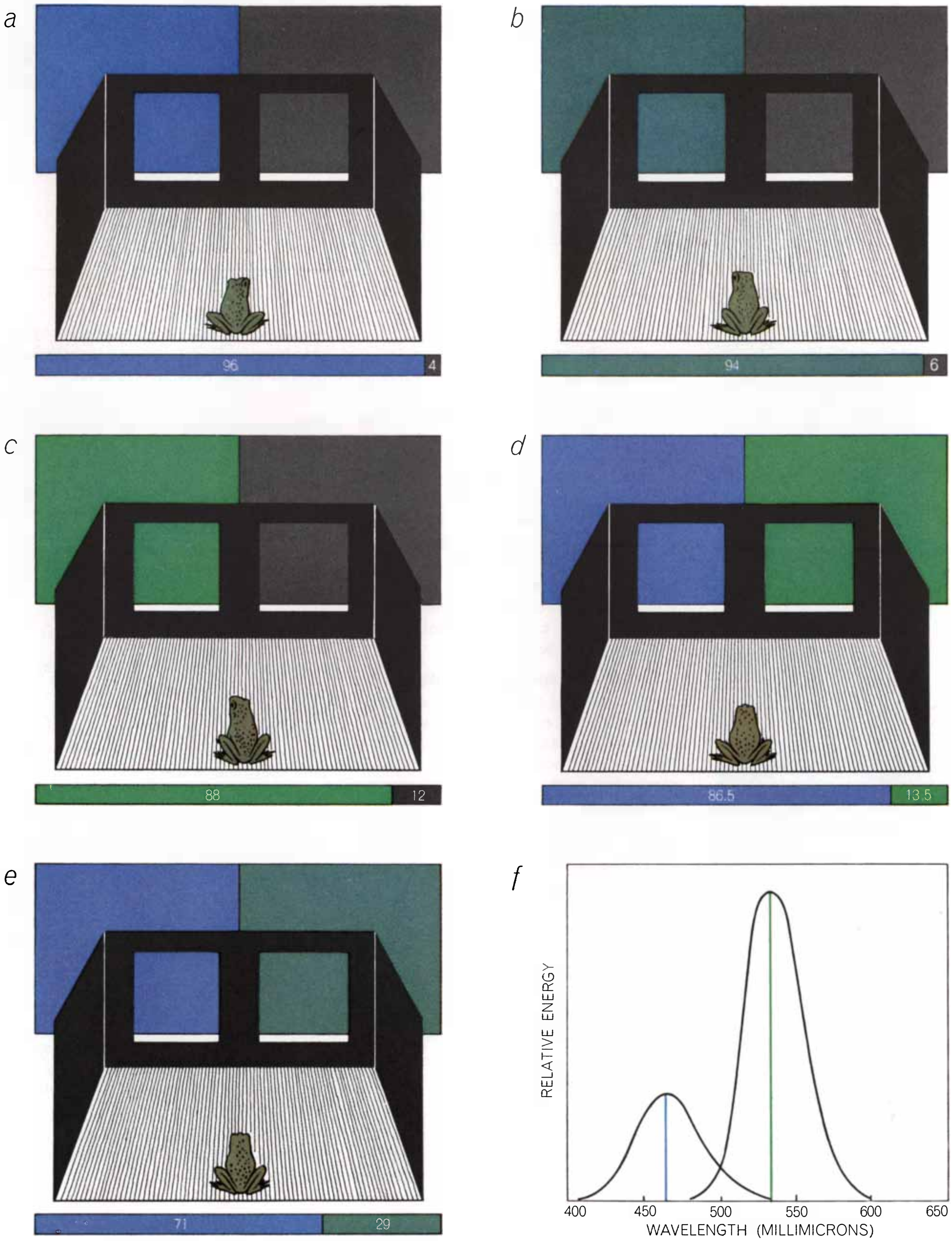
In considering this selective response to blue the first question to be settled was whether it represented mere color-dependence or true color vision. Any visual receptor responds only to the light it absorbs, and receptors absorb different wavelengths depending on the visual pigment they contain. For example, the retinal cells called rods, which are responsible for vision in faint light, contain a pigment (rhodopsin, or visual purple) that strongly absorbs blue-green light. Consequently rod vision is much more sensitive to blue-green than to other colors; it is color-dependent. The rods, however, are not capable of color vision, because they cannot distinguish between a low-intensity blue-green and, say, a high-intensity yellow. Although a blue-green barn may appear lighter than a red one in the moonlight, it will appear gray rather than blue-green. True color vision distinguishes among different wavelengths regardless of the intensity or the purity of the stimulating light.

What was manifested in the blue-sensitive system of the frog's dorsal thalamus: color-dependence ("spectral sensitivity") or color vision ("wavelength discrimination")? The question had an important biological aspect in view of the eminently useful nature of the information delivered to the optic tectum by the bug-detectors and similar fibers. The information about blue light supplied to the dorsal thalamus might be similarly significant, but not unless it was true color vision. That is, to be useful it must respond differentially not only to the pure colors I obtained from interference filters in my first experiments but also to the impure colors of nature. In addition it must also distinguish among colors regardless of their brightness, making the distinction, for example, between a dim blue and a bright green.

A series of experiments demonstrated that the on-fibers do indeed respond in just this manner, emitting a prolonged burst of impulses on exposure to anything that looks blue to the human eye. This was true, first of all, in the case of light transmitted by gelatin filters that passed a rather broad portion of the spectrum in contrast to the narrow band passed by the interference filters. Next the retina was exposed to light reflected from a series of colored papers. All of these were highly unsaturated—that is, they reflected light at all wavelengths with only a slight peak at the dominant wavelength of their apparent color—but they nevertheless stimulated the differential response to blue [*see top illustration on page 112*]. Finally, when I varied the intensity of the light reflected from these papers or passed by interference filters, there was a much stronger response to dim blue light than to bright yellow or green [*see bottom illustration on page 112*]. This was true even when the blue paper was illuminated only a tenth as brightly as the green, at which point the unsaturated green actually contained more blue than did the light from the blue paper [*see illustration on preceding page*]. This proved that the re-

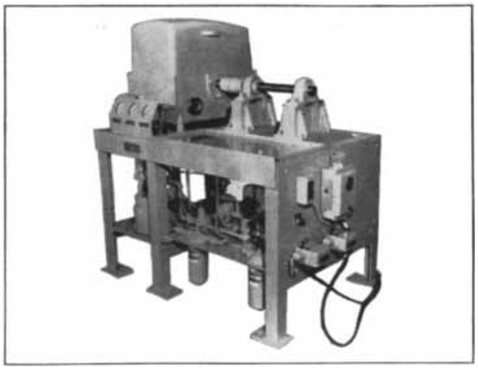


BEHAVIORAL EXPERIMENT showed that frogs preferred a blue light to other colors when they were tested in the apparatus illustrated on the opposite page. Six colors were displayed, each paired with one another and with darkness. Black curve shows average number of times frogs jumped toward each color out of a possible maximum of 12. The results are similar to those obtained in the earlier experiment on thalamic fibers (*colored curve*).

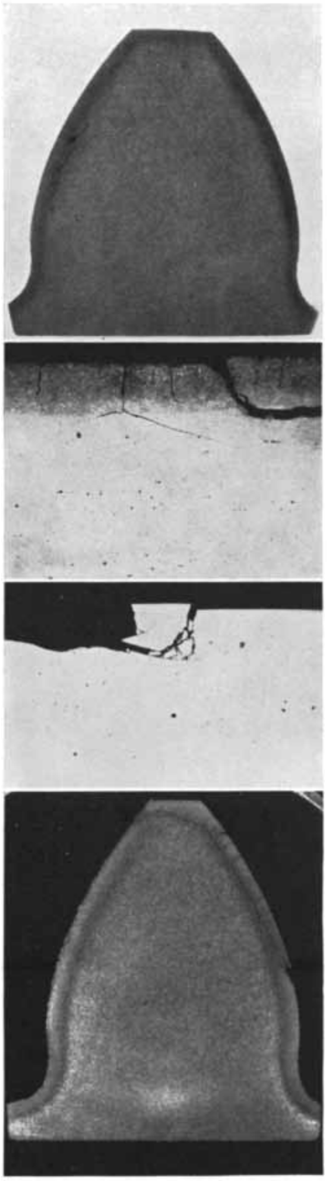


COLOR PREFERENCE of frogs was tested by placing them in a small box, drawn here with the top and back wall removed. The animals faced two windows backed by a screen. The part of the screen visible through each window was illuminated with a different color or left dark; the investigators recorded the number of times the frogs jumped toward each color. In the experiment illustrated here the colors were blue and green and an additive mixture of the two. The frogs preferred blue to darkness on 96 per cent of the occasions (*a*) and preferred blue-green and green to darkness as shown (*b*, *c*). They preferred blue to green (*d*) and even to the mixture of blue plus green (*e*). Ten frogs were tested several times on each pair of colors, which appeared at left or right at random. The wavelengths and relative intensities of the blue and green are shown by the two curves (*f*).

From Caterpillar research...comes a new testing device to study the twin problems of metal surface fatigue and lubrication failure



Today—as the relentless demand for ever-increasing horsepower from smaller and smaller components continues—research in metal fatigue and lubrication failure has accelerated tremendously.



Cross-sections reveal three distinct modes of failure in surface fatigue. Top photo shows a case crushed gear tooth. Second, a case crushed roller. Third, sub-surface pitting and fourth, a surface pitting crack.

Lubrication

Early work with lubricants involved application of the classic Reynolds Hydrodynamic Theory. Later the concept of thin film —or elasto-hydrodynamic lubrication support of machine elements—allowed a more basic understanding of why lubricants work as well as they do. But the question of the technique to be used in evaluating the load carrying capacity of the many lubricants and additives remained an unresolved one.

Lubrication failure data which can be correlated with actual parts has been virtually unobtainable because variables which affect lubricants could not be measured in a working gear mechanism.

Surface Durability and Wear

And in the past the only means of obtaining reliable data on surface fatigue, as well as lubricant capacity, has been Destruction Testing of full-scale components—a time-consuming, costly, frequently inconclusive procedure.

The theories for failures of material are equally as numerous and complex as those for the failure of the lubricants. The lack of knowledge about the many load, speed, and temperature variables has led to serious misunderstandings and misapplication of principles of design and heat treatment.

Our research people have long sought a better understanding of material and lubricant capacity. Their specific objective: an accurate means of predicting surface durability and scoring resistance in vital vehicle parts and components.

Controlled Environment Testing

Drawing heavily on earlier research, Caterpillar engineers devised the Geared Roller Test Machine. It reproduces—in a controlled environment—any load or sliding velocity generated in the transient conditions of actual machine operation.

Since the device can duplicate the entire known and anticipated range of gear loads and speeds, we can use it to predict how new gear, cam and bearing designs will function before such a system is manufactured.

And, too, we can now predict what type of lubricant will function effectively in a given gear machine and the conditions under which the lubrication will fail. The machine is also being used to evaluate new oils—and contributing to the development of lubricant refinements and additives.

Saved: Precious Time and Money

In addition to providing needed data and understanding on metal and lubricant behavior, the test machine has already played an important role in reducing hardware development time at Caterpillar

To speed the gathering of test data, Caterpillar is now offering Geared Roller Test Machines to other manufacturing firms, research organizations, universities, and government agencies. The device is already being used by an electronic computer manufacturer, an aircraft producer, oil companies, and bearing manufacturers, as well as gear manufacturers, in the evaluation and development of their own products—to the final benefit of industry.

Caterpillar's accumulated experience in basic metallurgical and lubrication research is also available to help purchasers of the machine set up their programs and evaluate their test data.

For further information, contact Defense Products Department, Caterpillar Tractor Co., Peoria, Illinois.

CATERPILLAR

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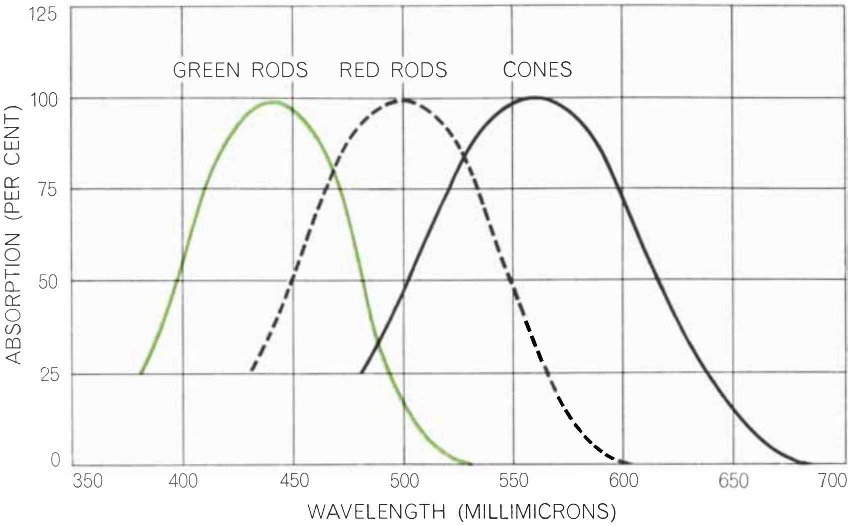
Caterpillar Tractor Co., General Offices, Peoria, Ill. • Caterpillar Americas Co., Peoria, Ill. Caterpillar Overseas S.A., Geneva • Caterpillar of Australia Pty. Ltd., Melbourne • Caterpillar Brasil S.A., São Paulo • Caterpillar Tractor Co. Ltd., Glasgow • Caterpillar of Canada Ltd., Toronto • Caterpillar France S.A., Grenoble • Caterpillar (Africa) (Pty.) Ltd., Johannesburg sponse to blue was genuine hue discrimination and that the on-fibers of the thalamus were indeed capable of true color vision.

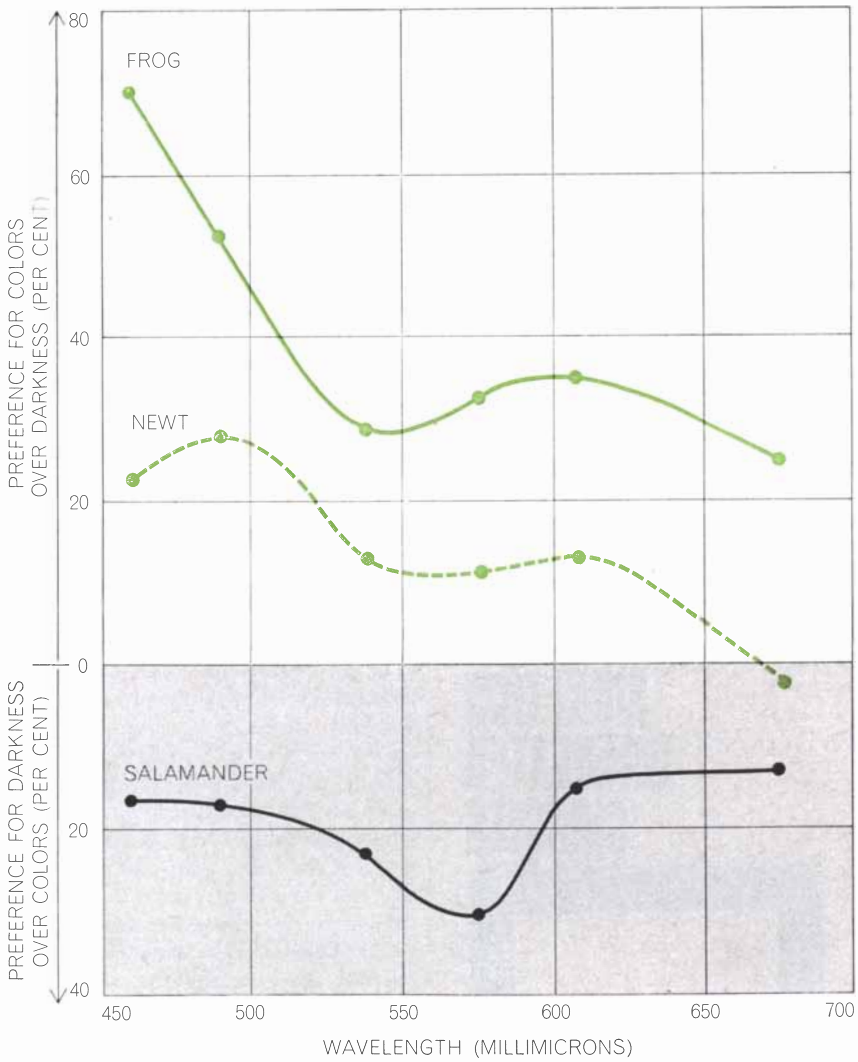
Does the frog use this information? Zoologists have known for many years that frogs tend to jump toward the light and that this "phototactic" behavior is stimulated particularly by blue light. In my laboratory at the University of Oxford we undertook to confirm this blue-seeking behavior and to find out if it was caused by the retinal signals carried by on-fibers to the dorsal thalamus. To test frogs for color preference we built a simple black box with two windows through which the animal could jump. A screen behind the windows was illuminated in turn with different pairs of colors. A frog placed in the box invariably jumped (sometimes a gentle poke was required) through one of the windows; we recorded the number of times each frog chose a certain color or a dark window. The experiment confirmed the frog's reputed preference for blue, and the curve for the behavioral response was very similar to the one for the electrophysiological response of the thalamic fibers [*see illustration on page 114*].

Subsequent experiments demonstrated clearly that the animals' behavior involved genuine color vision. For one thing, the degree of preference for blue was largely unaffected by variations in the intensity of the stimulating lights. In another parallel to the earlier tests of individual fibers, the frogs preferred a blue light to other colors even when it contained only about a tenth as much energy. The most striking demonstration involved various paired combinations of a blue and a green light [*see illustration on page 115*]. The green was almost three times brighter than the blue, but when the two were opposed the green was chosen on only 13.5 per cent of the occasions. Furthermore, adding the green to the blue reduced the attractiveness of the blue. When the blue and the blue-green were opposed, the frogs chose the pure blue 71 per cent of the time in spite of the fact that the additive mixture of blue and green contained nearly four times more energy and just as much blue. Like the colored-paper experiment, this ruled out the possibility that mere sensitivity is involved, because no visual pigment can exist that will absorb more of a pure blue light than it will of the same blue light plus green.

The frog shows a simple type of



AMPHIBIANS have three visual pigments, each with its own absorption pattern. The peak sensitivity of the green rods is at 440 millimicrons, that of the red rods at 502. The cone pigment has not yet been extracted but is believed to have its peak sensitivity at about 560.



COLOR PREFERENCES of three amphibians are compared on the basis of jumping or swimming behavior. Scores for each color and darkness were converted to percentages. Frog and newt have green rods; they seek light and are most sensitive to blue. Salamander lacks green rods; it seeks darkness and is most sensitive to green light rather than to blue.

color vision: it is capable of distinguishing blue from other colors. The parallelism between the blue-seeking behavior and the response of the fibers running to the dorsal thalamus is strong evidence that it is these thalamic fibers that underlie the behavior. Such a simple example of color vision merits close attention, because it should be possible to learn in detail how the retina performs the color analysis in the frog and perhaps to derive general principles that apply to other animals as well. We have made a small start in this direction by comparing the frog's color sensitivity with that of some other amphibians.

The spectral sensitivities of the visual pigments in the frog's receptor cells must account for at least the first stage of its color vision system. There are three pigments, each with a characteristic absorption curve [*see top illustration on preceding page*]. The pigment contained by the green rods is most sensitive at a wavelength of about 440 millimicrons and is therefore presumably implicated in the blue color vision. If it is, we reasoned, the blue-seeking behavior should not occur in certain amphibians that lack green rods. We tested two closely related amphibians: the European newt (*Triturus cristatus*), which has green rods, and the fire salamander (*Salamandra salamandra*), which does not. The testing apparatus differed from the frogs' jumping box in several respects, in particular in that it was filled with water and the animals swam toward the target screens.

When they were tested with the same colored lights that had been used with the frogs, the newts showed much the same behavior: they chose blue more often than other colors [*see bottom illustration on preceding page*]. (The newt's response curve, however, is shifted bodily toward the red end of the spectrum, probably because of a difference in the spectral sensitivity of the receptors; it is known that the rods of the newt have their maximum sensitivity at longer wavelengths than the peak sensitivity of the frog's rods, and it is likely that the same displacement toward the red occurs for the other receptors as well.) The salamander behaves quite differently, shunning light instead of seeking it. Our salamanders swam away from colors and toward a dark screen whenever they could. And the color to which they were apparently most sensitive—the one they most avoided—was green, not blue.

These results supported the finding

that the green rod is a basic factor in blue color vision. It cannot, however, be the only receptor involved. Since no single visual pigment can be more sensitive to pure blue than to the same blue plus green, no one kind of receptor can underlie the blue-seeking behavior. There must be some inhibitory element at work to account for the fact that adding green light to blue renders the blue less effective. We are investigating the nature of this inhibitory receptor and have some preliminary evidence that it may be the red rod.

As was suggested earlier, an efficient color vision system should offer some biological advantage to the animal. Why should a frog need to distinguish blue? I think it is quite possible that the function of the blue-sensitive system is to direct the jump of a frightened frog in such a way that it will leap into the water to avoid its predators. Frogs normally live at the edges of ponds, in the grass or under trees. The predominant color around the frog will therefore be green. In the direction of the water, however, there is likely to be less vegetation, and there may also be more blue light from the open sky. Since blue light is effective in guiding the direction of the jump and green light is very ineffective—even less effective than yellow or red—when the frog is frightened it will tend to jump away from the vegetation toward the open space and thus into the water. On this view the important point is that green is particularly ineffective in stimulating the blue-sensitive system, so that light from any other source will be more effective than the green light from the vegetation. Although ponds are not necessarily blue and the sky may be overcast, still the light from the open sky over the pond will contain more blue and less green than the light reflected from the vegetation.

A number of studies in the past few years have demonstrated that the frog's retina responds selectively to various attributes of the visual world, filters out information significant to the animal and sends it along to different areas of the brain. What happens to the messages when they reach the brain, however, is still largely unknown. Even at the retinal level there is much to be learned about how the different cells are interconnected to perform their complex tasks of reception and analysis. What the retina of the frog does is fairly clear; how it does its work remains to be investigated.

MATHEMATICAL GAMES

The remarkable lore of the prime numbers

by Martin Gardner

No branch of number theory is more saturated with mystery and elegance than the study of prime numbers: those exasperating, unruly integers that refuse to be divided evenly by any integers except themselves and 1. Some problems concerning primes are so simple that a child can understand them and yet so deep and far from solved that many mathematicians now suspect they *have* no solution. Perhaps they are "undecidable." Perhaps number theory, like quantum mechanics, has its own uncertainty principle that makes it necessary, in certain areas, to abandon exactness for probabilistic formulations.

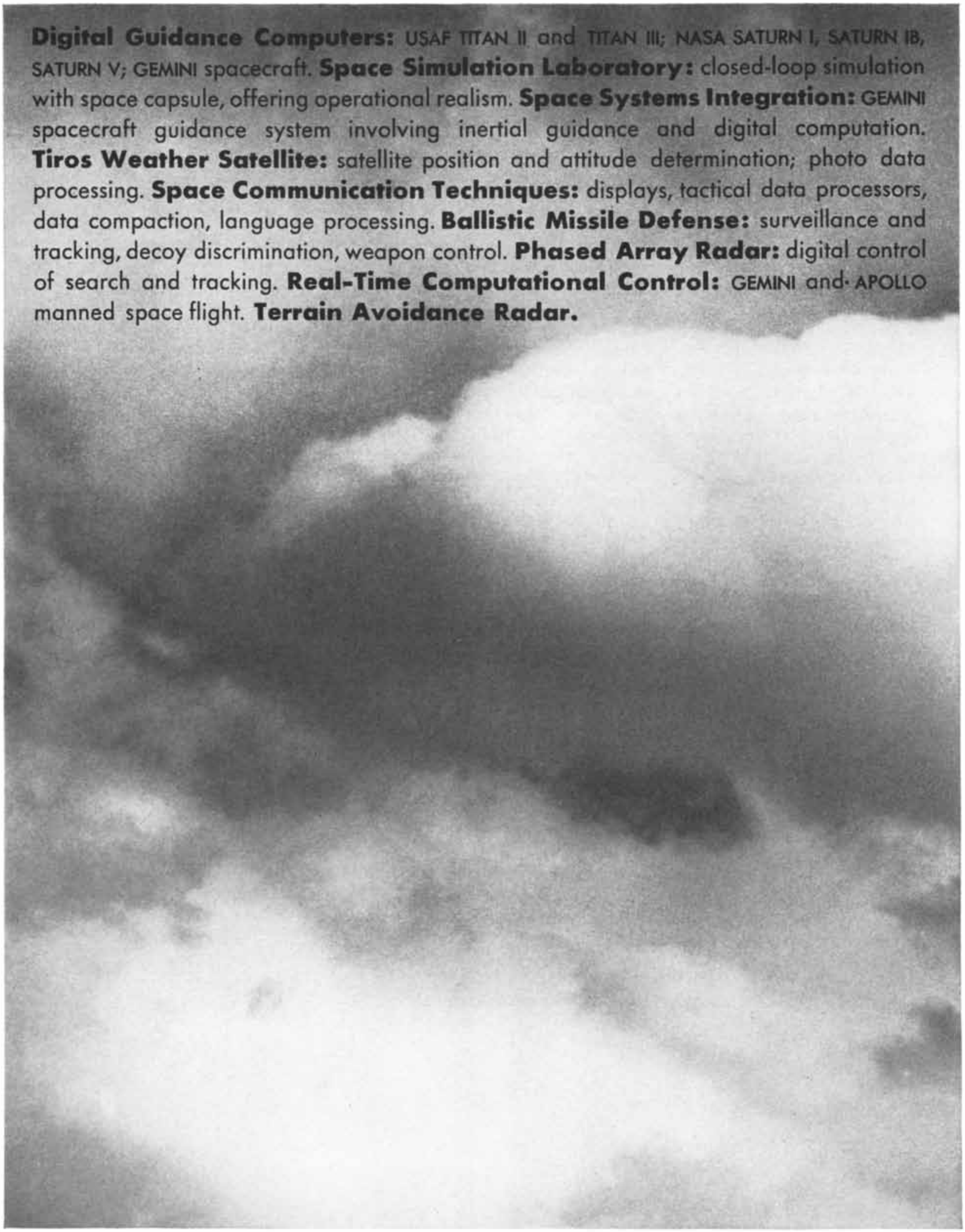
The central difficulty is that the primes are scattered along the series of integers in a pattern that clearly is not random and yet defies all attempts at precise description. What is the 100th prime? The only way a mathematician can answer is by obtaining a list of primes and counting to the 100th. How is such a list obtained initially? The simplest method is to go through the integers and cross out all the composite (not prime) numbers. Of course a computer can do this with great speed, but it still must use essentially the same simple-minded procedure that Eratosthenes, the Alexandrian geographer-astronomer and friend of Archimedes, devised 2,000 years ago.

There is no better way to become familiar with the primes than by using Eratosthenes' Sieve (as his procedure is called) for sifting out all primes under 100. Kenneth P. Swallow of Monterey, Calif., has proposed an efficient way to do this. Write the numbers from 1 to 100 in the rectangular array shown at the right. Cross out all multiples of 2, except 2 itself, by drawing vertical lines down the second, fourth and sixth columns. Eliminate the remaining multiples of 3 by drawing a line down the third column. The next integer not crossed out is 5. Multiples of 5 are removed by a series of diagonal lines running down and to the left. Remaining multiples of 7 are eliminated by lines sloping the other way. The integers 8, 9 and 10 are composite: their multiples have already been crossed out. Our job is now finished because the next prime, 11, is larger than the square root of 100, the highest number in the table. Had the table been longer, larger multiples of 11 would have been removed by diagonal lines of steeper slope.

All but 26 numbers (shown in color) have fallen through the sieve. These are the first 26 primes. Mathematicians prefer to say 25 primes, because various important theorems are simpler to express if 1 is not called a prime. For example, the "fundamental theorem of

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36
37	38	39	40	41	42
43	44	45	46	47	48
49	50	51	52	53	54
55	56	57	58	59	60
61	62	63	64	65	66
67	68	69	70	71	72
73	74	75	76	77	78
79	80	81	82	83	84
85	86	87	88	89	90
91	92	93	94	95	96
97	98	99	100		

The Sieve of Eratosthenes



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arithmetic" states that every integer greater than 1 can be factored into a unique set of prime numbers. Thus 100 is the product of four primes: $2 \times 2 \times 5 \times 5$. No other set of positive primes has a product of 100. If 1 were called a prime, we could not say this. There would be an infinite number of different sets of prime factors, such as $2 \times 2 \times 5 \times 5 \times 1 \times 1$.

Much can be learned about the primes by studying the illustration on page 120. You see at once that all primes greater than 3 are either one less or one more than a multiple of 6. Also, it is clear why there are so many "twin primes": pairs of primes that have a difference of 2, such as 71 and 73, 209,267 and 209,269, or 1,000,000,009,649 and 1,000,000,009,651. After eliminating multiples of 2 and 3, *all* remaining numbers are twin-paired. Subsequent sievings simply remove one or both partners of a pair, but they leave many untouched. Twin primes get scarcer as the numbers get bigger. It is conjectured that an infinity of them continue to sift through the sieve, but no one knows for certain.

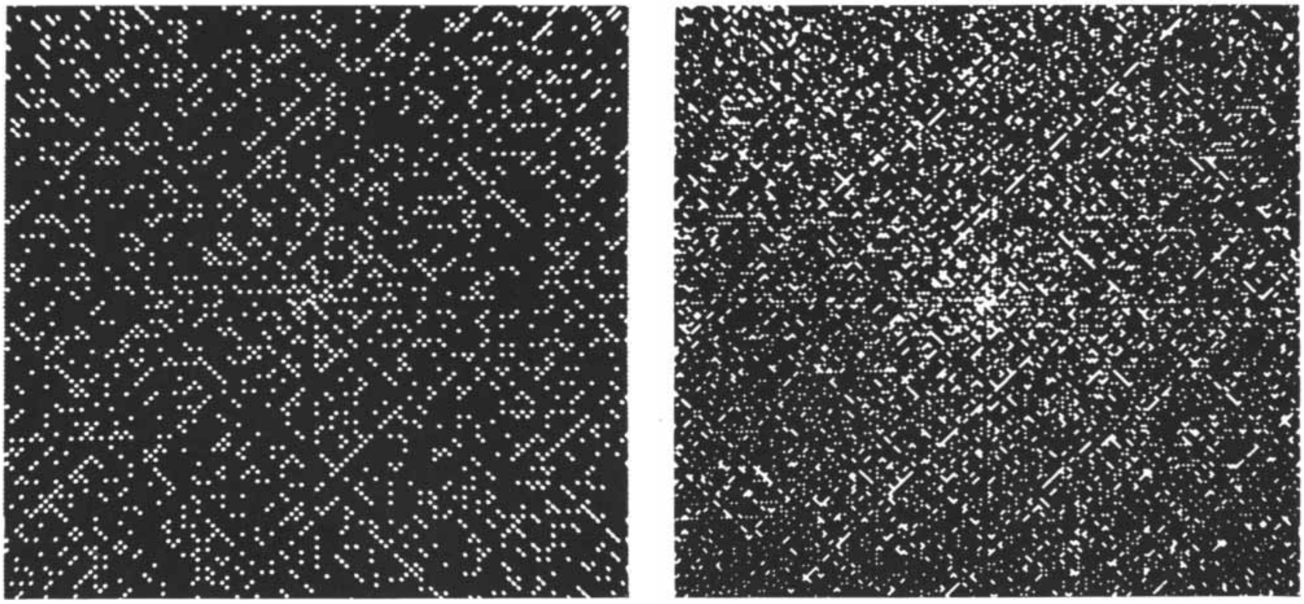
If the integers are differently placed, the primes will of course form a different geometrical pattern. Last fall Stanislaw M. Ulam of the Los Alamos Scientific Laboratory, attended a scientific meeting at which he found himself listening to what he describes as a "long and very boring paper." To pass the time he doodled a grid of horizontal and vertical lines on a sheet of paper. His first impulse was to compose some chess problems, then he changed his mind and began to number the intersections, starting near the center with 1 and moving out in a counterclockwise spiral. With no special end in view, he began circling all the prime numbers. To his surprise the primes seemed to have an uncanny tendency to crowd into straight lines. The illustration on the cover of this issue shows how the primes appeared on the spiral grid from 1 to 100. (For clarity the numbers are shown inside cells instead of on intersections.)

Near the center of the spiral the lining up of primes is to be expected because of the great "density" of primes and the fact that all primes except 2 are odd. Number the squares of a checkerboard in spiral fashion and you will discover that all odd-numbered squares are the same color. If you take 17 checkers (to represent the 17 odd primes under 64) and place them at random on the 32 odd-numbered squares, you will find that they form diagonal lines. But in the higher, less dense areas of the number series one would not expect many such lines to form. How would the grid look, Ulam wondered, if it was extended to thousands of primes?

The computer division at Los Alamos has a magnetic tape on which 90 million prime numbers are recorded. Ulam, together with Myron L. Stein and Mark B. Wells, programed the MANIAC computer to display the primes on a spiral of consecutive integers from 1 to about 65,000. The picture of the grid presented by the computer is shown at the right below. Note that even near the picture's outer limits the primes continue to fall obediently into line!

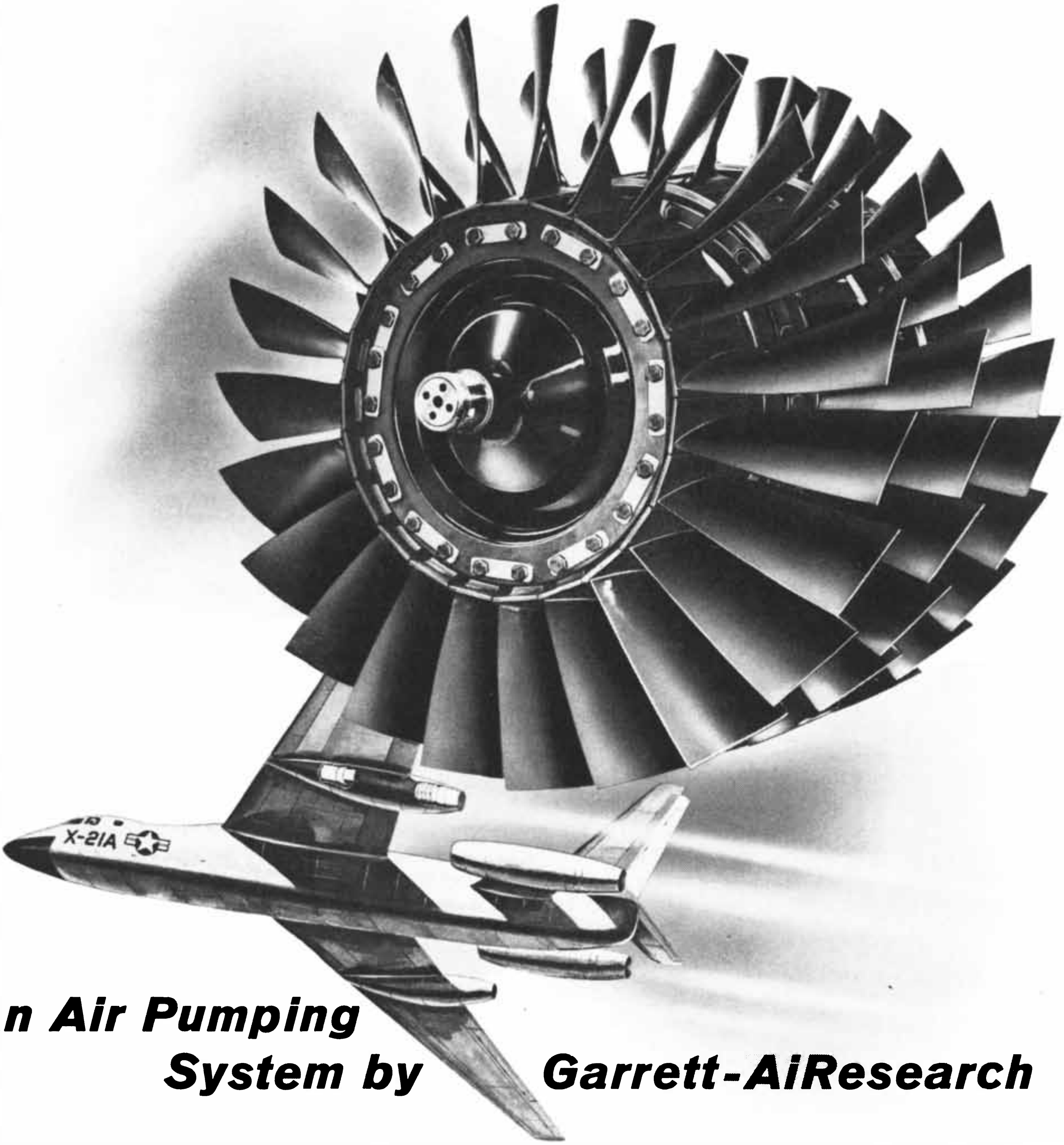
The eye first sees the diagonally compact lines, where odd-number cells are adjacent, but there is also a marked tendency for primes to crowd into vertical and horizontal lines on which the odd numbers mark every other cell. Straight lines in all directions (once they have been extended beyond the consecutive numbers on a segment of the spiral) bear numbers that are the values of quadratic expressions beginning with $4x^2$. For example, in the illustration on the cover the diagonal sequence of primes 5, 19, 41, 71 is given by the expression $4x^2 + 10x + 5$ as x takes the values 0 through 3. The grid on the cover suggests that throughout the entire number series expressions of this form are likely to vary markedly from those "poor" in primes to those that are "rich," and that on the rich lines an unusual amount of clumping occurs.

By starting the spiral with numbers higher than 1 other quadratic expressions form the lines. Consider a grid formed by starting the spiral with 17 [*see illustration at left on page 124*]. Numbers in the main diagonal running northeast by southwest are generated by $4x^2 + 2x + 17$. Plugging positive integers into x gives the diagonal's lower half; plugging negative integers gives the upper half. If we consider the entire diagonal, rearranging the numbers in order of increasing size, we find—pleasantly enough—that all the numbers are



Photographs of a computer grid showing primes as a spiral of integers from 1 to about 10,000 **(left)** ***and from 1 to about 65,000*** **(right)**

What is the Heart of LFC?



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33	32	31	30	29
34	21	20	19	28
35	22	17	18	27
36	23	24	25	26
37	38	39		

57	56	55	54	53
58	45	44	43	52
59	46	41	42	51
60	47	48	49	50
61	62	63		

Diagonals generated by the formula x^2+x+17 (left) *and x^2+x+41* (right)

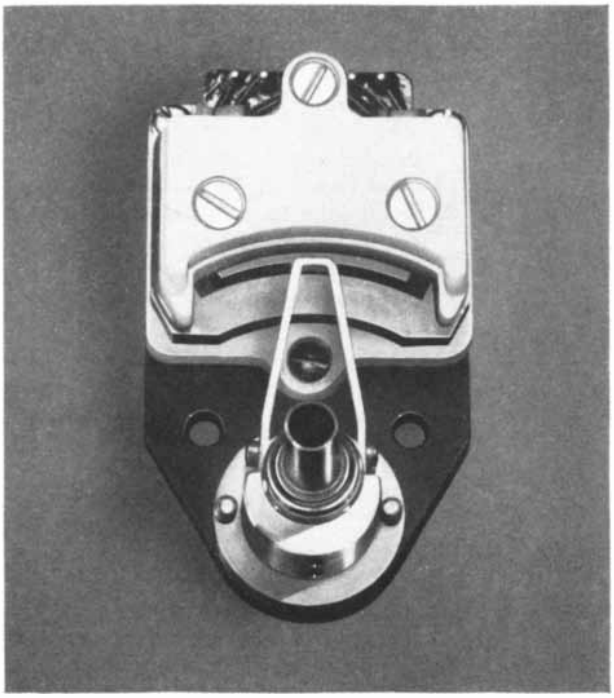
generated by the simpler formula $x^2 + x + 17$. This is one of many "prime-rich" formulas discovered by Leonhard Euler, the 18th-century Swiss mathematician. It generates primes for all values of x from 0 through 15. This means that if we continue the spiral shown in the illustration until it fills a 16-by-16 square, the entire diagonal will be solid with primes.

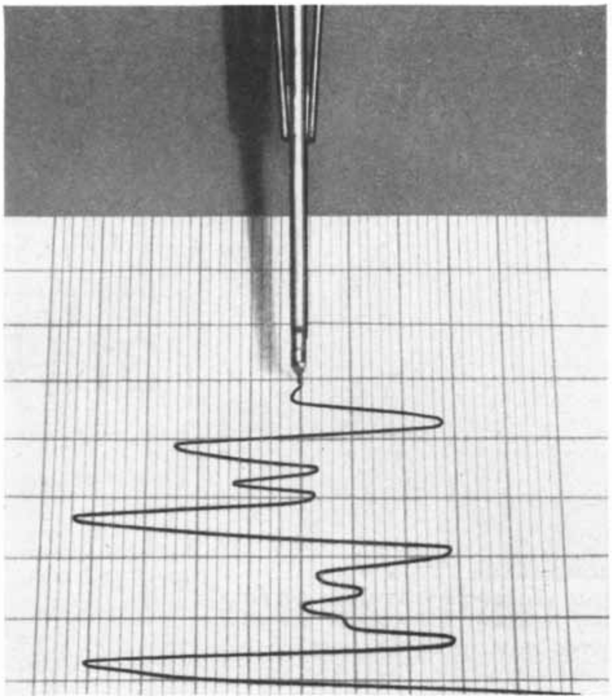
Euler's most famous prime generator, $x^2 + x + 41$, can be diagramed similarly on a spiral grid that starts with 41 [*see illustration at right above*]. This produces an unbroken sequence of 40 primes, filling the diagonal of a 40-by-40 square! It has long been known that of the first 2,398 numbers generated by this formula, exactly half are prime. After testing all such numbers below 10,000,000, Ulam, Stein and Wells found the proportion of primes to be .475... Mathematicians would like to discover a formula expressing a function of n that would give a different prime for *every* integral value of n, but no such formula has been found. It may not exist.

Ulam's spiral grids have added a touch of fantasy to speculations about the enigmatic blend of order and haphazardry in the distribution of primes. Are there grid lines that contain an infinity of primes? What is the maximum prime density of a line? On infinite grids are there density variations between top and bottom halves, left and right, the four quarters? Ulam's doodlings in the twilight zone of mathematics are not to be taken lightly. It was he who made the suggestion that led him and Edward Teller to think of the "idea" that made possible the first thermonuclear bomb.

Although primes grow steadily rarer as numbers increase, there is no highest prime. The infinity of primes was concisely and beautifully proved by Euclid. One is tempted to think, because of the rigidly ordered procedure of the sieve, that it would be easy to find a formula for the exact number of primes within any given interval on the number scale. No such formula is known. Early-19th-century mathematicians made an empirical guess that the number of primes under a certain number n is approximately n/natural log of n, and that the approximation approaches a limit of exactness as n approaches infinity. This astonishing theorem, known as the "prime-number theorem," was rigorously proved in 1896. (See David Hawkins' article "Mathematical Sieves," SCIENTIFIC AMERICAN, December, 1958, for a discussion of this theorem and its application to other types of numbers, including the "lucky numbers" invented by Ulam.)

It is not easy to find the mammoth primes isolated in the vast deserts of composite numbers that blanket ever larger areas of the number series. There are certainly millions of prime numbers with, say, exactly 100 digits, yet not one such number is known. At the moment the largest known prime is $2^{11213} - 1$, a number of about 3,376 digits. It was discovered in 1963 by Donald B. Gillies, who used a computer at the University of Illinois. Before the advent of modern computers, testing a number of only six or seven digits could take weeks of dreary calculation. Euler once announced that 1,000,009 was prime, but he later discovered that it is the product of two primes: 293 and 3,413. This was a considerable feat at the time, considering that Euler was 70 and blind. Pierre Fermat was once asked in a letter if 100,895,598,169 is prime. He shot back that it is the product of primes 898,423 and 112,303. Feats such as these have led some to think that the old masters may have had secret and now-





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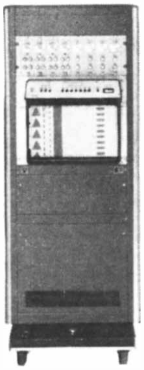

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67	1	43
13	37	61
31	73	7

Prime magic square with lowest constant

lost methods of factoring. As late as 1874 W. Stanley Jevons could ask, in his *Principles of Science:* "Can the reader say what two numbers multiplied together will produce the number 8,616,460,799? I think it unlikely that anyone but myself will ever know; for they are two large prime numbers." Jevons, who himself invented a mechanical logic machine, should have known better than to imply a limit on future computer speeds. Today a computer can find his two primes (96,079 and 89,681) faster than he could multiply them together.

Numbers of the form $2^p - 1$, where p is prime, are called Mersenne numbers after Marin Mersenne, a 17th-century Parisian friar (he belonged to a humble order known as the Minims—an appropriate order for a mathematician), who was the first to point out that many numbers of this type are prime. For some 200 years the Mersenne number $2^{67} - 1$ was suspected of being prime. Eric Temple Bell, in his book *Mathematics, Queen and Servant of Science,* recalls a meeting in New York of the American Mathematical Society in October, 1903, at which Frank Nelson Cole, a Columbia University professor, rose to give a paper. "Cole—who was always a man of very few words—walked to the board and, saying nothing, proceeded to chalk up the arithmetic for raising 2 to the sixty-seventh power. Then he carefully subtracted 1. Without a word he moved over to a clear space on the board and multiplied out, by longhand,

$$193{,}707{,}721 \times 761{,}838{,}257{,}287.$$

The two calculations agreed.... For the first and only time on record, an audi-

1	823	821	809	811	797	19	29	313	31	23	37
89	83	211	79	641	631	619	709	617	53	43	739
97	227	103	107	193	557	719	727	607	139	757	281
223	653	499	197	109	113	563	479	173	761	587	157
367	379	521	383	241	467	257	263	269	167	601	599
349	359	353	647	389	331	317	311	409	307	293	449
503	523	233	337	547	397	421	17	401	271	431	433
229	491	373	487	461	251	443	463	137	439	457	283
509	199	73	541	347	191	181	569	577	571	163	593
661	101	643	239	691	701	127	131	179	613	277	151
659	673	677	683	71	67	61	47	59	743	733	41
827	3	7	5	13	11	787	769	773	419	149	751

Smallest possible magic square of consecutive odd primes ence of the American Mathematical Society vigorously applauded the author of a paper delivered before it. Cole took his seat without having uttered a word. Nobody asked him a question." Years later, when Bell asked Cole how long it took him to crack the number, he replied, "Three years of Sundays."

The British puzzle expert Henry Ernest Dudeney, in his first puzzle book (*The Canterbury Puzzles,* 1907), pointed out that 11 was the only known prime consisting entirely of 1's. (Of course, a number formed by repeating any other digit would be composite.) He was able to show that all such "repunit" numbers, from 3 through 18 units, are composite. Are any larger "repunit" chains prime? Oscar Hoppe, a New York City reader of Dudeney's book, took up the challenge and actually managed to prove, in 1918, that the 19-"repunit" number 1,111,-111,111,111,111,111 is prime. Later it was discovered that 23 repeated 1's is also prime. There the matter rests. No one knows if the "repunit" primes are infinite, or even if there are more than three. It has been shown that no "repunit" number is prime unless the number of its units is prime. Numbers of 29, 31, 37, 41 and 43 (as well as 53, 61 and 73) units have been found to be composite, therefore the lowest unknown possibility at the moment is a number consisting of 47 1's.

Can a magic square be constructed solely of different primes? Yes; Dudeney was the first to do it. The top illustration on the opposite page shows such a square. It sums in all directions to the "repunit" number 111: the lowest possible constant for a prime square. The primes are not consecutive, however. Can a magic square be made with consecutive odd primes? (The even prime, 2, must be left out because it would make the odd or even parity of its rows and columns different from the parity of all other rows and columns, thereby preventing the array from being magic.) In 1913 J. N. Muncey of Jessup, Iowa, proved that the smallest magic square of this type is one of order 12. This remarkable curiosity is so little known that I reproduce it in the illustration at the bottom of the opposite page. Its cells hold the first 144 consecutive odd primes, starting with 1. All rows, columns and the two main diagonals sum to 4,514.

Until next month, when answers will be given, readers may test their familiarity with primes by answering the following elementary questions:

1. Identify the four primes among the following six numbers. (NOTE: The sec-

ond number is the first five digits in the decimal of pi.)

10,001
14,159
76,543
77,377
123,456,789
909,090,909,090,909,090,-
909,090,909,091

2. Two gear wheels, each marked with an arrow, mesh as shown in the illustration below. The small wheel turns clockwise until the arrows point directly toward each other once more. If the large wheel has 181 teeth, how many times will the small wheel have rotated? (Contributed by Burris Smith of Greenville, Miss.)

3. Using each of the nine digits once, and only once, form a set of three primes that have the lowest possible sum. For example, the set 941, 827 and 653 sum to 2,421, but this is far from minimal.

4. Find the one composite number in the following set:

31 331 3331 33331 333331 3333331 33333331 333333331

5. Find a sequence of a million consecutive integers that contain not a single prime.

Last month's sliding-block puzzles can be solved as follows:

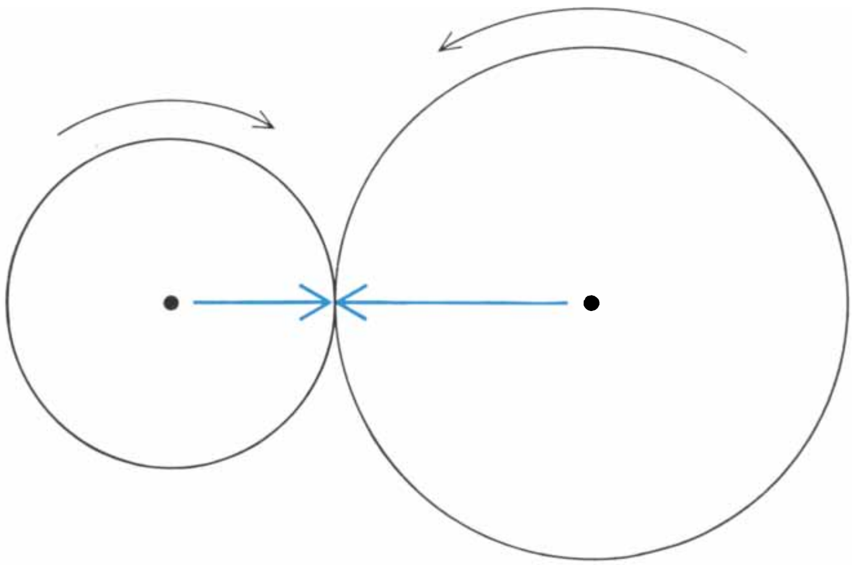
Dad's Puzzle: 59 moves. 5, 4, 1, 2, 3, 4 (up, right). 1, 6, 7, 8, 9, 5. 4, 1, 6, 7, 8, 9. 5 (left, up), 9, 8, 5, 4, 1. 3, 2, 7, 6, 4 (up, left), 6. 7, 4, 5, 6, 7, 5 (right, up). 3, 2, 5, 4, 3, 2. 4 (down, right), 2, 3, 6, 7, 1. 4, 5, 2, 3, 6, 7. 1, 4 (left, up), 9, 8, 1.

L'Âne Rouge: 81 moves. 9 (halfway), 4, 5, 8 (down), 6. 10 (halfway), 8, 6, 5, 7 (up, left). 9, 6, 10 (left, down), 5, 9. 7, 4, 6, 10, 8. 5, 7 (down, left), 6, 4, 1. 2, 3, 9, 7, 6. 3, 2, 1, 4, 8. 10 (right, up), 5, 3, 6, 8. 2, 9, 7 (up, left), 8, 6. 3, 10 (right, down), 9 (down, left), 1. 4, 2, 9, 7 (halfway), 8. 6, 3, 10, 9 (down), 2. 4, 1, 8, 7, 6. 3, 2, 7, 8, 1. 4, 7 (left, up), 5, 9, 10. 2, 8, 7, 5, 10 (up, left). 2.

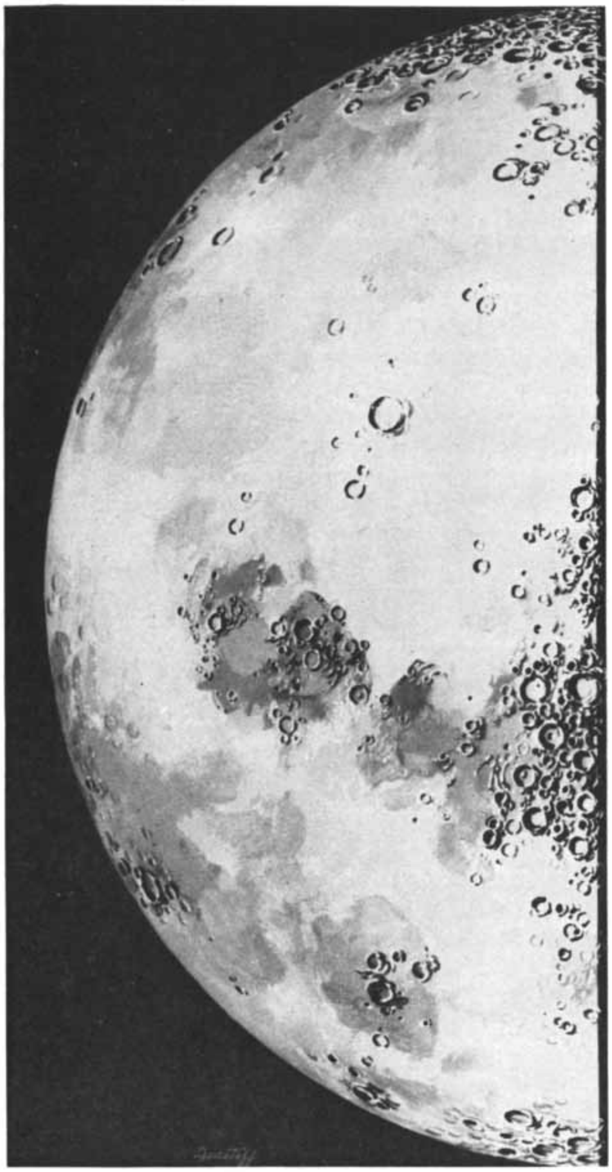
Line Up the Quinties: 30 moves. 9, 8, 1, 2, 3. 6, 8 (up, left), 2, 5 (right, down), 3. 6, 8 (up, left), 9, 2, 8. 6, 3, 1 (right, down), 6. 3. 5 (up, right), 1 (right, down), 7, 1 (left), 8. 5 (down), 3, 6 (halfway), 4, 9.

Ma's Puzzle: 32 moves. 9 (left), 8, 7, 6, 5. 9 (up), 8, 7, 6, 4. 2, 1, 3 (up), 9 (up), 5. 4 (left, up), 6 (left, up, left), 2, 4, 6. 5, 9 (straight down), 6 (left, down), 4, 2. 5 (right), 6 (right, down), 4 (down), 3, 1. 2, 5.

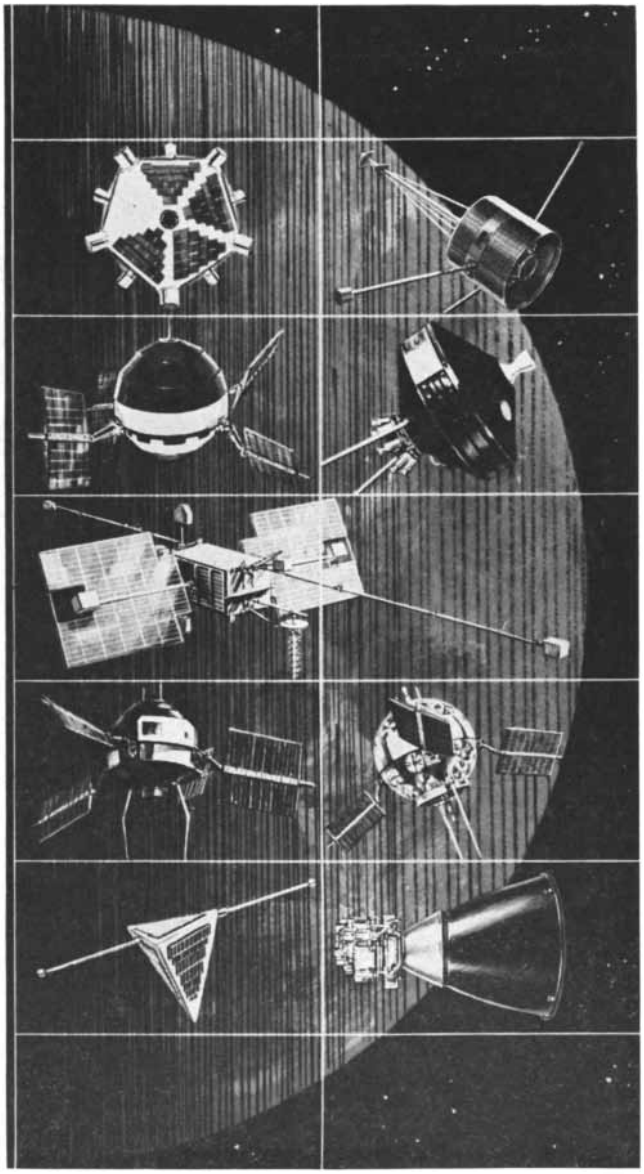
Tiger Puzzle: 49 moves. 8, 5, 6, 2, 3. 1, 4, 2 (left), 3 (left), 1. 4, 2, 3 (up), 7, 8 (left, up). 5, 6, 1, 4, 3. 2, 7, 8 (up), 5, 6. 1, 8 (right, down), 5, 6, 1. 8 (down), 4, 2 (rotate 90 degrees and place vertically under 3), 7, 5. 6 (rotate 90 degrees, place horizontally under 5, fence-side down), 4, 2 (rotate 90 degrees and place horizontally under 7), 3 (to right end of 2), 7. 8, 1, 4, 6 (rotate 90 degrees and slide up between 5 and 7, fence on right), 4. 8 (left, down), 2 (down, left), 3 (down, left), 1.



A problem in primes



TRW SPACE TECHNOLOGY LABORATORIES In Perspective



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THE AMATEUR SCIENTIST

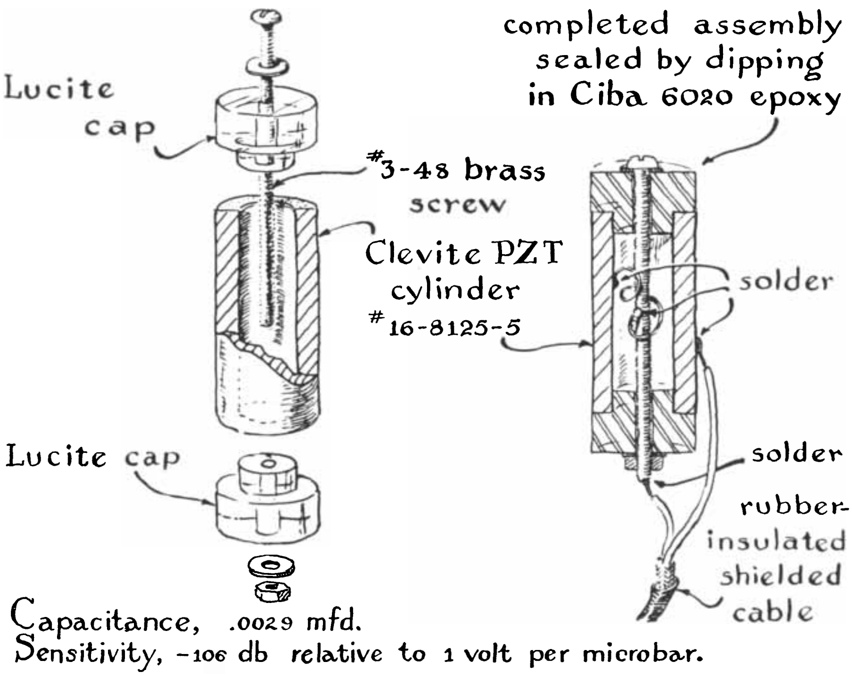
Two devices for listening in on underwater sound, and a sundial that tells clock time

Conducted by C. L. Stong

Three and a half years ago in "The Amateur Scientist" (October, 1960) Frank Watlington described how to make an inexpensive hydrophone. With such an instrument one can enter the recently discovered world of natural underwater sound: the hiss of breaking waves, the rattle of pebbles carried along by a current and the remarkable variety of noises made by fishes and other aquatic organisms. Now Watlington, a specialist in underwater sound whose avocation is listening to whales and porpoises off Bermuda, has devised two new hydrophones that are easier to construct and that should make the study of underwater sound more accessible to amateurs. To give only one example of such a study, a snorkel diver with a confederate at the surface can maneuver a hydrophone up to a sound-making organism and record its sounds for the purpose of identifying their source in "broadcast" listening. Perhaps the hydrophone will join the camera as a standard adjunct to the explorations of the skin diver who prefers not to kill fish.

One of Watlington's new hydrophones is designed to operate at substantial depths; the other, which is more sensitive, to work in shallow water. Watlington writes: "Hydrophones for converting variations of sound pressure into equivalent variations of electric current are of three types: electrodynamic, magnetostrictive and piezoelectric. The electrodynamic type operates on the principle of a conventional electric generator. A coil of wire, actuated by a diaphragm in contact with the water, moves in a fixed magnetic field. A voltage proportional to the velocity of the diaphragm is induced across the terminals of the coil. Instruments of this type are satisfactory but difficult to construct. Hydrophones of the magnetostrictive type take advantage of the fact that the magnetic properties of certain materials, such as nickel, are altered by mechanical stress. A coil of wire surrounding a core of such material picks up a proportional voltage when sound waves stress the core. Although magnetostrictive hydrophones are easier to make than the electrodynamic types, the coil must be wound by means of a bobbin—a tedious operation. Piezoelectric hydrophones are based on the property of certain materials to acquire electric charge when they are stressed, an effect that was first described by Pierre Curie in 1880. A number of minerals show the effect, but barium titanate, an inexpensive ceramic, is commonly used for making hydrophones. Barium titanate can be molded in any shape and is fired much like clay. Both tubes and disks of the material are used for hydrophones. When a tube is stressed radially, its outer and inner surfaces become oppositely charged. When a disk is fixed at its edge and pressure is applied to one face, its two faces also become oppositely charged. Electrical connection to barium titanate is made through silver electrodes that are deposited on the material during manufacture. Numerous U.S. manufacturers supply the parts. Mine were obtained from the Clevite Corporation (3631 Perkins Avenue, Cleveland 14, Ohio).

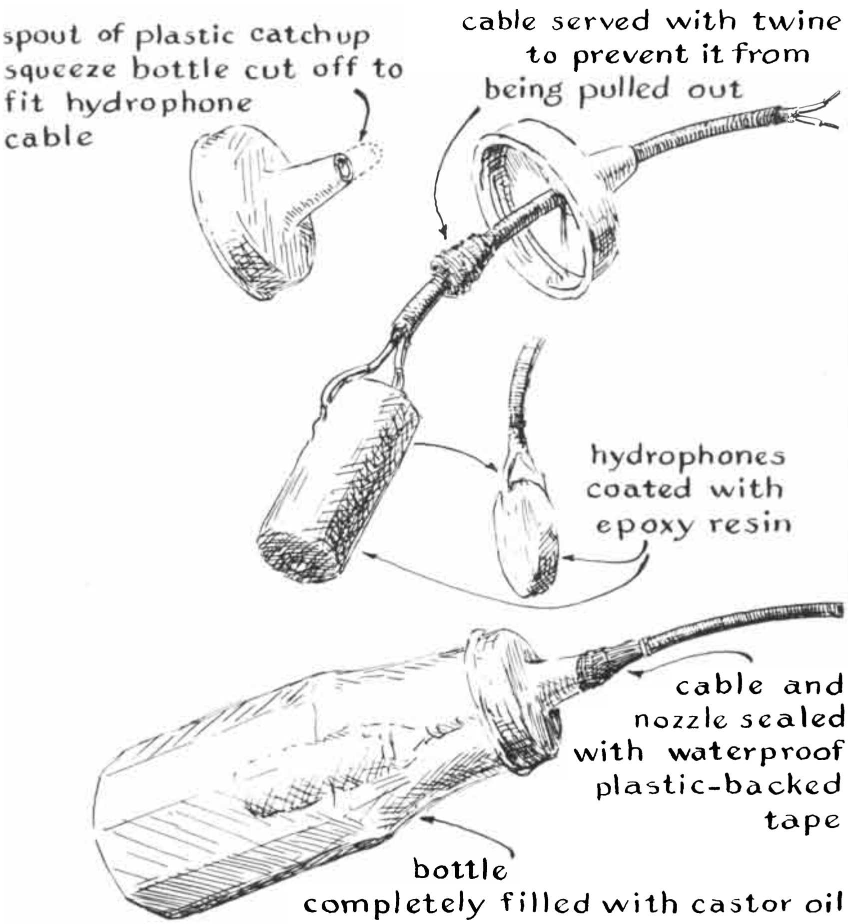
"The deepwater hydrophone uses a tube of barium titanate one inch long with an outside diameter of 1/2 inch and an inside diameter of 1/4 inch. The part comes from the manufacturer fully finished, with ground ends and silver electrodes on the outer and inner surfaces. Flexible copper leads must be soldered to the electrodes, an operation that requires some care because the silver is in the form of a thin deposit that can be damaged by excessive heat. Make the joint with rosin-core solder applied with an electric iron that draws no more than 25 watts. Acid flux will corrode the electrodes. Apply the well-



Details of deepwater hydrophone pickup unit heated iron to the silver just long enough to cause the solder to flow. The tube must be closed at the ends by two caps of Lucite or a similar plastic that are drilled for a brass retaining screw as shown in the accompanying drawing [*preceding page*]. The caps must make a snug fit with the inner surface of the tube and the ends. Before these parts are assembled insert the screw through one cap and then solder the lead from the inner surface of the tube to the screw. Next apply a thin coat of silicone grease to the mating surfaces of the tube and the caps. Most dealers in radio parts stock silicone grease. Complete the assembly by tightening the nut just enough to hold the end caps solidly. Then cut off the screw flush with the top of the nut and solder the output leads to the end of the screw and the outer electrode as shown in the illustration.

"The assembly can be tested by connecting the leads to either a high-gain speaker system or an oscilloscope. A gentle tap on either end with the handle of a screw driver should produce a sharp click from the speaker and a pip on the oscilloscope. Sound pressure deflects the wall of the tubing inward against the cushion of trapped air and sets up stresses that appear as fluctuations of voltage at the electrodes.

"For service as a hydrophone the assembly must be sealed and specially housed to keep fluid from leaking into the air space, to protect the unit against corrosion and to prevent water from short-circuiting the leads. The seal can be made with common beeswax. Simply hold the unit by the leads and dip it into the melted wax. Apply two or three coats, allowing each coat to harden before applying the next. Let the unit remain in the wax about three minutes during the first dip. Make succeeding dips quickly to prevent preceding coats from melting. I prefer a more durable sealing material, such as epoxy resin, and I sealed my unit with a product known as Araldite 6020, which is manufactured by the Ciba Corporation. This epoxy resin is mixed with No. 951 hardener in the ratio by weight of 10 parts resin to one part hardener. Two coats were applied. On standing at room temperature for 24 hours the material sets as a hard, glassy coating of considerable strength and excellent electrical insulating properties. Like all epoxy resins, Araldite is toxic and must be used with care. Prolonged contact with the skin results in a rash that resembles the one caused by poison ivy. Wear rubber gloves and work with the



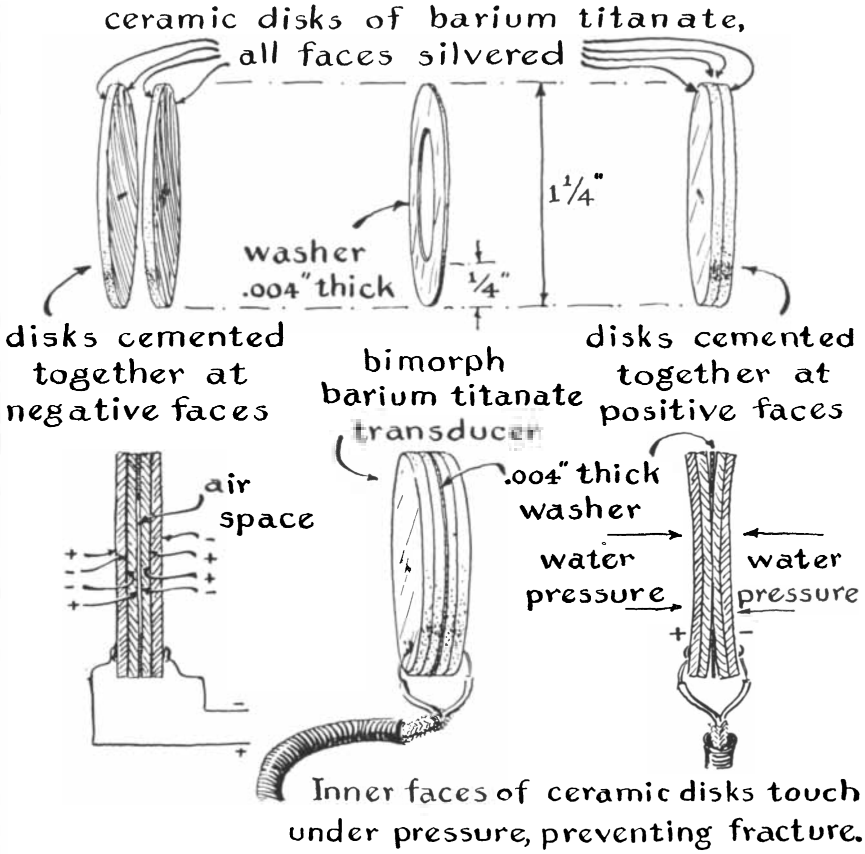
Details of housing assembly for the hydrophone

material in a well-ventilated room. Fortunately epoxy compounds are soluble in water before they harden. Smears can be removed from the skin by scrubbing with strong soap and hot water.

"For additional protection the sealed unit is potted in a plastic container completely filled with castor oil. A plastic squeeze bottle of the kind used for dispensing mustard or catchup makes an ideal housing. The flexible sides transmit sound readily to the oil and the tapered spout provides a handy orifice for attaching the microphone cable to the pickup unit. The microphone cable should be mechanically strong and of the two-conductor type that has a braided shield, such as Belden No. 8422 microphone cable.

"The tapered nozzle of the squeeze bottle is snipped off at just the right spot to make a tight fit with the cable. The cable is then pulled through the spout and the outer covering and the braiding are skinned to expose about six inches of the leads. Strip about half an inch of insulation from the tips of the leads and splice them to the pickup unit. Insulate the splices with a few inches of plastic 'spaghetti.' Lash the cable an inch or so above the joint with a dozen turns of thin twine to form a stop large enough to prevent the cable from slipping through the spout when it is pulled. Next fully immerse the squeeze bottle and cap assembly in a deep bowl of castor oil. Dislodge all bubbles that may adhere to the apparatus; even a small amount of air trapped inside the housing will lower the efficiency of the hydrophone. When the bubbles have been removed, and while the apparatus is still fully submerged, screw the cap securely in place. Remove the assembly from the oil, wash it thoroughly with a strong detergent, rinse it, dry it and apply several layers of plastic-backed tape to the joint between the spout and the cable and between the bottle and the cap. Finally skin the remaining end of the cable and terminate the leads with connectors that mate with the amplifier [*see illustration on this page*]. The completed hydrophone should then be tested as described earlier.

"The barium titanate tube is designated by the Clevite Corporation as part

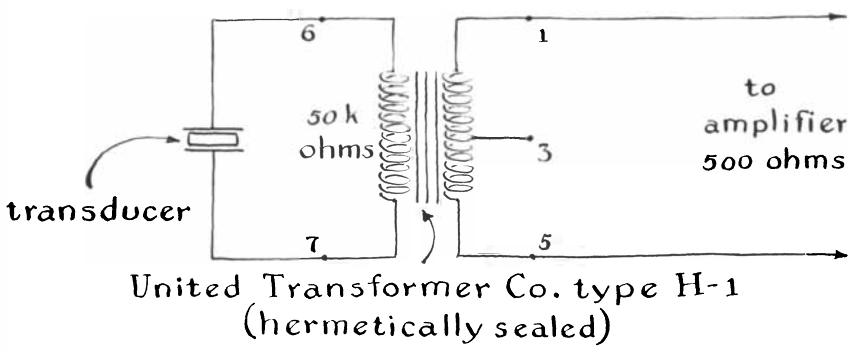


Details of shallow-water hydrophone pickup unit

No. 16–8125–5, priced at $5. It withstands a pressure of 10,000 pounds per square inch and has a sensitivity of approximately −106 decibels relative to one volt per microbar. This means that if a pressure of one microbar (about a millionth of an ounce per square inch) is applied to the cylinder, its output voltage, measured with a high-impedance voltmeter as the only load, should be five millionths of a volt. Greater sensitivity can be achieved by using a larger tube of barium titanate. Clevite also sells for $10 a tube of lead zirconium titanate, designated part No. 16—24125—5 PZT; it measures one inch long and 1½ inches wide and has a sensitivity of −91 decibels relative to one volt per microbar.

"Still greater sensitivity can be achieved by using an entirely different construction technique, one that employs four piezoelectric units in the form of disks cemented together in pairs to form 'bimorph' assemblies. The hydrophone of this type that I made was found by measurement to have a sensitivity of −81 decibels relative to one volt per microbar. Although the unit is designed for use in shallow water, it has a fail-safe feature. It becomes inoperative at a critical depth but is not damaged by the pressure at that depth.

"The increased sensitivity of bimorph

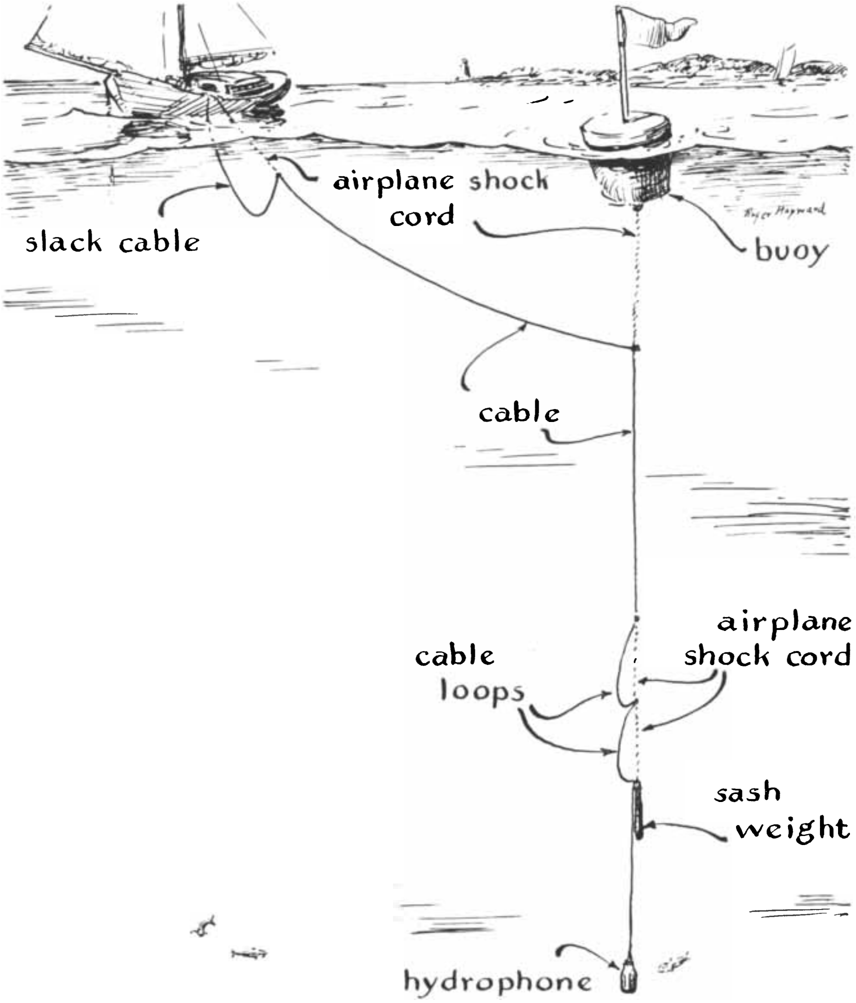


Circuit diagram of the hydrophone

hydrophones arises from the fact that a pair of cemented disks develops a greater potential difference when stressed than a single disk of the same size does. When a single disk is stressed, its faces acquire a charge of characteristic polarity: one face is positive and the other negative. A bimorph is made by cementing two disks together with the faces of like polarity in contact. A bimorph hydrophone requires two such assemblies, one with positive faces cemented in contact and the other with negative faces cemented. The pairs are then combined with a thin spacing washer sandwiched between them, as shown in the accompanying illustration [*at left*]. Opposing pressure applied to the outer faces of the sandwich causes the bimorphs to flex inward and a charge of opposing polarity to appear on their outer faces. A voltage proportional to the stress appears across leads connected to the outer faces. The maximum deformation of the disks is limited by the thickness of the washer. The washer of my assembly was cut from brass shim stock .004 inch thick. It allows each disk to flex only .002 inch, well below the point of fracture. The sensitivity of the unit drops when the disks flex enough to touch in the middle but does not fall to zero because the separation remaining near the edge allows some additional movement.

"The disks of my unit are 1¼ inches in diameter. Prior to assembly they are thoroughly cleaned with a strong detergent to remove grease and then joined as bimorphs by means of a conducting cement, such as Hysol No. 4238 epoxy resin and its companion No. 3475 hardener. The same cement is used for simultaneously joining the bimorphs to the spacing washer. Apply a thin film to all surfaces, taking care to prevent the cement from entering the air space between the bimorphs. Heavy pressure should not be applied to the stack during the hardening period. Simply place the coated elements on a flat surface and put a small weight—a pound or so—on top. After the cement has hardened for about 24 hours, solder leads to the outer faces as shown in the illustration. Avoid burning the silver electrodes. Test the unit with an appropriate speaker system or oscilloscope, then seal with beeswax or, preferably, Silastic RTV No. 731 (a product of the Dow Corning Corp.). The unit is then potted in a plastic container filled with castor oil as previously described.

"The electrical output of all these hydrophones is small, of course. Appropriate circuits must be employed to



Suspension system for minimizing noise in hydrophone

conserve this output. Piezoelectric units are high-impedance devices. They deliver maximum power only when their terminals are connected to a load of equal impedance. I achieved an adequate impedance match between the hydrophones and amplifier by means of a step-down transformer connected as shown in the accompanying diagram [*bottom of page 134*].

"The choice of amplifier is dictated by both the sensitivity of the hydrophone and the availability of power for driving the amplifier. The requirements of the deepwater hydrophone can in general be met by a conventional high-fidelity phonograph amplifier equipped with a preamplifier. For field work the 110-volt, 60-cycle power can be derived from a battery-operated inverter. The more sensitive hydrophones work satisfactorily with inexpensive transistor amplifiers such as the basic five-transistor push-pull audio amplifier (PK-544) that is sold for $7 by the Lafayette Radio Electronics Corporation of New York City. Two amplifiers are used in series.

"The motion of a hydrophone through the water causes extraneous noise that must be minimized. The drifting of a boat from which observations are made, currents in the water and wave action combine to cause trouble. The difficulty can be met, at least in part, by suspending the microphone cable in loops from airplane shock cord, particularly at points of attachment to the boat, the supporting buoy and at the instrument itself" [*see illustration above*].

Charles J. Merchant, a mathematician at the University of Arizona, submits the following description of a sundial for indicating standard clock time that can be made in less than an hour. "A sundial," writes Merchant, "even when it is perfectly constructed and correctly installed, generally indicates a time substantially different from standard clock time. This often leads people not familiar with the beautiful intricacies of sun time to the erroneous conclusion that a sundial is an inherently inaccurate device. Sundials that indicate time correctly to within one minute can be constructed with no great difficulty; with refinements they can be accurate to within a few seconds.

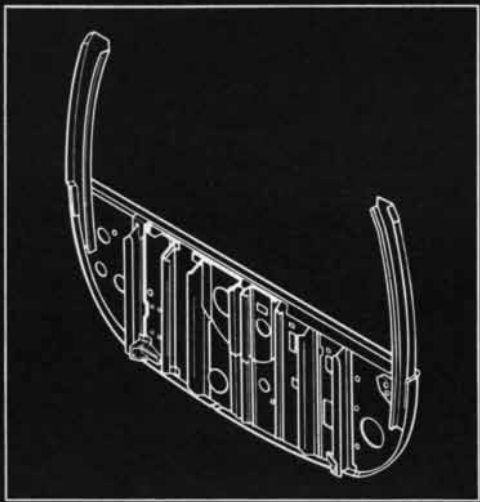
"The difficulties with sun time versus standard time stem from two sources. The eccentricity of the earth's orbit and the obliquity of the ecliptic cause the sun to gain or lose as much as a minute a day over considerable periods of time, with accumulated inaccuracies of plus or minus 15 minutes at certain times of the year. The correction for this variation is known as the equation of time. When this correction is applied to the reading of a sundial, the result is local mean time. Local mean time, however, is the same as standard time in the U.S. only in those cities whose longitude is 75, 90, 105 and 120 degrees. In all other localities standard time differs from local mean time by a constant amount depending on the longitude of the place. This second cause of a sundial's apparent inaccuracy is known as the longitude correction.

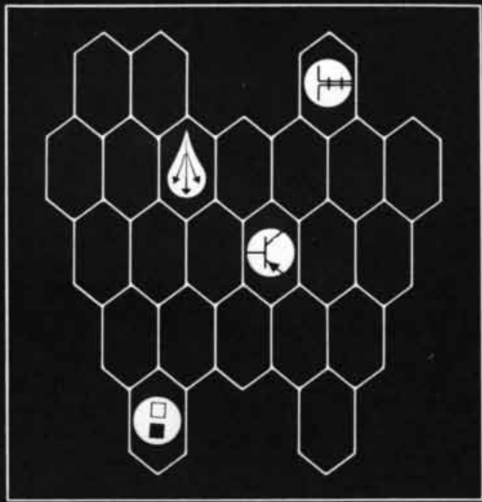
"Two corrections must therefore be applied to the reading of a conventional sundial in order to derive standard time: the equation of time, which varies from day to day, and the longitude correction, which is constant for a given place.

"Numerous methods, some of considerable ingenuity, have been devised for making a sundial indicate standard time directly. My sundial accomplishes this by means of a circular computer. The face of an equatorial-type dial is rotated by various amounts depending on the setting of a pair of disks. When the device is properly adjusted, it indicates standard time correctly to within better than five minutes. It operates only during the spring and summer months, from the vernal equinox to the autumnal equinox; during the other six months of the year the sun lies below the equatorial plane. A set of disks could be calibrated for this interval, but they have not been included with this model.

"The dial was designed to be cut out and mounted on thin cardboard, using a nonwrinkling cement such as Gripit. Rubber cement does an excellent job, but it is not permanent. After they have been mounted on the stiff backing the parts are carefully cut out. The base is then cut off for the latitude of the place where it is to be used and bent at right angles along the broken lines [*see illustrations on page 139*]. When properly mounted on a baseboard and placed on a level surface, the face makes an angle with the horizontal equal to the colatitude of the place.

"The disks are then assembled on the





face. A needle, pushed through the center mark from below, serves both as the means of assembly and as the gnomon. The gnomon should be as exactly perpendicular to the face as possible!

"The larger of the two disks, the correction disk, is placed face up on the needle first, then the smaller of the disks. Finally a small piece of cardboard, to act as a retaining washer, is pressed down on the needle.

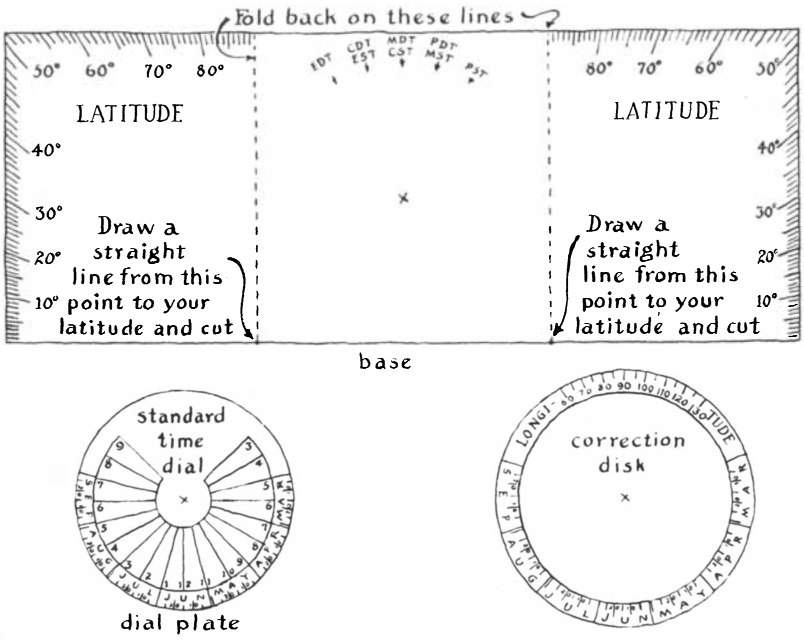
"To operate the sundial the correction disk is first rotated so that the longitude of the place is opposite the arrow on the face that indicates the local time zone. (The abbreviations are self-explanatory: CST means Central Standard Time, MDT means Mountain Daylight Time, and so on.) For example, when the dial is to be used in New York City during the period of Eastern Daylight Time, the correction disk is turned so that 74 degrees, the longitude of New York City, is at the arrow marked EDT. This disk will require further adjustment. It can be fixed to the base plate with a small piece of drafting tape. The tape must not interfere with the movement of the smaller disk, however. This disk must be adjusted every few days.

"The correction disk carries a date scale that is graduated nonlinearly to correct for the equation of time. The outer edge of the dial plate also carries a date scale, but this scale is graduated linearly. When the dial plate is rotated so that a given date on the dial plate coincides with the same date on the correction disk, the time scale is automatically rotated by the amount necessary to correct for the equation of time on that date.

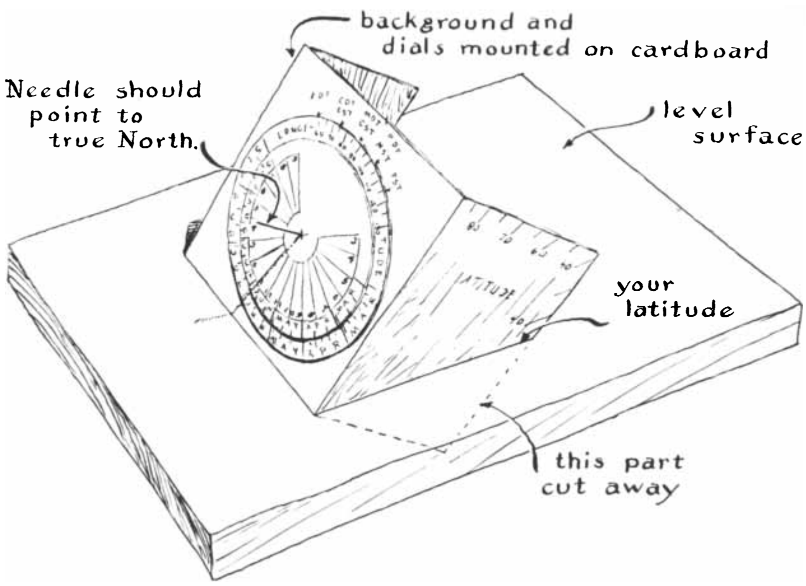
"Finally, the dial is set on a level surface—in the sun—with the gnomon pointing exactly north. The dial then indicates correct standard or daylight time. For instance, assume that the dial is to be used in New York City on July 10. The latitude of New York City is 41 degrees. The base support should be cut for this angle. The longitude of New York City is 74 degrees. On July 10 Eastern Daylight Time is in effect. The correction disk is therefore rotated so that longitude 74 degrees is at the EDT arrow. The correction disk should be taped to the face plate. The smaller disk is then turned so that July 10 coincides with the July 10 date on the larger disk. The dial is next placed on a level surface in the sun with the gnomon pointing exactly north. The shadow of the gnomon now indicates correct Eastern Daylight Time for New York City.

"It should be noted that this dial will indicate correctly even in those cases where a city operates under an incorrect standard time zone. Certain cities in eastern Indiana and western Ohio, for example, operate on Eastern Standard and Eastern Daylight Time even though they are well within the Central Standard Time zone. In these cities follow the rule of setting the longitude of the city to the arrow representing the time zone under which it operates. The dial will indicate the correct clock time.

"Although the dial is calibrated only for the time zones of the continental U.S., it can be used anywhere in the Northern Hemisphere. Merely add or subtract from the longitude of the place that multiple of 15 degrees which results in a longitude within plus or minus 7.5 degrees of 90 degrees, and then use the resulting longitude with the arrow for CST or CDT, depending on whether standard or daylight time is in use. All longitudes must be converted to longitude west of Greenwich, however. Thus longitudes east of Greenwich should be subtracted from 360 degrees to give west longitude."



Details of a sundial that indicates standard time



How the sundial is mounted

BOOKS

Aldous Huxley's view of the "two cultures"

by Max Black

Literature and Science, by Aldous Huxley. Harper & Row, Publishers ($3.50).

This little book by the late Aldous Huxley is introduced as a contribution to the running fight between representatives of the "two cultures." Its opening words are: "Snow or Leavis? The bland scientism of *The Two Cultures* or, violent and ill-mannered, the one-track, moralistic literalism of [Leavis'] Richmond Lecture? If there were no other choice, we should indeed be badly off." Huxley was unfair to both parties: Snow has never maintained that science is the sole avenue to knowledge, nor has Leavis, for all his lifelong commitment to questions of "How to live?" ever denied science's rightful pretensions to insight in its own realm. Still, in proposing to bring the debate down to earth by using "terms more concrete," Huxley usefully diverted attention from personalities to the basic issues of the still controversial relations between the scientific and the literary modes of thought. Whether or not his own position constitutes "a more realistic approach to the subject," his elegant essay has the merit of raising important questions.

Huxley's discussion is controlled by a theme that was prominent in much of his writing. He always tended to see human beings as "multiple amphibians," living "at one and the same moment in four or five different and disparate universes" and therefore existing "in a chronic state of mild or acute civil war." For him man was the chronic schizophrenic. Tensions between man's animal nature and his spiritual aspirations, or between demands for social accommodation and a yearning for any kind of religious absolute, always fascinated Huxley and provided him, in a novel such as *Point Counter Point,* with a ready source of surrealistic juxtapositions. In the present book he concentrated for the most part on the ways in which the distinctive purposes of science and literature are displayed in correspondingly contrasted uses of language. "The aim of the scientist is to say only one thing at a time, and to say it unambiguously and with the greatest possible clarity. To achieve this, he simplifies and jargonizes.... At its most perfectly pure, scientific language ceases to be a matter of words and turns into mathematics." (May not the historian, the moralist or the philosopher also aspire to clarity and precision? And could mathematical symbolism, adrift from observational moorings, ever serve the purposes of an empirical science?) The "literary artist," it seems, is necessarily committed to ambiguity and "multiple meanings" (to saying several things at once and all unclearly?): "He purifies, not by simplifying and jargonizing, but by deepening and extending, by enriching with allusive harmonics, with overtones of association and undertones of sonorous magic."

Huxley dwelt appreciatively on the poet's devices: "mysterious implication ...by means of the *mot juste,*" metaphor, manipulation of syntax, "the magic of what may be called verbal recklessness" and so on. All the while, however, he was searching for what lies behind these verbal differences—some fundamental contrast between alternative yet complementary modes of understanding the universe and man's place in it. Meditating on the problem of the right "relationship between literature and science," he was led to answer some of the most controversial problems of the philosophies of the two disciplines. Reconciliation is achieved in the end by a mysticism that can find no better expression than references to "the Something whose dwelling is everywhere, the essential Suchness of the world, which is at once immanent and transcendent." Here there is a kind of "verbal recklessness," to employ Huxley's useful formula, that some readers may find less than satisfying. But Huxley's residual mysticism can be ignored without detriment to his enjoyable wit. Huxley may have been prone to substitute an epigram for an argument, but he was never dull.

With so much to appreciate, it may seem ungrateful to submit Huxley's philosophical framework to closer examination. Yet the effort is worthwhile, because this essay illustrates in an illuminating way the dangerous consequences of an oversimplified conception of the functions of both science and literature. Huxley set out from a plausible conception of these functions. Both science and literature, in their different ways, he says, concern themselves with the organization, expression and communication of "experiences" (a key word). This common purpose makes them partners, not competitors, in the struggle for mastery and comprehension of a reality that "remains forever whole, seamless and undivided." (How sharp a contrast he drew between the ultimate harmony and unity of reality and the strife-torn condition of man!) There is a crucial distinction, if only one of degree, in the different ways in which reality can manifest itself to the individual consciousness: "All our experiences are strictly private; but some experiences are less private than others." And so, as one might expect, science operates with "the more public of human experiences," literature and fine art with the "more private." The raw material of science, the more public experiences, are relatively "sharable," whereas the poet and novelist have the paradoxical task of trying to communicate what at best is essentially personal, private, "unsharable." The greatest art is committed to the absurdity of trying "to speak about the ineffable, to communicate in words what words were never intended to convey." Public and private, sharable and unsharable, routinely expressible and intrinsically ineffable—these contrasts ran through Huxley's thoughts and the phrases that mark them recur like incantations throughout.

Certainly there is an initial plausibility in the notion of men using a raw material of "experiences" to fashion elaborate structures of science, literature and other modes of knowledge and insight. There could hardly fail to be some merit in a leading idea that has served the theoretical purposes of earlier empiricism and positivism. But the grand idea, in Huxley's simplified version, has the serious defect of bundling together, under the all-too-capacious title of "experience," everything that could loosely be said to belong to a person's "inner life," everything that in some sense happens consciously to him, including sensations, ideas, thoughts, beliefs, moods and so on. To realize how far the term "experience" is thereby stretched from its ordinary usage is to be armed against Huxley's metaphysics. Had Huxley seen that his label of "experience" would have to cover such disparate items as aesthetic judgments, moral insights, logical inferences—indeed everything that could conceivably be given linguistic expression—he might have been profoundly dissatisfied with his starting point.

The objection is not to an inept mode of expression but rather to the distorted vision it encourages. What is notably unsatisfactory about this picture of the passive recipient of "experiences" is the gulf it sets between the received impression and its supposedly subsequent organization and conceptualization. (First the experience, then the *mot juste.*) Only the misleading enticements of the pictured experience-gatherer could have allowed Huxley, against what surely must have been his own better judgment, to make such remarks about poetical composition as this: "The ability to have poetical impressions is common. The ability to give poetical *ex*pression to poetical *im*pressions is very rare. Most of us can feel in a Keatsian way, but almost none of us can write in a Keatsian way" (that "almost none of us" is charming). This is about as plausible as saying that every man has the power to think in a Newtonian way, lacking only the power to express himself adequately. On this naïve view of the poet's labors it is hardly surprising that a gifted reader may be credited with the occasional power of having impressions "of a higher order of 'poeticalness' than those from which the writer set out." Unheard songs might indeed be the sweetest. Such a conception of literature, as "a device for inducing in the reader impressions of the same kind as those which served as raw materials for the finished product," encourages judgments as crude as the following: "The function of drama is to arouse and finally allay the most violent emotions"—a vulgarization of the ancient doctrine of catharsis that might well have made Aristotle shudder. By Huxley's criterion a public hanging would be high drama.

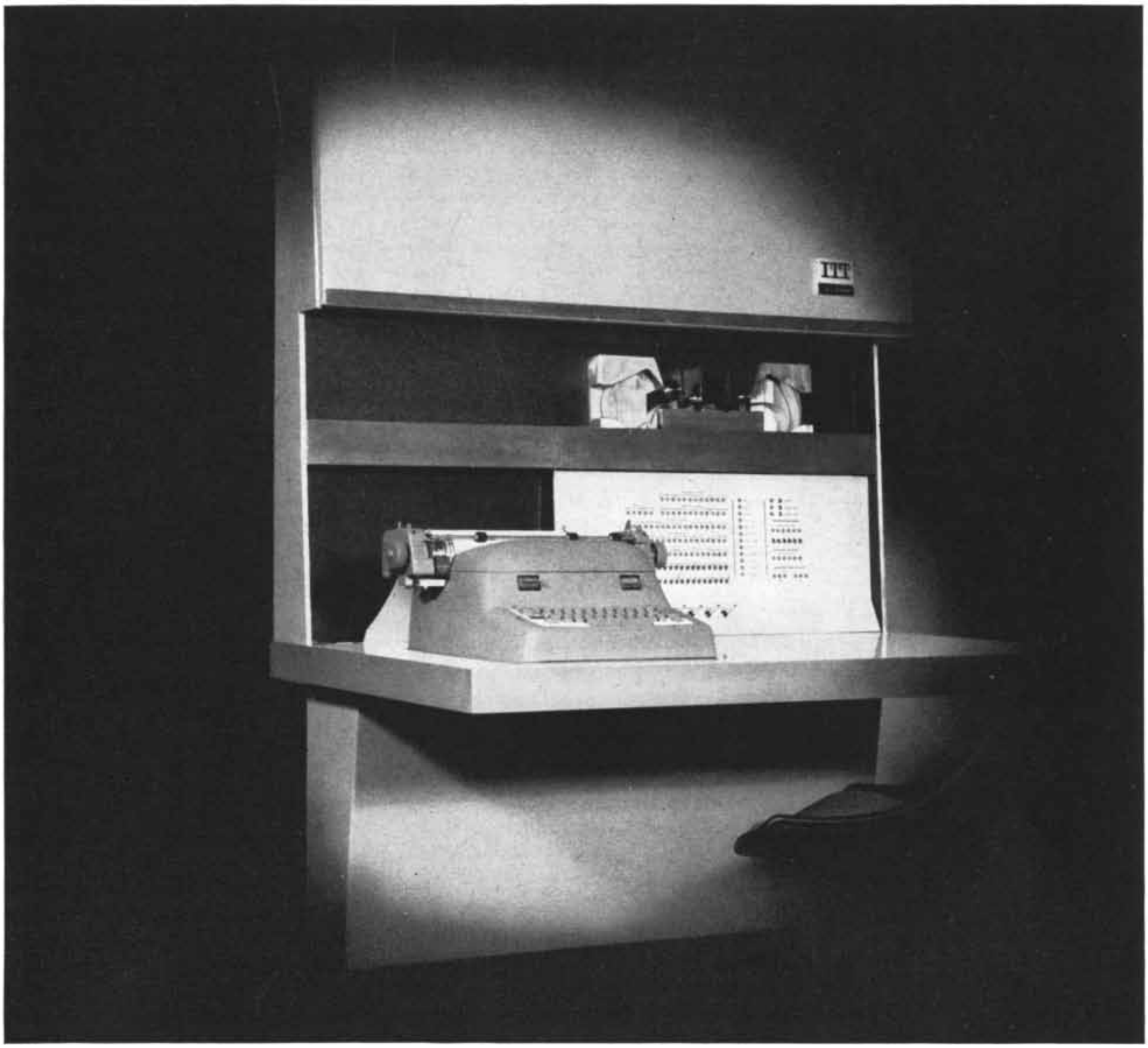
Still more indefensible, if possible, is the following characterization of the function of science: "The man of science observes his own and the reports of other people's more public experiences; conceptualizes them in terms of some language, verbal or mathematical, common to the members of his cultural group; correlates these concepts in a logically coherent system; then looks for 'operational definitions' of his concepts in the world of nature, and tries to prove, by observation and experiment, that his logical conclusions correspond to certain aspects of events taking place 'out there.' " How did this mythical scientist, confined within the world of "strictly private" experience, ever come to suspect the existence of other people and a world "out there"? And how did he ever come to control a language that, one might have supposed, could never be a private possession?

Any serious criticism of Huxley's offhand metaphysics might profitably start by challenging his notion of the contrast between the "private" and the "public." Philosophers who speak of the privacy of experiences have in mind a supposed metaphysical barrier to the sharing of mental life: my pain cannot *be* yours, however it may resemble it, and the same is true of my glimpse of the setting sun or, for that matter, my thoughts about the civil rights bill. In this sense of "privacy" (a misleading one at best, in my opinion) the distinction admits of no degrees: it is senseless to say that your pain is *partly* mine or to allege that my pleasure at Huxley's remarks on obscenity will be *partly* shared by you—what is mine is mine and that is the end of the matter. (Huxley may have been thinking of this metaphysical conception when he said that all experience is *strictly* private.) Since Huxley in fact insisted on a distinction of degree, he must have also been relying on another sense of experience. Indeed, part of the time he had in mind the degree of uniformity of response to standard stimuli: "emotional experiences," he says, are more private than "sense experiences" because normal people may differ widely in the former although agreeing in the latter. It is to be doubted if Huxley is right about this in general; nearly all normal persons will be frightened by a lion's roar, whereas their observations of, say, a street accident are notoriously variable.

In any case, uniformity of response to stimuli is irrelevant to the admitted difficulty of unambiguously rendering attitudes and emotion. It can be granted that the literary artist has peculiar problems of communication. This has less to do, however, with an alleged idiosyncrasy of emotional response than with the absence of an established tradition of interpretation, criticism and evaluation. By restricting crucial observations to the registration of pointer readings, scientists can facilitate agreement between competent observers (although this model hardly fits scientific observation in general), but still more important is the established tradition of representation, explication and verification that on the whole ensure mutual comprehension and ultimate consensus.

The vaunted "objectivity" of science rests on an elaborately fashioned tradition of discussion, comparison of results and resolution of disagreement by methods acceptable to all members of the scientific community. What is most unsatisfactory about Huxley's conception of the supposed contrast between the "publicity" of science and the relative "privacy" of literature is that he abandons without discussion any hope of objectivity in the poet or novelist's judgment about life, condemning them to the precarious transmission of thrills and pangs. So far is this from being the case that all great literature aspires to make, in its own distinctive way, statements that are true, to present a view of life claiming the acceptance and allegiance of all who can understand. Here we are in what Leavis has called "the third realm," which is "neither merely private and personal nor public in the sense that it can be brought into the laboratory or pointed to. You cannot point to the poem; it is 'there' only in the re-creative response of individual minds to the black marks on the page."

Leavis makes the essential point when he adds that it is a "necessary faith" that the meaning of the poem is "something in which minds can meet." If we are to continue to use the overworked word "public" in a metaphorical sense, it had better stand for whatever can generate rational disagreement. In this sense literature is potentially as public as science. All of which Huxley implicitly recognized when he forgot his own theory of the relations between science and literature. When he spoke of Shakespeare making it possible for us to see "enlightening truth" or of literature as a device for "reporting the multifarious facts and expressing their various significances," he was far away from his simple metaphysical model and unconsciously slipped into common sense. In



the realm of the "strictly private" there is neither truth nor facts, but everything is what it is and nothing more, devoid of significance, value and everything else that presupposes the existence of a community and a tradition. For all his occasional recognition of the power of great literature to teach as well as to give pleasure, Huxley leaves the large questions concerning the source of this power and its relation to the more purely intellectual resources of science very much of a mystery.

A disadvantage of Huxley's way of looking at these matters is that it encourages a tendency to attend excessively to the mechanism of literary expression ("verbal recklessness" and the like) in isolation from and in neglect of any context. Concentration on isolated examples of technique diverts attention from the far more important questions of the literary artist's over-all purpose and intention. It is perhaps significant that the numerous, and for the most part well-chosen, quotations with which Huxley's discussion is ornamented are left unidentified, except for rare cases where the publisher may have had copyright problems; favorite tags like "purifying the language of the tribe" (an inept characterization of the writer's task at best) are used as if any educated reader might be expected to know their origin and intended meaning. The imputation, however flattering, is often unwarranted.

The same fragmented perspective led Huxley to conceive of the value of science for the writer as consisting mainly in scraps of curious information. (This "believe-it-or-not approach," which is congenial to someone like Huxley, who was a lifelong pilferer of encyclopedias, surely overstresses the element of the sensational in scientific discovery.) Thus we have a strange chapter in Huxley's book in which ornithological data concerning the nightingale are supposed to supply a writer with "potentially poetic raw material" that it would be "an act of literary cowardice" to ignore. But the relevant information is that, all the poets notwithstanding, the singing nightingale is a male, not a female, who sings "not in pain, not in passion, not in ecstasy, but simply in order to proclaim to other cock nightingales that he has staked out a territory and is prepared to defend it against all comers." It would be interesting to know how Huxley was able to deny the nightingale any access to relatively private experience, or how such a claim could be supported by scientific evidence. In any case, it is a curiously literal-minded conception of poetry that supposes an invocation to Philomela might conflict with and need to be checked by ornithological or ethological data. How odd to think of the poet's duty as that of "expressing simultaneously [there's the rub] the truth about nightingales, as they exist in their world of caterpillars, endocrine glands and territorial possessiveness, and the truth about the human beings who listen to the nightingale's song"! Why not also the "truth" about the eaten caterpillar, as long as we are to be all-inclusive? Huxley complains that modern poets have been reprehensibly indifferent to the results of science, but poets might be excused for ignoring scraps of anthropomorphic chitchat about birds "proclaiming," "staking" and "defending" their "territories."

Of course, Huxley was not so silly as to take this oddly chosen example as paradigmatic; he also had his gaze fixed on the supposed "ethical and philosophical implications of modern science," which prove to be, as any follower of Huxley's pilgrimage through the assorted theologies might have expected, "more Buddhist than Christian, more Totemistic than Pythagorean and Platonic." Here Huxley is finding what he expected to find. Had he realized the extent to which science, for all its marvelous achievements, has no ethical or philosophical implications at all, he might have been even more hard put than he was to render an intelligible account of the mutual relations of scientist and poet. We may agree with Huxley that the man of letters could use "a general knowledge of science, a bird's-eye knowledge of what has been achieved in the various fields of scientific inquiry," and we can applaud his further demand that this needs to be supplemented by "an understanding of the philosophy of science." But the requisite philosophy of science will have to be something better than is to be found in this book. It would be agreeable if the literary man could have "an appreciation of the ways in which scientific information and scientific modes of thought are relevant to individual experience and the problems of social relationships, to religion and politics, to ethics and a tenable philosophy of life." But this is an ambitious syllabus of questions, to which Huxley provided only confused, if stimulating, answers.

Short Reviews

THE GREEN TURTLE AND MAN, by James J. Parsons. University of Florida Press ($8). Surprisingly little is known about *Chelonia mydas,* the edible green turtle, which, although it has suffered severe depletion of its numbers, is still such an important protein food source for the inhabitants of many tropical coasts that a leading authority, Archie Carr, calls it the world's most valuable reptile. Here, in a fascinating, splendidly illustrated book, we are given a summary of what has been learned about the green turtle and its relation to man.

Chelonia pastures in the sea—mostly in waters whose temperature does not fall below 65 degrees Fahrenheit—and lays its eggs on beaches from the Cape Verde Islands and Ascension to the Mozambique Channel and the Seychelles. It is a large, powerful creature—the mature female usually weighs about 250 pounds, but specimens weighing 700 to 800 pounds have often been reported—and spends almost its entire life grazing on aquatic vegetation and making prodigious journeys of as much as 1,000 miles between feeding grounds and breeding areas. It basks in the sun during daylight hours; it is unshakably peaceful and pathetically vulnerable to the greatest of all predators, man. There are few more touching sights than the female lumbering ashore during the night in the summer breeding season "to deposit her clutch of 100 or more soft-shelled eggs the size of ping-pong balls in a hole she digs in the soft sand," all the while weeping profusely and sighing. (The tears may be nature's way of keeping sand from caking in the turtle's eyes as she excavates her nest; the sighing, "an admission that the buoyancy of the water is sorely missed by a 300-pound creature that is not structurally designed for life ashore.") All one has to do to capture this gentle flatfoot is to turn her on her back, whereupon she is completely helpless as she lies wheezing and weeping awaiting her executioners.

Parsons describes the history of the green turtle, the emergence of the profitable turtle trade as the meat and soup made from it became the epicure's and glutton's special delight, the broadening of the trade so that what had once been a food of the rich has found its way to the shelves of grocers throughout Europe and America. This expanding demand, together with the growth of population in the tropical world, has laid heavy pressure on the species and has led to field studies by marine biologists of the turtle population and the turtling grounds, to conservation measures and the establishment of hatcheries. One of the most interesting chapters describes the extraordinary custom of fisherfolk of using suckerfish for catching both green and hawkbill turtles. A long line is secured to the base of the suckerfish's tail, and the line is then tethered to a fishing boat. When the fisherman believes a turtle may be near, the suckerfish is released and, "wearied of its confinement, it dashes off in the direction toward which it is pointed, its line trailing behind it. When a turtle is found, the 'hunter fish' by some instinct attaches itself firmly to the carapace by its powerful dorsal suction cup, and remains fastened while both are drawn to the boat or canoe. Skillful and patient handling of the light line is required, for the turtle usually dives, exerting all its strength to escape. But the adhesive power of a large suckerfish is marvelous, and only when raised above the water does it normally release its hold." Columbus, on his second voyage in 1494, observed this practice on the islands off the southern coast of Cuba. It has since then been described many times, but it had taxed the credulity of biologists until, in recent years, exhaustive researches and field observations completely confirmed its authenticity. This is a most enjoyable book.

THE NATURAL PHILOSOPHER: VOLUMES I AND II, edited by Daniel E. Gershenson and Daniel A. Greenberg. Blaisdell Publishing Company ($1.95 each). These two paper-backed volumes initiate a series that brings together studies devoted to the history of physics and to the influence of physics on human life and thought through the ages. Among the noteworthy papers are Martin J. Klein's historical examination of the evolution of Max Planck's concept of quanta and of his ultimate conversion, after an initially negative attitude, to Boltzmann's way of looking at entropy; the same author's enlightening study of Einstein's contribution to the quantum theory of energy; Gershenson and Greenberg's new translation of the first chapter of Aristotle's *Foundations of Scientific Thought;* Robert E. Beardsley's paper on the scientific, ethical and historical background of the fearful problem of radiation control, and the personal reminiscences of Lord Rutherford's laboratory assistant, William Alexander Kay, as tape-recorded and annotated by Samuel Devons. This is a fine start for a series that promises to be more original, imaginative and literate than the usual publications on the history of science.

NEVER CRY WOLF, by Farley Mowat. Atlantic–Little, Brown ($4.95). A few years ago the author of this book was sent to the Keewatin Barrens a few hundred miles northwest of Hudson Bay as official biologist for the Canadian government, his mission being "to determine the range/population ratio of *Canis lupus* in order to establish contact with the study species." In other words, he was to learn about the wolf population as part of the Canadian government's concern over the shocking decline of the caribou population during the past 30 years: from about four million in 1930 to fewer than 170,000 in 1963. Hunters, trappers, "sportsmen" and others had led the government to believe that this decline was mostly due to the voraciousness of the wolves, and the government had responded by encouraging their wholesale slaughter by every means from strychnine baits to airplane safaris by offering a generous money bounty for each wolf tail brought in. Mowat spent months in the field observing a small family of wolves, watching caribou herds in contact with wolves, analyzing the droppings of wolves to determine their caribou content and in related activities. On the basis of this work and from what the Eskimos of the region told him, he is able to mount an argument to the effect that human rather than four-legged wolves are primarily responsible for the caribou catastrophe. In fact, *Canis lupus,* by attacking mostly the weak, diseased and feeble animals, strengthens the herd by natural selection. The wolves' main diet, he discovered, is field mice, which are consumed in enormous quantities. Mowat nailed the point down, at least to his own satisfaction, by heroically dining on field mice for several weeks and flourishing on the diet. His book is interesting and at times quite funny, but the taste of nature-fakery is so strong that the main argument is hard to swallow without a large bag of salt.

GAMES, GODS AND GAMBLING, by F. N. David. Hafner Publishing Company ($6.50). An interesting account of the origins and history of probability and statistical ideas from the earliest times to the Newtonian era. There is available Isaac Todhunter's standard *History of the Mathematical Theory of Probability,* which is a major reference work, carrying the story through the time of Laplace. But Todhunter, although he is scholarly and almost always accurate, is pretty ponderous and is not, as David says, to be read for pleasure; moreover, he does not begin his history early enough and thereby neglects the first stirrings and manifestations of the science of random events that has now become so important in almost every department of human affairs. David discusses, among other things, the methods of gambling in ancient times; the use of the random event in divination practices; the notion, first advanced by Greek philosophers, of enumerating possibilities or causes in order to be able to judge the likelihood of an event; the work of Tartaglia and Cardano; Galileo's brief preoccupation with the subject of dice games; the famous exchanges of letters between Fermat and Pascal (which are skillfully analyzed); Captain John Graunt's lugubrious *Natural and Political Observations on the Bills of Mortality* (which is the embryo of today's massive industry of statistics); Christian Huygens' remarkable introduction to the theory of probability in his treatise *De ratiociniis in aleae ludo;* Isaac Newton's delightful letters to Samuel Pepys in which he explains the rudiments of the probability calculus and answers a burning question relating to dicing raised by a Mr. Smith of London, who was the writing master of Christ's Hospital but also enjoyed gaming in his leisure hours; James Bernoulli's immortal *Ars conjectandi,* in which he laid down at least one rule, pertaining to large numbers, that has both enlightened and plagued students of probability theory for almost three centuries; Pierre-Rémond de Montmort's *Essai d'Analyse sur les Jeux de Hasard,* which was a major contribution to the growth of probability theory, and Abraham de Moivre's *Doctrine of Chances,* a first-class attack by a powerful algebraist on the subtle mathematics of probability. David enlivens his treatment of the mathematical side of the subject with biographical details. He has it in mind, as he tells us, to continue his history with a monograph on the work of Laplace and perhaps to go even further. The student of probability theory will enjoy what David has already accomplished and will hope for a continuation of his illuminating and entertaining studies.

PAINTING OF INDIA, by Douglas Barrett and Basil Gray. The World Publishing Company ($25). This Skira art book contains 82 reproductions in full color, each separately mounted, of examples of Indian painting of different periods. It presents, among others, wall paintings from the famous caves of Ajanta, frescoes of the Rajarajesvara Temple of Tanjore and examples of the enchanting miniatures that began to appear about the middle of the 16th century, reflecting many schools and styles and mirroring the contemporary scene. These are widely distributed and are to be found not only in the remoter regions of the north but also in the small hill states of the western Himalayas. The text is informed by the results of researches of the past 20 years; the reproductions capture the variety, the delicacy and even the brilliance of the originals.

A History of Greek Philosophy: Volume I, by W. K. C. Guthrie. Cambridge University Press ($10). This first volume of a projected five-volume history of ancient Greek philosophy, by the Laurence Professor of Ancient Philosophy in the University of Cambridge, covers the earlier Presocratics and the Pythagoreans. The book discusses the systems of Thales, Anaximander and Anaximenes, then turns to the new approach of Pythagoras and his school, the doctrines of Alcmaeon and the work of the philosopher-poet Xenophanes, and concludes with an examination of the enigmatic, aphoristic and oracular Heraclitus. No comparable survey has been undertaken since Theodor Gomperz' four-volume history was published more than half a century ago. Since then a vast amount of research has been done that "has left no corner of the field untouched, and in some places has radically altered its contours." Guthrie is a lucid writer and a master of his subject. Although his book will be a boon to students and scholars, one need not have Greek to be able to read it; the use of this language is confined to the footnotes, the guiding principle being to make them "indispensable as foundations for the argument, but superfluous for understanding it." Since there are opposing views by reputable scholars on many of the points raised in this account, the author has stated his objective as that of mediating between them and giving the most reasonable conclusions in clear and readable form.

Einstein's Theory of Relativity, by Max Born. Dover Publications, Inc. ($2). A revised edition, prepared with the collaboration of Günther Leibfried and Walter Biem, of this distinguished physicist's semipopular account of the theory of relativity. Born's book was first published in an English translation in 1924. It begins with a sketch of the classical theories of astronomy and physics, introducing the questions and problems that these disciplines had raised by the end of the 19th century, and then examines the special theory of relativity, which was able to provide a satisfactory answer to a number of riddles. The last chapter considers general relativity and modern cosmology. As an explainer of hard scientific ideas, particularly of the work of Einstein, Born has never been surpassed and seldom equaled. He uses little mathematics and then only at the level of elementary algebra; he invents effective analogies and is especially convincing in the treatment of the famous paradoxes; he makes wholly understandable the drastic impact of Einstein's theories on traditional concepts of space and time. A first-rate book and, since it is offered as a paperback, a bargain.

The Fallen Sky: Medical Consequences of Thermonuclear War, edited for Physicians for Social Responsibility by Saul Aronow, Frank R. Ervin, M.D., and Victor W. Sidel, M.D. Hill and Wang ($1.50). A balanced, objective, irrefutable and horrifying survey of the human and ecological effects to be anticipated in the event of a thermonuclear attack on the U.S. The contributors, most of whom are physicians and who participated in a symposium published in 1962 by *The New England Journal of Medicine* (on which this volume is based), also deal with such topics as the physician's role in the post-attack period, psychiatric considerations in planning for defense shelters, the illusion of civil defense and the biology of nuclear war. It is a pity that this enlightened and powerful document does not have the official sanction and the publicity given to such a report as that of the Surgeon General's committee on the relation between smoking and lung cancer. A paperback.

Proteins and Nucleic Acids, by Max F. Perutz. American Elsevier Publishing Company, Inc. ($9). Perutz' book, which consists of his Weizmann Memorial Lectures given in 1961, deals with the structure of enzymes, how their structure determines their catalytic function, the structure of the genetic material, the replication of this material and how it controls the synthesis of enzymes. This is an excellent account, but very few concessions are made to those who do not already possess a working knowledge of the concepts, methods and vocabulary of biochemistry. Many illustrations.

A History of Russia, by Nicholas V. Riasanovsky. Oxford University Press ($10.50). A straightforward, comprehensive, lucid history of Russia from the beginning up to the present.

Riasanovsky, who is professor of history at the University of California at Berkeley, explains all aspects of Russian life, exhibiting both sympathetic understanding and admirable disinterestedness. No similar survey is to be found in English. Maps, charts, photographs, tables and bibliography.

LINCOLN IN PHOTOGRAPHS: AN ALBUM OF EVERY KNOWN POSE, by Charles Hamilton and Lloyd Ostendorf. University of Oklahoma Press ($19.50). This is incomparably the best collection of Lincoln photographs, not only because it has more pictures than any other—including 108 previously unpublished photographs of people and places known intimately to Lincoln—but also because of the informative captions that add greatly to one's enjoyment of the portraits. This superb gathering gives the viewer a sense of presence, a feeling that one is seeing Lincoln as one has never seen him before.

FRESHWATER FISHES OF THE WORLD, by Günther Sterba. The Viking Press ($17.50). An authoritative 878-page handbook on aquarium fishes by the director of the Zoological Institute at the University of Leipzig. The text describes each of 1,300 species and gives information as to care, breeding and eccentricities. For example, *Pseudopimelodus raninus* should be kept in a large, darkened aquarium with dark, soft bottom soil studded with thick tangles of roots; in these circumstances it is "very peaceful and easily satisfied" and will eat almost anything. On the other hand, *Hollandichthys multifasciatus* is a "beautiful, lively, but unfortunately rather unsociable and snappy species which should be kept in large, unshaded and not too thickly planted aquaria . . . temperature 16–23° C. Omnivorous, with a preference for smaller fish." The book contains more than 1,000 illustrations, including color photographs, black-and-white photographs and line drawings.

A SOPHISTICATE'S PRIMER OF RELATIVITY, by P. W. Bridgman. Wesleyan University Press ($4.50). This provocative book, Percy Bridgman's last service to the operationalist philosophy of which he was founder, is flavored by his intellectual idiosyncrasies and enriched by his perceptiveness. What he has to say about the special theory of relativity is certain to irritate some students, but Bridgman's insight was a pebble in the shoe of accepted scientific opinion, which prevents the wearer from ambling on too complacently; one simply cannot pretend the pebble does not exist.

PHYSICOCHEMICAL HYDRODYNAMICS, by Veniamin G. Levich. Prentice-Hall, Inc. ($20). A translation from the second Russian edition of a book whose central theme is the elucidation of mechanisms of transport phenomena; for instance, connective diffusion in liquids, diffusion rates in turbulent flow, heat transfer in fluids, the passage of current through electrolytic solutions, motion induced by capillarity, the motion of bubbles in fluid media, waves on a liquid surface, motion and diffusion in thin liquid films. Based on studies made for 20 years by Levich and his associates, the book contains many results never before reported in English.

Notes

THE ART AND SCIENCE OF GROWING CRYSTALS, edited by J. J. Gilman. John Wiley & Sons, Inc. ($20). The various articles in this book discuss in great detail an important new branch of "agriculture" whose inorganic products, namely crystals, have already caused a major transformation of the electronics industry and will increasingly affect mechanical technology, chemical processes and the biological sciences. Many illustrations.

A CLASSICAL DICTIONARY OF THE VULGAR TONGUE, by Captain Francis Grose, edited by Eric Partridge. Barnes & Noble, Inc. ($7.95). A reissue, with minor corrections, of Partridge's 1931 edition of a famous 18th-century dictionary. An abbess is a bawd; to arsy varsey is to fall head over heels; an Athanasian wench is a Quicunque vult; Yankey Doodle is a country lout; a boung nipper is a pickpocket; a lully prigger is a thief who steals wet linen.

RADIOECOLOGY, edited by Vincent Schultz and Alfred W. Klement, Jr. Reinhold Publishing Corp. and the American Institute of Biological Sciences ($16.50). A report of a symposium, held at Colorado State University in 1961, concerned with the effects of radiation on plants, animals and the terrestrial environment.

DISCOVERERS OF BLOOD CIRCULATION, by Tibor Doby. Abelard-Schuman ($6.50). A sound history of the men who worked on the circulation of the blood, from Erasistratus of Alexandria to William Harvey and Marcello Malpighi. It includes many old illustrations that have not been seen before in the historical literature of physiology.

MATHEMATICS: THE MAN-MADE UNIVERSE, by Sherman K. Stein. W. H. Freeman and Company ($6.50). A sound and in some ways refreshingly inventive introduction to mathematics, with the subjects chosen from number theory, topology, set theory, geometry, algebra and analysis. Based on a college course designed primarily to display the "beauty, extent and vitality of mathematics," the book is open to the understanding of the general reader as well as that of high school and college students.

SCIENCE AND THOUGHT IN THE FIFTEENTH CENTURY, by Lynn Thorndike. Hafner Publishing Company ($8). This collection of studies by a foremost scholar, dealing with topics in the history of medicine and surgery, natural and mathematical sciences, philosophy and politics, was published in 1929 and has long been out of print. Illustrations.

THE ANCIENT EXPLORERS, by M. Cary and E. H. Warmington. Penguin Books Inc. ($1.25). A reprint of a scholarly, ably written work on the activities of ancient travelers and the growth of geographic knowledge that sprang from these activities. Maps.

HOW ANIMALS MOVE, by James Gray. Penguin Books Inc. (95 cents). A paperback of Gray's delightful Royal Institution Christmas Lectures of 1957, which explain the various forms of animal movement: swimming, walking, running, jumping, creeping and flying.

THE MOTHERS, by Robert Briffault. Grosset & Dunlap ($2.65). A much abridged edition—the abridgment is by Gordon Rattray Taylor—of Briffault's million-and-a-half-word anthropological treatise on the matriarchal theory of social origins. His main thesis is that a primitive matriarchy universally preceded patriarchy. A paperback.

THE SEAS, by F. S. Russell and C. M. Yonge. Frederick Warne & Co., Ltd. ($7.95). The third edition—revised, enlarged and updated—of an inviting handbook of our knowledge of life in the sea and how this knowledge is gained. The authors, distinguished British biologists, have had the needs of the general reader foremost in mind and have enhanced the value of the book by many line drawings and 127 exceptional plates, 64 of which are in color. Altogether a little treasure.

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