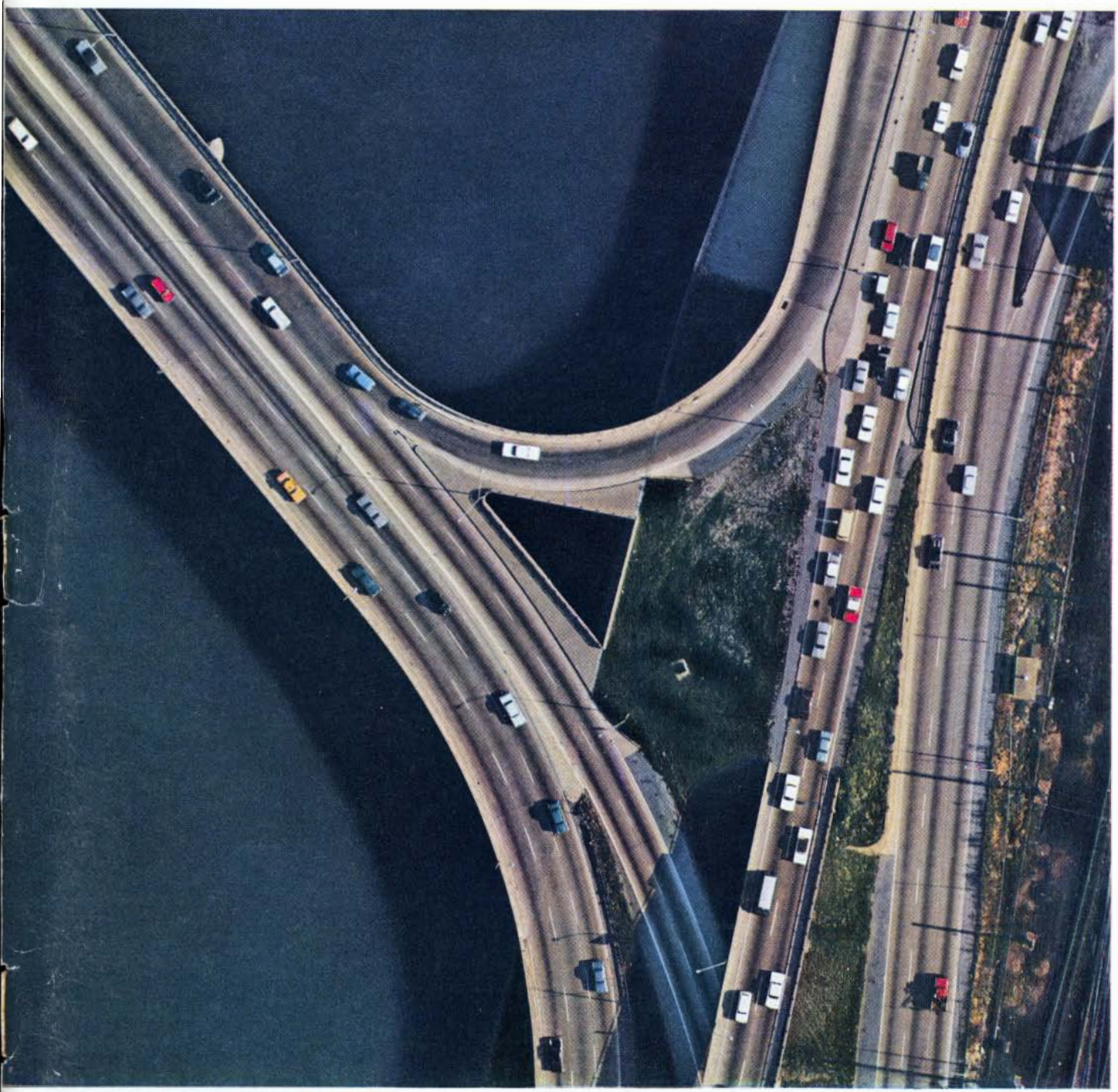
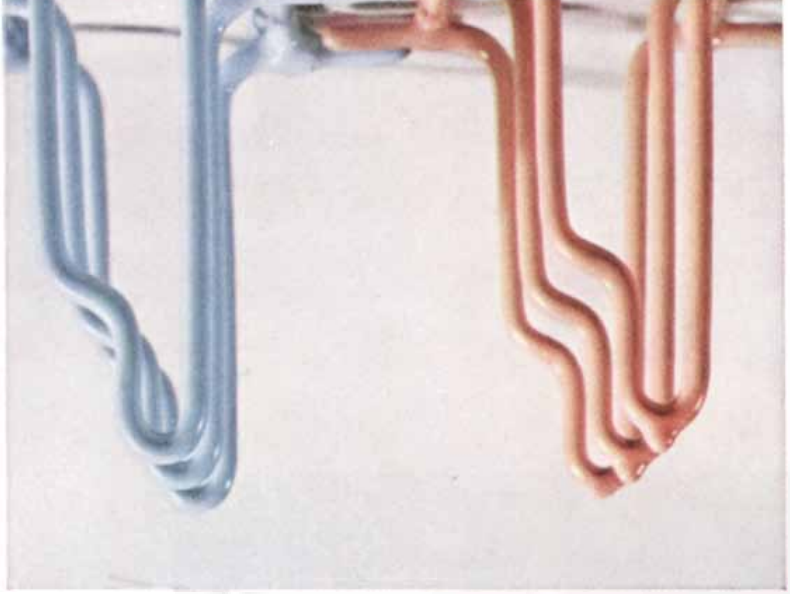
SCIENTIFIC AMERICAN



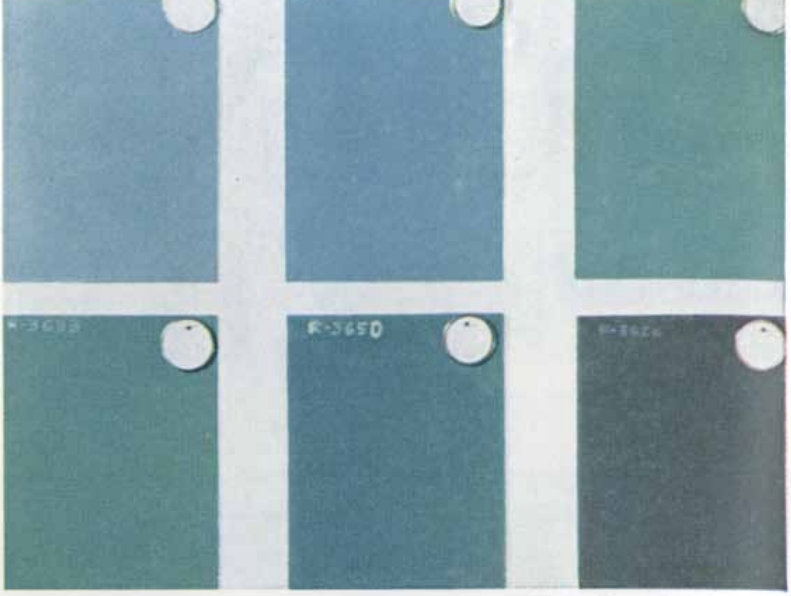
VEHICULAR TRAFFIC FLOW

FIFTY CENTS

December 1963



Change of color changes properties: Spectrophotometers and color computers help to control color in M&T vinyl coatings to within one MacAdam unit. But change colors significantly and you often change physical properties, as indicated above. Here human capability comes in. Putting experience to work, M&T chemists often come up with entirely different formulations for two colors to have the same physical and chemical properties.



Which panel has the most color pigment?: The answer: they all contain the same amount. And that's the basis for the current M&T work with antimony-based flame retarders. Our chemists have developed six types to match color requirements. Each one has high flame retardancy. Main difference is in amount of tinctorial strength. Result: users of M&T flame retarders save on costly color pigments for deep colors or improve translucency in others.

How to keep color under strict control: Only the most skilled color matcher can detect color variations of less than 1 N.B.S. unit in ceramic tile. Nevertheless, control to 1 N.B.S. unit isn't good enough for many tile producers. To meet standards such as these, M&T completely controls the uniformity of its Ultrox® ceramic opacifiers so that test glazes checked by colorimeter will have color variations of less than 0.5 N.B.S. units. This minute variation is well below the normal levels of visual perception.

M&T works with chemical and physical properties, such as color, in many materials. M&T capabilities may help solve your problems in chemistry, ceramics, plating, organic coatings, minerals and welding. Write M&T Chemicals Inc., General Offices, Rahway, New Jersey.

M&T Chemicals Inc.

FORMERLY METAL & THERMIT CORPORATION

FROM TOLEDO SCALE: A WORLD OF PROGRESS IN THE WORLD OF WEIGHING

The Kelly-Springfield Tire Company utilizes the most modern techniques and automatic equipment for materials handling, weighing and control at its new tire plant in Tyler, Texas.

For example: Toledo Scale, working with Kelly-Springfield engineers, designed and built an automatic system to control handling, weighing and mixing of ingredients for finished compound that goes into tires. Toledo furnished scales, automatic controls, bins, feeders, chutes . . . everything needed to automatically charge ingredients to the Banburys. The system provides quality control far superior to that available with conventional methods and equipment . . . cuts costs for reprocessing and scrappage to the bone.

Operation is synchronized from a central control room (partial view above) where material requirements are preset on a master control board for each Banbury unit, and the mixing cycle is established. All controls are in self-contained "modules" to provide for easy expansion of the system.

In the words of William C. Day, senior compounder . . . "With our Toledo Control System, we've eliminated human errors that spoil batch uniformity and lead to high costs for reprocessing and scrappage. What's more, processing data automatically recorded by the system adds extra muscle to our quality control program."

The Toledo System in operation for Kelly-Springfield is but one example of how Toledo Scale's broad capabilities in weighing, material handling and control are solving problems for industry. Toledo can help you, too. Complete information is yours for the asking. Call or write today.

TOLEDO SCALE

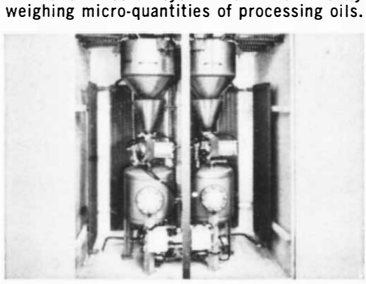
Division of Toledo Scale Corporation • Toledo 12, Ohio

Toledo Scale Co. of Canada, Ltd., Windsor, Ontario

Prime Source for Weighing Equipment and Technology

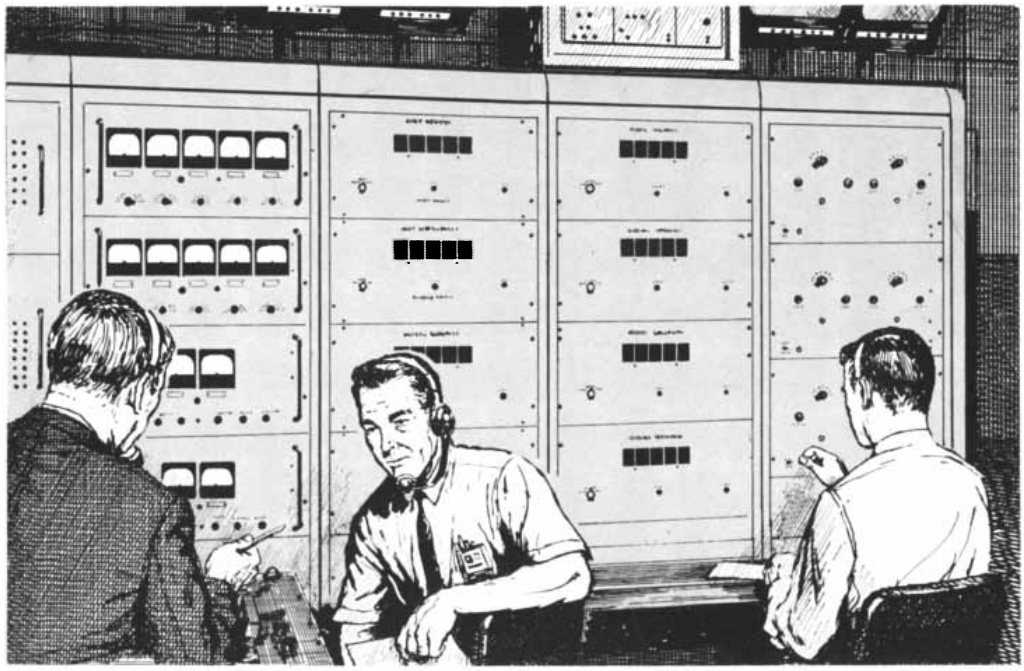
Unloading operations to this carbon black storage tank are precisely controlled by the Toledo Scale Automatic System.

Toledo Scale designed and built this steam-heated dual scale system for automatically weighing micro-quantities of processing oils.



All controls are in self-contained "modules" for ease of expansion. Additional modules can be added, and locked into the Banbury control.

In "check out" system similar to this, EI engineers first developed the input filter now standard on all EI voltmeters.



Classic Jobs of Measurement

Performed by Electro Instruments

THE EI VIEWPOINT

by Dr. Walter East
President, Electro Instruments, Inc.

Almost never, in actual practice, is a purely stable source of voltage encountered in measuring DC voltages. Minor variations go undetected if measurement is done with an instrument employing a mechanical needle movement, because of the friction involved in the needle movement itself. On the other hand, a digital voltmeter – highly sensitive to, and reacting rapidly to minute voltage changes – reflects even small variations faithfully. The trouble is, rapid voltage fluctuations will have the voltmeter reacting so rapidly that accurate, stable reading is impossible.

Dr. East

Two Types of Interference

Besides variations inherent in a voltage source, a secondary set of variations can come about with the introduction of a magnetic field, either natural or man-made. We know these variations as normal mode and common mode interference voltages, with unwanted normal mode voltages being called "ripple." It was over two years ago that Electro Instruments took the forward step that other digital voltmeter manufacturers still have to make. Recognizing that, in 95% of cases, unwanted variations in DC voltage measurements result from normal mode voltages rather than common mode voltages, we incorporated an input filter in every model voltmeter in our extensive line.

An interesting story about "ripple" appears above. It's another actual instance in which we fulfilled our promise: "You name it, we'll find a way to measure it!"

Filtered EI Voltmeter Ends Threat to Aircraft Program

What is today a standard feature of Electro Instruments' voltmeters was first developed to meet the emergency needs of a major aircraft designer*.

In actually flight testing a new type aircraft, it had been planned to telemeter information gathered by transducers placed throughout the ship to a ground-located monitoring station. Equipment of latter included several EI digital voltmeters.

Threat of Costly Delay

Despite satisfactory preliminary tests, actual engine run-up produced unwanted normal mode voltages so great that accurate voltmeter readings were impossible. Trouble was traced to electrical wiring within the aircraft. Rewiring would mean a 30-day program delay, and a loss of $100,000.

At this point, EI engineers suggested filtering out the undesirable noise at the input to the voltmeters, and letting major portions of all transmitted information be channeled through them. The suggestion was adopted, and a satisfactory filter developed within days. This first successful use of a "ripple" filter led to its being made an integral part of future Electro Instruments' voltmeter models. *Name on request.

Oscilloscope Raises Level of Confidence in Tape Recordings

The mere presence of recorded electronic impulses on tape does not necessarily constitute usable information. Operational tests of aircraft, missiles, spacecraft, etc., rely on tape recordings for depth analysis of performance. Mechanical needle movement metering provides only quantitative observation. Use of monitor oscilloscopes provides qualitative presentation as well, increases confidence level of tape recorded information.

Electro Instruments, Inc.
8611 Balboa Avenue, San Diego 12, California

EI SALES, SAN DIEGO, CALIF. • ELECTRO INTERNATIONAL, INC., ANNAPOLIS, MD. • TRANSFORMER ENGINEERS, SAN GABRIEL, CALIF.

Established 1845 **SCIENTIFIC AMERICAN** December 1963 Volume 209 Number 6

ARTICLES

DEPARTMENTS

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THE COVER

The aerial photograph on the cover of this issue symbolizes the theme of the article "Vehicular Traffic Flow" beginning on page 35. The photograph, which was made from an altitude of 2,300 feet, shows the intersection of Schuylkill Expressway (*right*) and Vine Street (*left*) in Philadelphia.

THE ILLUSTRATIONS

Cover photograph by Aero Service Corporation

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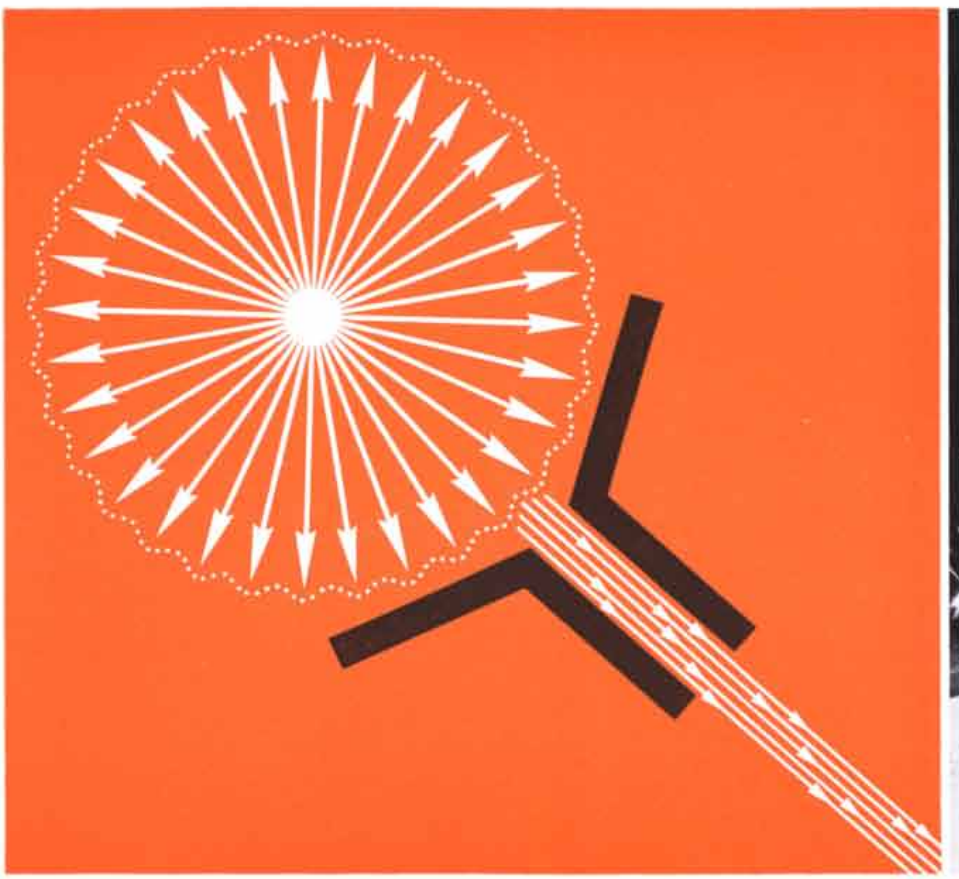
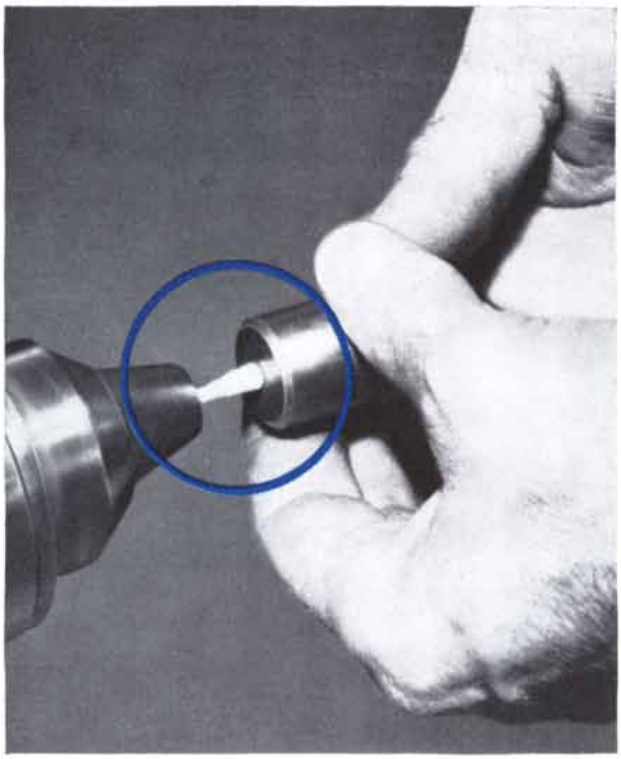


WORKING THE LIGHT FANTASTIC

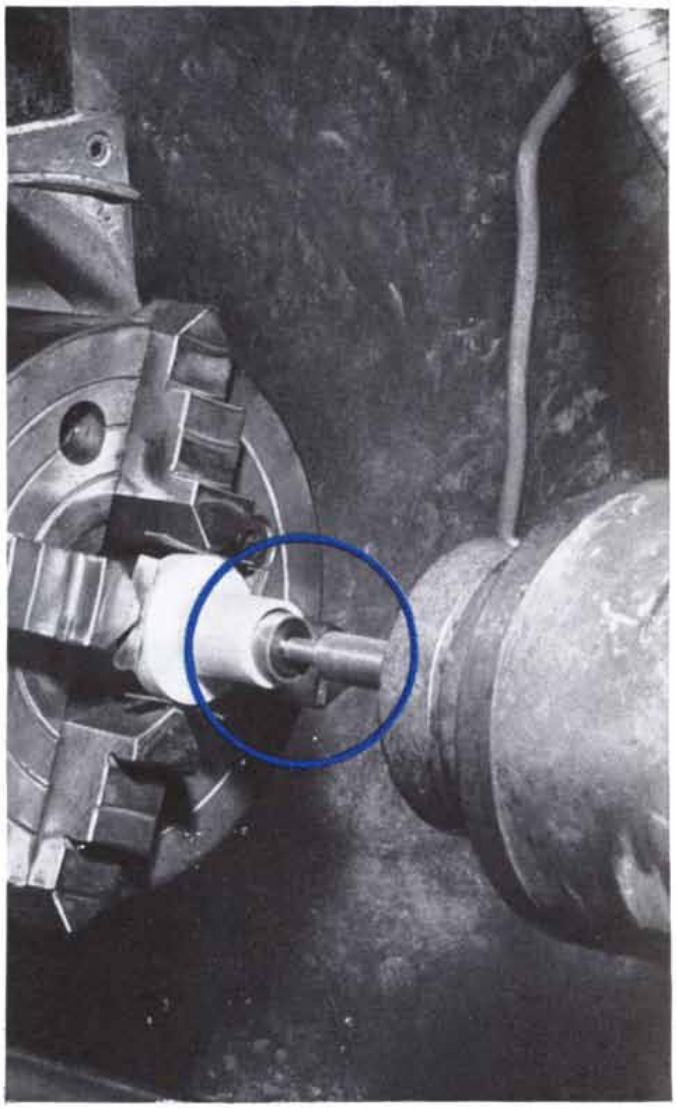
Someday hundreds of TV channels may soar through space on a single beam of light. Surgeons may perform delicate brain operations with light rays. Soldiers may pinpoint targets by determining precise range with light beams. / ITT System scientists foresee these and other dazzling possibilities through their experiments with lasers—those revolutionary devices that emit intense, coherent beams of light. / Light from lasers is just one of the strikingly new subjects under investigation by more than 25,000 R&D specialists in ITT labs around the globe. Their genius has given ITT basic patents in satellite communications, television, radio, telephony, radar, navigation and other areas. / These achievements, in turn, have helped make ITT the world's largest international supplier of electronic and telecommunication equipment. / International Telephone and Telegraph Corporation. World Headquarters: 320 Park Avenue, New York 22, New York.

worldwide electronics and telecommunications

ITT



FINAL FINISH is produced on radius of hardened tool steel hammer (55-62 Rockwell C) with a felt bob charged with 3000-mesh Hyprez diamond compound. Bottom: These two hammers used to produce electrical contact parts at Deringer Mfg. Co., Skokie, Ill., show the superfinish produced by lapping the hammer on right with diamond compounds. Finish is essential in achieving precise tolerances on stock (gold, silver, palladium or other precious metal).



ALUMINA CERAMIC CYLINDER is ID ground, OD ground and sliced into rings with diamond tools at Intl. Pipe & Ceramics Corp. (INTERPACE). A 16-inch diameter wheel at rear of machine grinds outside diameter to within ±.001 inch of specified dimensions. Small diamond wheel then grinds inside diameter to same tolerance. Concentricity is held within .002 inch. Both resin-bond and metal-bond diamond tools are employed, including centerless wheels.

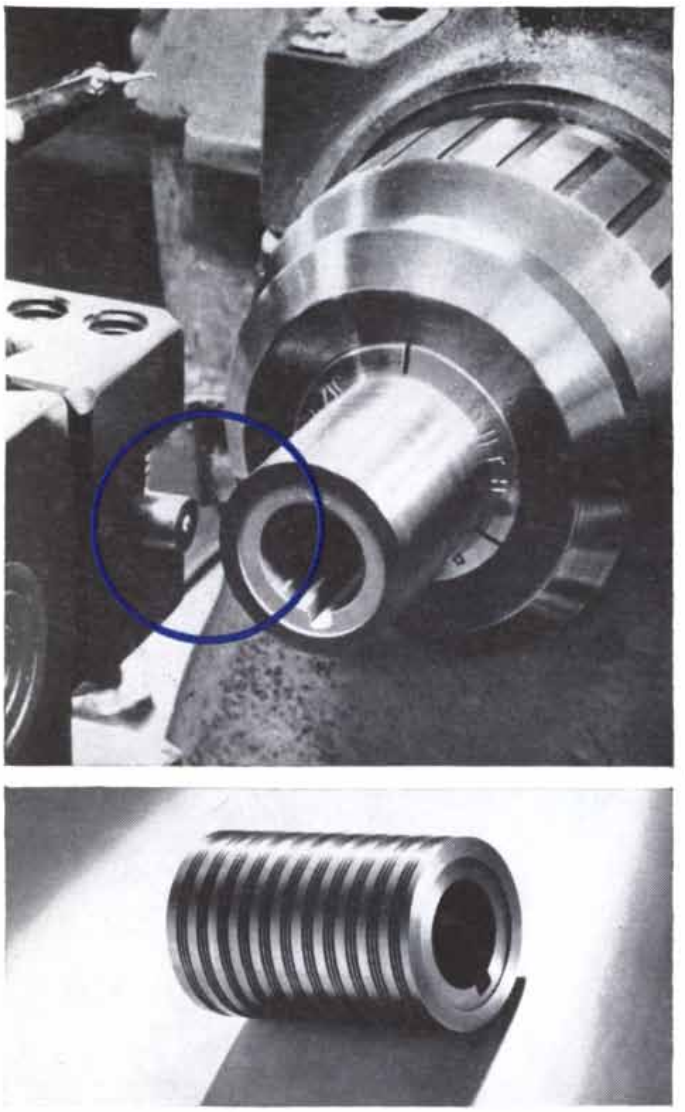
Each of these jobs is done better with diamonds

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

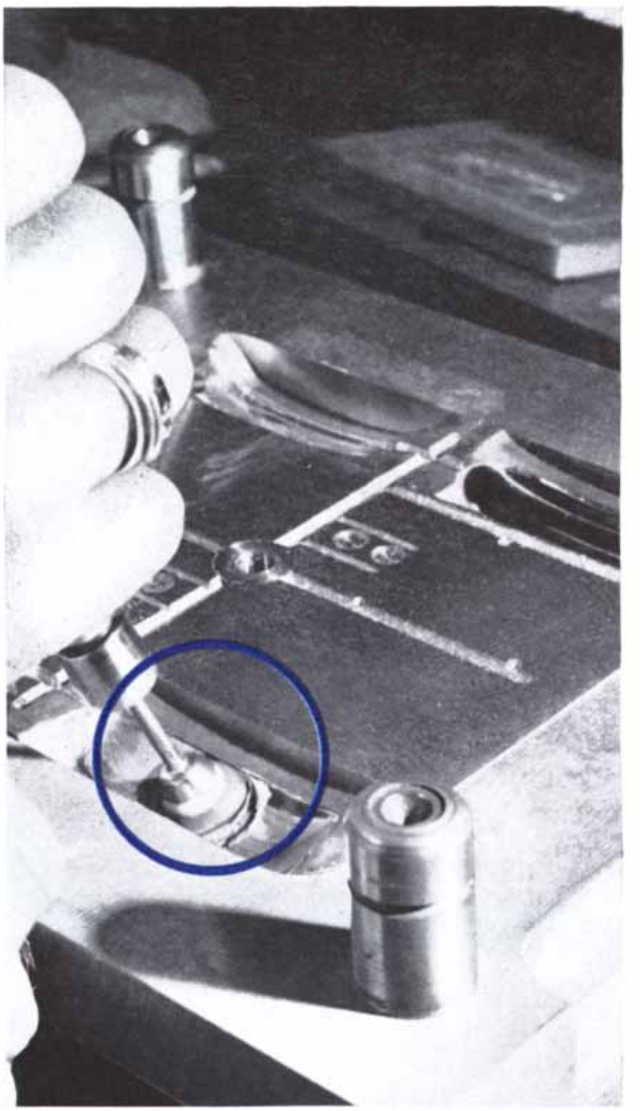
When you use diamonds, you get the unique combination of excellent cutting ability linked with fantastic endurance. Result: your diamond tools last longer than any other tools. Your people spend more time producing, less time changing tools.

If you cut, sharpen or smooth anything in your business, you can probably use diamonds to ad-

INDUSTRIAL DIAMONDS CUT PRACTICALLY EVERYTHING . . . ESPECIALLY YOUR PRODUCTION COSTS



HARDENED STEEL ROLLERS (Rockwell 60) are grooved with single-point diamond tool at Dinger Machine Co., Springfield, N. J. Natural diamond is .03 carat; lathe is driven at 875 rpm. Bottom: finished roller. The grooves guide resistance wire. Tolerance of groove depth: ±.0001 inch. Other abrasives had failed to maintain specifications.



POLISHING STEEL MOLDS with Hyprez diamond compounds is final step before injection of plastic in making model kits at Revell, Inc., Venice, Calif. Work is hand-done with rotary hand tools and natural diamond paste to provide mirror-smooth finish that will transfer every detail to the finished kit. This mold is for the windshield of a model car.

vantage. Test them against the method you're now using. You'll see how efficient—and economical—a diamond can be.

Best grit for metal-bond wheels developed by the Diamond Research Laboratory in Johannesburg

A special impact crushing method for natural diamonds is producing the strongest and most durable grit ever obtained for metal-bond wheels. Your tool and wheel manufacturer is ready to help you select the tool that's right for your job.

Announcing De Beers synthetic grit

De Beers announces two new synthetic grits for both resin-bond and metal-bond applications. Both of these grits have been extensively tested by the Diamond Research Laboratory, Johannesburg, world's leading authority on all phases of diamond technology.

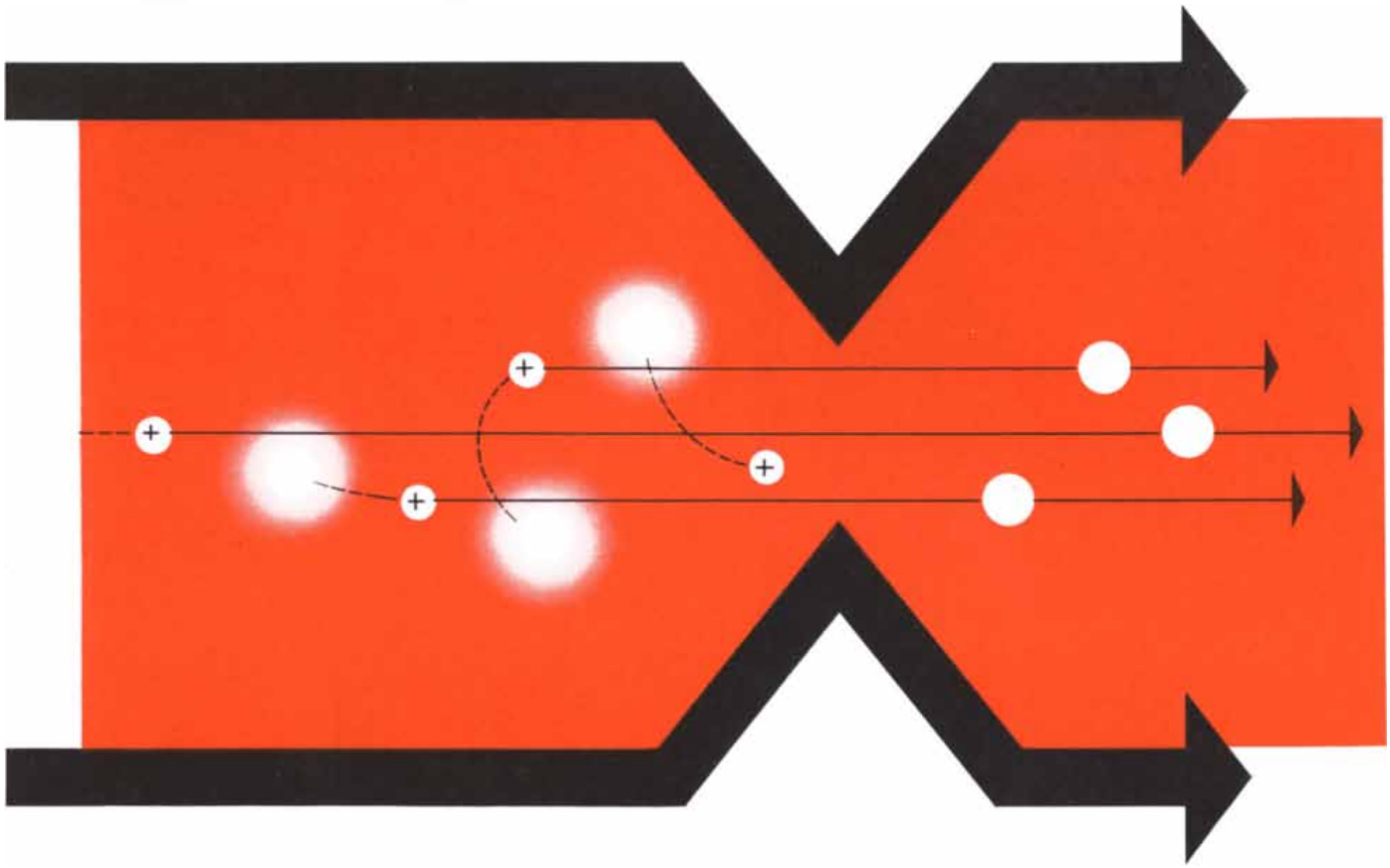
De Beers SYN-RB is especially useful for heavy wet grinding with a high stock-removal rate ... medium grinding, wet or dry, where both stock removal and finish are important ... light dry grinding involving finishing operations and tool sharpening.

De Beers SYN-MB has been designed for cutting and slicing semi-conductor materials, carbides and ceramics.

The addition of SYN-RB and SYN-MB to the wide range of natural-diamond abrasives puts your tool and wheel manufacturer in a better position than ever to fill all of your industrial diamond requirements.

INDUSTRIAL DISTRIBUTORS (SALES), LTD., JOHANNESBURG · LONDON

World's leading supplier of diamonds for industry



PHYSICS: ADVANCING THE STATE OF THE ART

AGN'S Research Division is conducting experimental and theoretical investigations in the fields of plasma physics and electric propulsion; explosive-electric energy conversion; and nuclear and solid state physics.

Objectives: reduction by charge exchange of energy used for ionization in accelerators ▪ verification, through advanced research, of approaches to controlled thermonuclear reactions ▪ achievement of high mass utilization and current densities by means of an energetic arc for plasma propulsion ▪ efficient production of electric power by converting the energy of high explosives ▪ creation of multi-million gauss magnetic fields ▪ improvement of satellite reliability by determining effects of extraterrestrial nuclear radiation.

For information on AGN'S research in plasma physics, write for AGN Active File No. 5.

AGN

AEROJET-GENERAL NUCLEONICS / San Ramon, California

GENERAL TIRE T.M.

Special Report:

"THE LAND-ROVER AND CRIME"

PREFERRED BY THE POLICE OF 37 COUNTRIES AND THE BANDITS OF AT LEAST 1

DUE TO THE GROWING POPULARITY of the Land-Rover in the commission of grand theft, an interim report seems in order. Apparently our 4-wheel drive vehicle has latent virtues which may be of interest to the prospective owner.

It is not our intent here to point out raffish ways for one to pick up a great deal of extra money in one's spare time. Rather the opposite: to abet law and order by useful suggestion.

For instance: in two recent major crimes Land-Rovers were most helpful in hauling away £2,500,000 ($7,000,000) and £90,000 ($252,000), respectively. Now, although it is well-known that the police of the United Kingdom also employ Land-Rovers, *nowhere is it reported that they employed them on these occasions for hot pursuit of the brigands*. Perhaps that was their mistake.

NEAR LEIGHTON BUZZARD, BEDS.

The first theft, widely if grudgingly admired for its sheer bulk of loot, was, of course, the Great Train Robbery which brought the title back to England.

This Olympics of knavery took place, you recall, at Cheddington, just five miles out of Leighton Buzzard, Bedfordshire, on August 8 last, a Thursday.

Nearly a week passed before any clues turned up. Then, on Tuesday, August 13, a Times of London article datelined Brill, Buckinghamshire, reported:

"A lonely farmhouse near here, twelve miles from Oxford, was the hideout for the mail train gang and their haul of £2,500,000 in bank notes. Mailbags in three abandoned vehicles—an Army type truck and two Land-Rovers—have been found but no money."

NOT LIKE DARTS

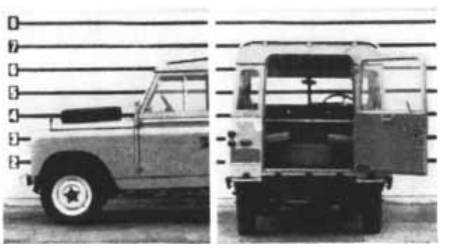
Dismissing the Army lorry, one surmises that the Land-Rovers were given the arduous getaway assignment not only for their rugged dependability, but for their capacious rear doors, as well.

Bank notes in excess of so many tend to be cumbersome. When you are trying to on-load literally bags and bags of the stuff you simply haven't got the time to aim nicely; it's not like darts.

No, robbing a train is a very near thing at best and one has got to have the tools to do the job.

FOUND BY MUSHROOMER

Paradoxically, another Land-Rover feature, its outstanding over-all height, caused the thieves to flee the farm, it is thought. According to The Times:



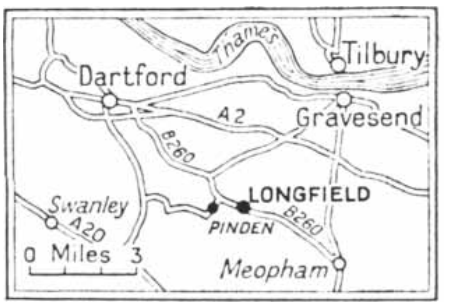
Left Profile Rear View

"On Sunday afternoon a local man went mushrooming near the farm and noticed the top of a Land-Rover sticking out of a dilapidated outhouse among the trees." This he duly reported.

The Times account continues: "Police believe that the gang fled in haste. In the garden, near a row of runner beans, was a partly dug hole about 3 ft. deep, a spade still standing in a mound of clay.

"Detective Superintendent Fewtrell, head of Buckinghamshire's C.I.D., surveyed the hole and commented: 'Presumably they intended burying the evidence. We know they got out before they intended... they must have got the wind up'."

Naturally we are pleased that, having been an accessory to the crime, the Land-Rover was also helpful in its solution.



LAND-ROVER STRIKES AGAIN

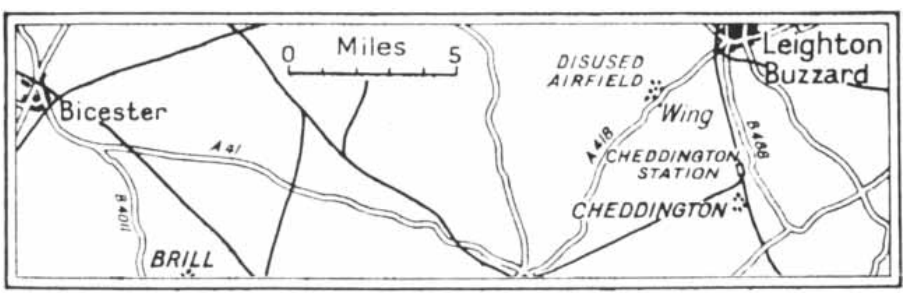
Though piddling by comparison, the latest Land-Rover effort—the Longfield, Kent, job of September 27—was respectable by county competition standards. It also illustrated an entirely different aspect of the Land-Rover's amazing versatility.

Under the headlines "£90,000 Stolen In Bank Van Ambush" and "Getaway By 8 Masked Men: Guard Felled By Cosh", The London Times describes how the armoured car was high jacked. The bandits lay in wait with their vehicles along a hedgelined road at the T-junction leading off to Horton Kirby and South Darenth. And then:

"A brick was hurled through the windscreen of the bank van, forcing the driver to stop. The bank van was hemmed in by the Land-Rover and the lorry." Whereupon the bandits leaped from the ambush vehicles armed with pick-axe handles, enveloped the bank van, carried the day, and drove off towards Horton Kirby.

To our knowledge this is the first time the Land-Rover has been used in the actual *commission* of a stick-up of this magnitude. While this dubious demonstration of its versatility would seem conclusive, one wonders: what would the

(cont. on next page)



"THE LAND-ROVER AND CRIME"

(*cont. from previous page*)

outcome have been had the victim-vehicle *also* been a Land-Rover (Model 109 Bank Van)? An interesting conjecture.

LAW-FEARERS ASK

"Why," decent, law-fearing people may ask, "do you sell Land-Rovers to chaps who are going to use them to rob trains and banks?"

Actually, we can't always tell.

We've sold Land-Rovers to all sorts of customers in over 160 countries, including the armed services of 26, the police forces of 37, veritable legions of country squires, desert chieftains, titled persons, oil and gold prospectors, light and heavy sportsmen; and to multitudes of nice families for skiing, beach buggying and other pleasant things. With this limitless range we often don't know precisely how a buyer intends to use his Land-Rover.

NEW OWNER OFTEN CLUELESS

More often than not the new owner doesn't know himself until he's tested its enormous virtuosity. For all we know, the recent bandits were ordinary citizens who only turned to lives of crime *after* they found their Land-Rovers were just the thing for sticking up trains.

As a matter of fact, we can give you what appears to be a character reference on one of our customers; this one also from The London Times of August 13. A member of the Mail Train Mob got the key to the farmhouse hideout from a neighboring housewife (he said he was the new owner).

She describes him thus: "He was a well dressed, well spoken, and charming man. I have not seen him since."

Neither have we; we do hope he's keeping it serviced.

LETTERS

Sirs:

In his recent article "The Evolution of Bowerbirds" [SCIENTIFIC AMERICAN, August] E. Thomas Gilliard, having been "seized by the notion that some rapidly operating mechanism is directing the evolution" of polygamous arena birds, develops the principal point that there is "a speed-up in evolutionary processes" in birds having "promiscuous polygyny" as a mating system. That this is presented, both in the article's subtitle and in the text itself, as a recently developed hypothesis comes as a distinct surprise to readers familiar with the evolutionary literature and particularly with the classic writings of Charles Darwin (1871), R. A. Fisher (1929) and Julian Huxley (1938) on the theory of sexual selection. As noted by Fisher in his lucid analysis of Darwinian sexual selection in *The Genetical Theory of Natural Selection:* "In species so situated that the reproductive success of one sex depends greatly upon winning the favour of the other, as appears evidently to be the case with many polygamous birds, sexual selection will itself act by increasing the intensity of the preference to which it is due, with the consequence that both the feature preferred and the intensity of the preference will be augmented together with ever-increasing velocity, causing a great and rapid evolution of certain conspicuous characteristics, until the process can be arrested by the direct or indirect effects of Natural Selection."

Having discovered that sexual selection in polygamous mating systems leads to rapid evolution of secondary sexual characters, Gilliard suggests that "the biological advantage" of polygamous arena behavior "may be precisely that it does speed up evolution." Gilliard does not define or explain his use of the phrase "biological advantage" with reference to mating systems, but it is apparent that he implies some superiority of polygamy over monogamy and believes that the origin and maintenance of the former mating system is somehow inexplicable in terms of selection on the individual. This questionable line of thinking leads to the unwarranted and, in any event, unnecessary supposition that polygamy per se is selected in an evolutionary line because of its value in promoting rapid evolution.

While I would be the first to acknowledge that many ecologic and other aspects of the evolution of mating systems remain to be explored, I fail to see progress in understanding in the tracing of already familiar pathways.

ROBERT K. SELANDER

University of Texas
Austin, Tex.

Sirs:

The probability of possible evolutionary acceleration as a result of arena behavior was introduced near the end of my article. This section does recross some old ground, and I admit that the subtitle emphasizes the one point of acceleration, but this was not the meat of my article. However, I would point out that *I* did not say that *I* was "seized by the notion" of a speed-up of evolution in these birds but that [any]one who considered them would be! Moreover, my suggestion that the speed-up of evolution associated with this type of behavior may be of basic importance in avian evolution goes beyond the mere question of the rapid evolution of the secondary sexual characters themselves (the chief consideration of the earlier authors quoted by Selander).

The emphasis of my article was in quite a different area. It was intended to review the remarkable behavior of the various groups of birds that have an arena type of courtship behavior and in particular to discuss the bowerbirds as representing, in many respects, the cul-

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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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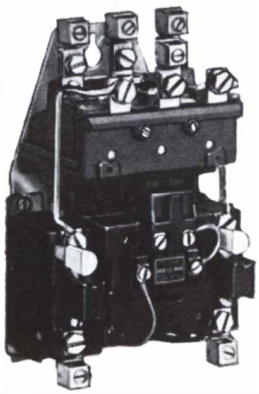
GM
GENERAL MOTORS

mination of this development in birds. My principal points were (a) that bowerbirds, at least many of them, practice arena behavior, *not* pair-bond behavior as generally thought, and this, I hypothesized, was the key factor that made possible the development of the extraordinary ornamented bowers ("bundles of externalized secondary sexual characters"), and (b) that the development of this ornamented bower made possible the hypothesized secondary loss of sexual plumage once the forces of sexual selection had been transferred from colorful feathers to colorful objects.

Right or wrong, these are original ideas, not tracings of "already familiar pathways" of evolutionary thought. The noted evolutionary geneticist Ernst Mayr recognizes this. In a personal communication (to which I refer with his permission) he wrote me, with special reference to (b) above: "Thank you for sending me a copy of *Scientific American* with your fascinating article on the evolution of bowerbirds. We have discussed this subject many times in the past and I largely accept your reasoning; indeed, I feel that your suggestion of 'transfer' is not only most original but quite likely correct."

Selander doubts that a biological advantage is conferred through polygynous behavior in arena birds. He seeks an explanation of my statement that one seems to exist. The advantage, I think, is a fundamental one. It operates through the combined effects of polygyny and transfer noted above, but the threshold at which it becomes operative is reached by way of the simpler forms of polygyny. To explain: Darwin's theory of sexual selection has two main elements: (a) a selection exerted through rival males that results in the selection of special weapons (antlers and so forth), and (b) a selection exerted through females as a consequence of their sexual preferences that results in the development of certain physical features in males (plumage, wattles and so on). This second force, I believe, is the key one operating in all arena birds below the level of the bowerbirds.

On rare occasions near peaks of development in the evolution of polygynous animals, I believe, these two forces are reinforced by a third one that is released by the transfer of sexual signals from the physical features of the male to the objects used by the male in his courtship displays. At first the effects are disarmingly subtle, but I think this force is so potentially powerful it can open a pathway through the almost impenetrable maze of barriers (counterselective forces) imposed by natural selection. It



six big reasons why...

Bulletin 709 Series K starters lead the parade!

1.

this starter has only six basic parts

The design is so simple, *you* can disassemble the new Bulletin 709 Series K starter in less than four minutes—reassemble it in less than five—*blindfolded!* That's because there are only six rugged basic parts. Think of all the sources of trouble that have been eliminated with this design simplicity—more trouble free life is the result.

2.

accurately machined aluminum diecasting is the "bedrock" on which the starter is assembled

All Bulletin 709 Series K designs start with a one-piece, accurately machined diecasting—the base that "locks" each unit assembly in precise, permanent alignment. It's a heat sink for the coil, too. And cooler coil operation means longer coil life. The die-cast base also serves as a guide for the movable contact arm—the starter's only moving part.

3.

immersing in acids proves coils can really take it

In "acid tests," which would quickly destroy most coils, Bulletin 709 Series K coils proved just how remarkable they really are. Immersion in boiling water, acid and alkaline solutions, salt water, and exposure to weather proved the complete protection A-B's pressure molding gives. Real effort is needed to cause mechanical damage.

4.

contact inspection takes less time than does the telling

It's *so* simple—just loosen two screws, lift off the arc hood cover, and all contacts are in plain view. You're back in operation just as quickly—replace the cover and tighten the captive screws. Simple as this is, you'll rarely have to look at the contacts, possibly two or three times a year—because they're always in perfect operating condition.

5.

change coils in less than five minutes—blindfolded

Takes about two minutes to remove the coil—loosen two coil screws and slide out spade connectors . . . loosen four captive coil cover screws . . . now the cover, coil, and magnet yoke assembly lifts out as a unit . . . slide the coil from cover—that's all! Reassembly takes less than three minutes. And, all parts are keyed so you can't go wrong.

6.

Series K starters are adaptable to necessary changes

You'll really appreciate the "built-in" simplicity of Bulletin 709 Series K motor starters the firsttime your control needs change. Auxiliary contacts mount on the front of the arc hood in seconds. A third overload relay is easily added from the front. Push buttons, selector switch, and pilot light kits permit simple additions in the field also.

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does this, I think, by allowing for the externalization and proliferation of sexual signals and thus unshackling an evolving animal from the inhibiting effects of direct counterselection. This process of externalization through transfer, I think, is accompanied by bursts of evolutionary activity of such intensity they sometimes carry an animal into an entirely new adaptive zone. In my opinion this process, with polygyny as the boosting force, played a key part in the evolution of bowerbirds.

Concerning this phenomenon in bowerbirds, in a 1956 paper entitled "Bower Ornamentation versus Plumage Characters in Bowerbirds" (*Auk*, pages 450 and 451) I wrote that the adoption of objects as sexual releasers apparently has no parallel among vertebrates except perhaps among humans. The transfer, I hypothesized, has permitted the evolution of the extraordinary structures built by bowerbirds. "Psychologically but no longer physically linked to the bird, such 'secondary sexual characters' are open to a much greater variety of expression. Sticks, paint, insects, fungus, seeds, stones, clay balls, charcoal, animal and plant silk, grasses, flowers, fruits, shells, moss and all manner of shiny, odd and colorful objects are incorporated in the pattern of bowerbird behavior." I should have added the manipulation of light and the use of a tool.

Therefore, in bowerbirds my hypothesis is that the biological advantages of polygynous behavior coupled with transfer are (a) that it enabled the stock to cross into a new adaptive zone wherein sexual objects replaced sexual plumage as secondary sexual characters, and (b) that it permitted rapid shifts in physical structure and contributed to the unique genetic reorganization of the group.

E. Thomas Gilliard

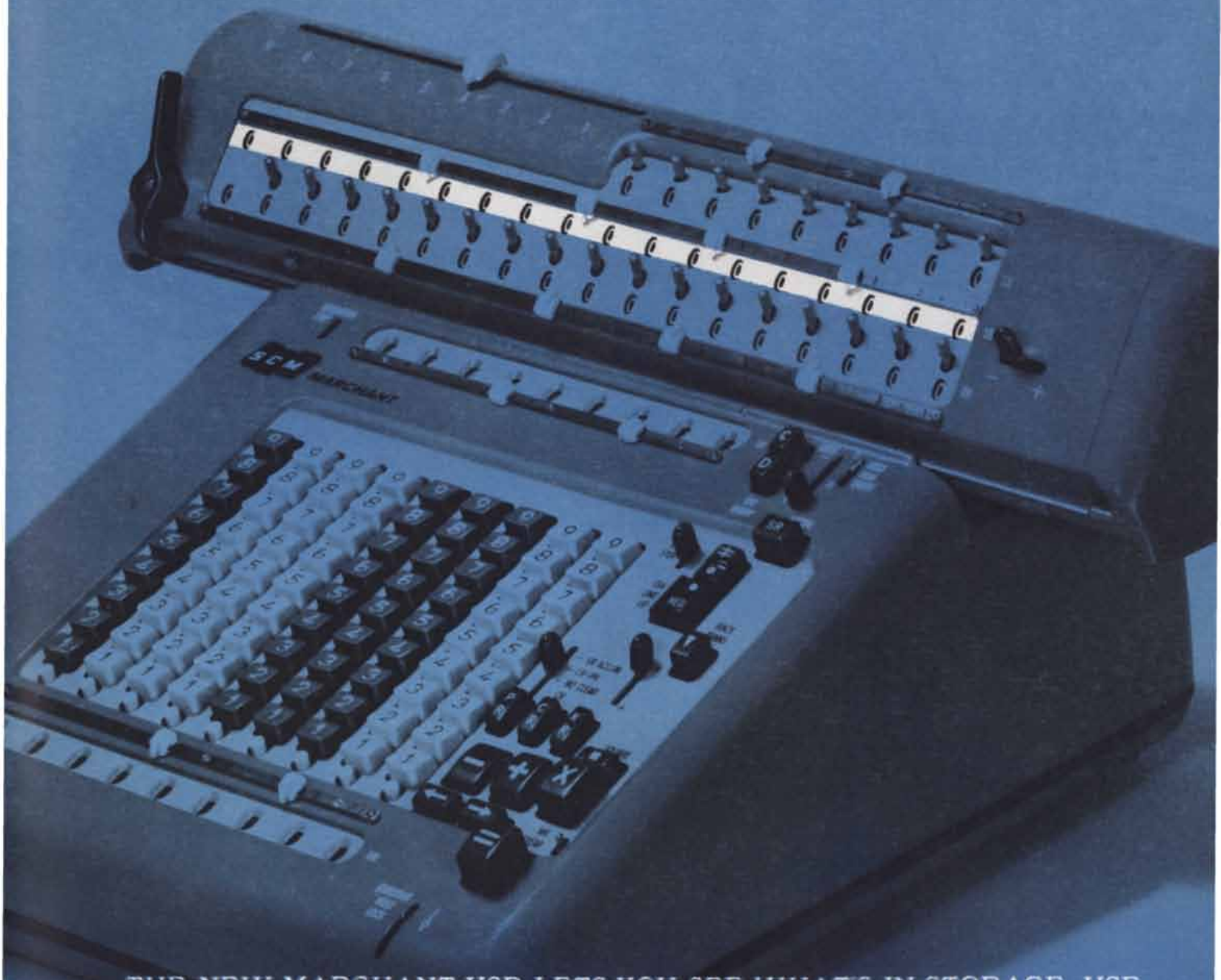
American Museum of Natural History
New York, N.Y.

Erratum

In the article "Energy" in the issue devoted to technology and economic development (Scientific American, September) it was stated that uranium 238 and thorium 232 could be converted into uranium 235 and thorium 233. The last two isotopes should be plutonium 239 and uranium 233.

A TOUCH OF GENIUS

[The Visible Storage Register]



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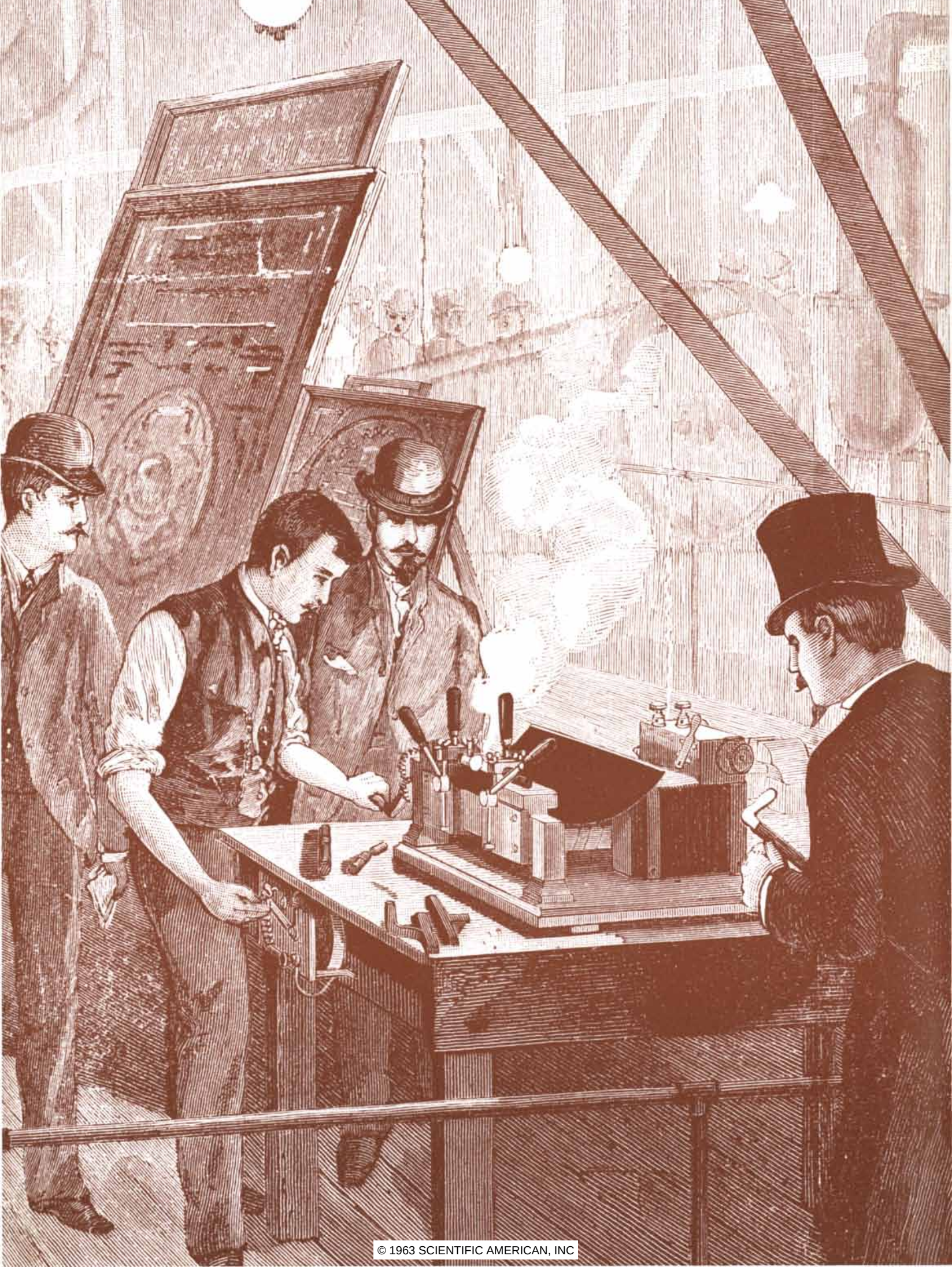

Illustration courtesy of Thomson Electric Welder Company, Lynn, Mass.

The art of joining metals has come a long way since 1887

Now there are new Palladium-containing brazing alloys offering exceptional combinations of properties for metal-to-metal joining at temperatures as high as 2260°F.

As new and better metals open the way to new and more challenging application areas, design and development engineers are faced with the problem of joining them.

Today, more and more designers are finding the answer in brazing alloys containing Palladium.

Palladium-containing brazing alloys are available with melting points from 1490°F to 2260°F. The numerous alloys within this temperature range permit selection for step brazing. They also facilitate the matching of brazing temperatures with that required to heat treat the base metal. Where wetting of the base is a problem, Palladium-containing brazing alloys pay off with excellent wettability and good fillets. Additional important features are minimum base erosion, high temperature strength, good ductility and low vapor pressure. Some of the available Palladium-containing brazing alloys are:

Palladium-containing brazing alloys effectively join a wide range of metals including:

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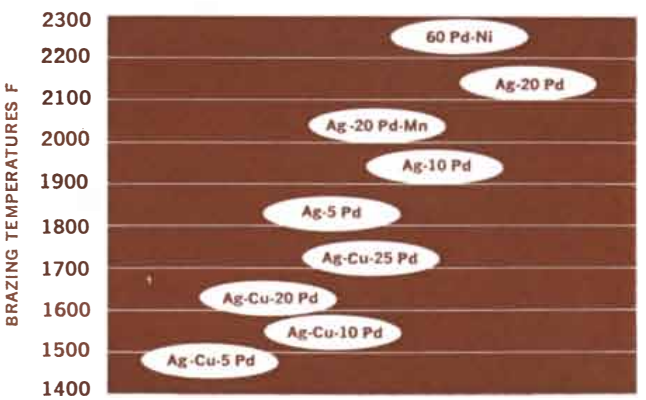
- Cobalt base alloys
- Austenitic stainless steels
- Ferritic stainless steels
- Precipitation hardening high temperature alloys



These brazing alloys are finding use today in electronics, atomic energy, rocketry, space applications, airframe construction and similar fields.

Inco does not market these alloys but has developed considerable data on their characteristics and applications. Write for a copy of *"New Era Brazing Turns to Filler Metals with Palladium."*

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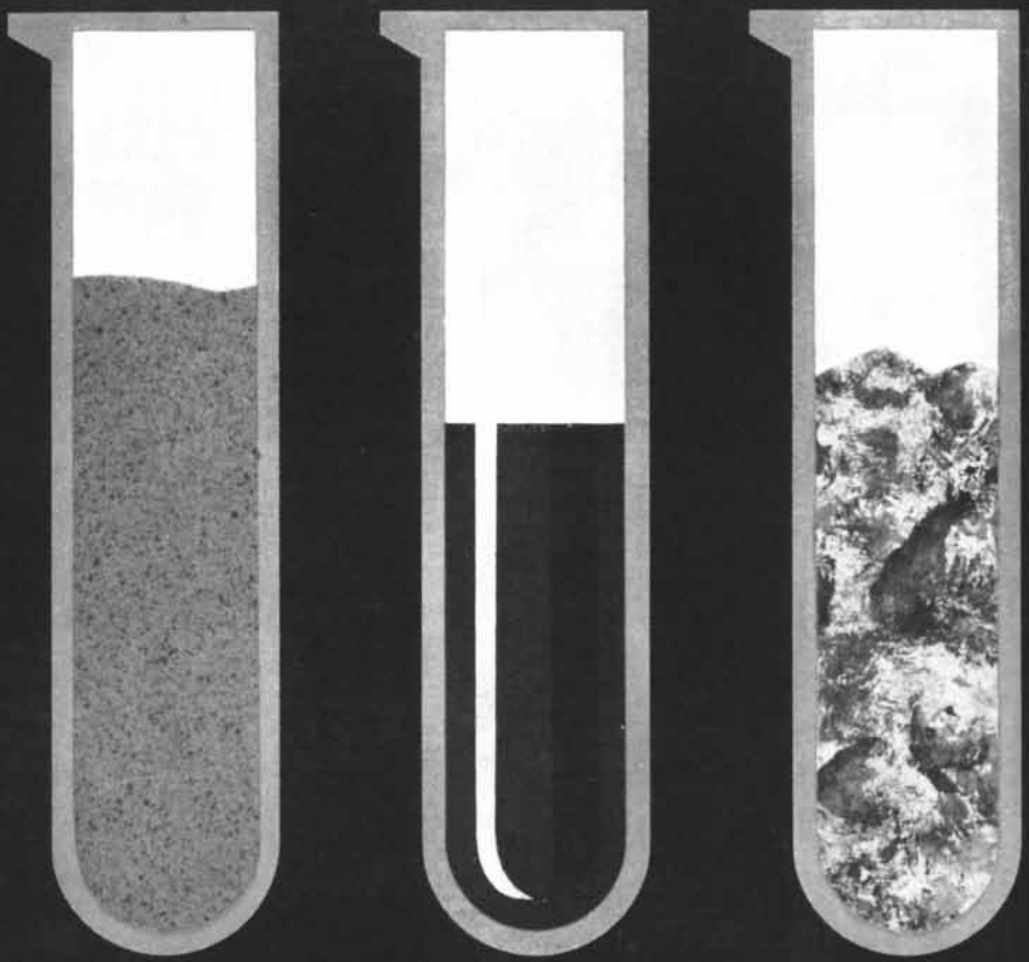

EVEN THE SOIL IS REPRODUCED TO SCALE

Scale modeling—an exacting laboratory science—is helping Caterpillar to strikingly telescope research time and costs. And it has taught us much that no one ever knew before about what happens when an earthmoving machine meets soil.

Our Soil Mechanics Laboratory spent years developing the miniature instrumentation, models and techniques needed to reproduce field conditions exactly—and without the usual uncontrollable field variables. Even soil is recreated to scale. Using measured amounts of mixed sand, fire clay and oil in specially built soil bins, Caterpillar research men can reproduce a wide variety of types and consistencies of soil for their model testing. To simulate other soil conditions, they've employed several unusual materials. Toothpicks, for example, have yielded information on soil failure (breakage from digging tools) that field studies never revealed.

The results have been beyond expectations. Models of new designs (as small as 1/15 scale) now move quickly through test programs that would ordinarily take months in full-scale testing. New information has already led to important new vehicle changes. And, equally important, these laboratory techniques have produced new knowledge—knowledge not obtainable by other techniques—to give us better answers, faster, to future questions.

Unique research capabilities are only part of Caterpillar's capacity to serve the defense program. Caterpillar also seeks contracts or subcontracts for manufacture of machines, components or parts. For more information, contact Defense Products Department, Caterpillar Tractor Co., Peoria, Illinois.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1913: "Spurred on by the accomplishments of Pégoud, a number of prominent flyers in France, England and America have lately been imitating this daring Frenchman. On the 15th ult., at Versailles, Hanouille flew upside down for 20 seconds and 'looped the loop' twice in quick succession. The English aviator Hucks surpassed him in his Blériot by remaining inverted 35 seconds and making four consecutive loops. On November 18th Chevillard, with his Farman biplane, 'looped the loop' twice with a passenger, and subsequently he turned over sideways while flying along in a straight line, thereby performing a sort of cork-screw twist. On the 21st ult. Chanteloup did three vertical circles in a high wind and, dropping from a height of 2,000 feet like a plummet, he righted his machine within 70 feet of the ground. H. Lee Temple flew upside down at Hendon, England, for a short distance on November 24th, and two days later Hucks made six circles in a vertical plane while descending from a height of 2,000 feet. Lincoln Beachy, at San Diego, Calif., 'looped the loop' twice on the 25th ult., starting from a height of 2,500 feet, and on Thanksgiving Day he made three such circles while descending from a slightly greater elevation. Pégoud has made as many as 10 loops in a single descent and has flown inverted for more than 1¾ minutes. He has done great good by showing the flying fraternity that all is not lost when the machine capsizes in mid-air."

"The daily press recently reported that William Marconi had succeeded in sending wireless telephone messages across the Atlantic. However, Mr. Marconi has denied the report but admits that important experiments are now being carried on and expects that before long such a feat will be accomplished. Up to the present he has not succeeded in telephoning by wireless more than 200 or 300 miles."

"All that is left of the historic Wright biplane with which Calbraith P. Rodgers flew from the Atlantic to the Pacific two years ago is to be presented to the Carnegie Museum at Pittsburgh by the late aviator's mother. The machine was badly damaged when Rodgers fell to his death in the Pacific Ocean a short time after completing his wonderful flight. Subsequently it was used by Andrew Drew until that aviator also was killed with it. The machine has been restored to its original condition and will no doubt be prized by the museum to which it has been presented."

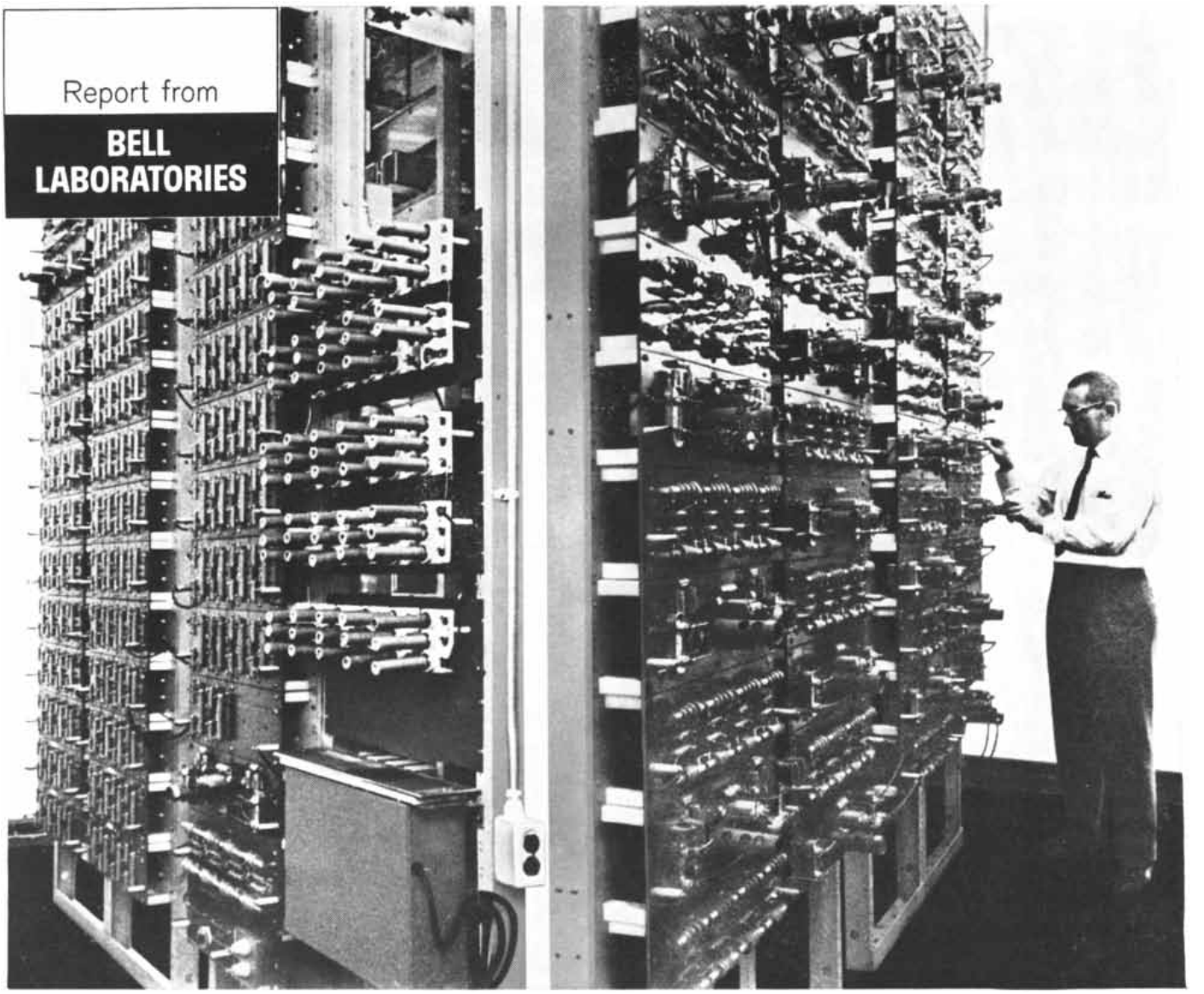
Scientific American.

DECEMBER, 1863: "Chloride of nitrogen will, it is said, soon be utilized as an implement of war. Its employment would seem likely to put an end to all war. Mr. Isham Baggs, an English chemist, in announcing his discovery proposes to carry up his composition in balloons and drop it from the air in the midst of armies and fortresses. 'The very mention of this compound,' he goes on to say, 'as a proposed element in modern warfare may possibly provoke a smile among chemists, who know that the most accomplished among their number would scarcely dare to experiment with it in quantities larger than a grain of mustard seed, and even then at a respectful distance and under guard at the moment of its detonation. And yet not one of those chemists will be bold enough to deny that with two or three chemically clean carboys of this terrible compound present in a city or fortress, however strong, the slightest cuttings of phosphorus or a single drop of olive oil coming in contact with it would in one instant decide the fate of the place and its inhabitants.' Mr. Baggs then proceeds to affirm that he has discovered a method of overcoming the contingent difficulties, and that he is able to manufacture this deadly material with perfect safety, and in any required quantity, and that it can be safely conveyed to its destination."

"Blockade runners are rapidly coming to grief, if we can believe the correspondence which has been intercepted of late between the rebel agents in England and traders there who have been conniving at and concerned in breaches of international law by running cargoes into Southern ports. These virtuous 'neutral' shippers want heavy securities from Southern agents before they will

Report from

BELL LABORATORIES



Engineer A. H. Evans measures the effect of voltage surges on Bell Laboratories' simulated undersea telephone cable. Simulating 180 amplifiers and 181 cable sections, with a total length of 3600 miles, the arrangement includes over 1100 electrical components. Photo merges two sides of the simulated cable so that both can be viewed at once.

THE UNDERSEA "CABLE" THAT NEVER GOES TO SEA

In undersea cable systems, electric power for the amplifiers is transmitted along the cable itself. To make this possible, precisely engineered circuits and devices must be designed into the system for protecting electron tubes and other components from sudden voltage surges which may result from accidental damage to the cable.

In systems such as these, the computation of the effects of such surges to establish the needed design parameters is extremely complex. Here, as in many other areas of our work, a solution to the problem has been found through electrical simulation.

Full-scale simulation is achieved by means of networks of electrical components. For the new 128-channel cable scheduled for transatlantic service this year, a network (above) was built to simulate the power path of a 3600-mile cable with its 180 amplifiers.

With the aid of this simulator, engineers can study the effects of voltage surges, the operation of electron tube protectors, and the performance of the power supply in the various contingencies that may occur in active service.

This study of unknown factors by means of electrical simulation is an example of how engineers at Bell Laboratories work to assure the performance and reliability of new communications systems before they are committed to service.

Bell Telephone Laboratories

World center of communications research and development

venture to run rich cargoes into blockaded ports, and it is a gratifying fact to every loyal heart that many of these traders have been financially ruined. If piratical *Alabama*'s and *Florida*'s have succeeded in destroying the commerce of loyal citizens, it is agreeable to know that thousands of tuns of shipping have been captured by our vigilant blockaders and gratifying to find that those who most vehemently denounced the blockade as a paper one have suffered most in testing its strength."

"Some months ago M. Scott, well known among the savants of Paris, exhibited experiments of a very interesting character in the art of fixing sounds. The same species of natural means so successfully employed in photography with reference to form, namely the aerial undulations of which sounds consist, are, by the construction of the 'phonograph,' made ingeniously to subserve the intricate purpose in view. The representation of the various curves and vibrations performed by an instrument of highly susceptible mobility, while acted upon by these atmospheric movements, has been perfectly accomplished. Although a serious difficulty seems to obstruct a retranslation of this somewhat indefinite language into the regular and fixed signs for the verbal signs which produced it, M. Scott is sufficiently sanguine about the result to give cause for alarm in the minds of shorthand writers, whose occupation would be more detrimentally affected by this wonderful apparatus for reporting than even artists have been by the sister invention of photography."

"M. Jules Seguin has brought before the Parisian public a project for aerial locomotion between the Place de la Concorde and the Porte de la Muette, on Moreaud's system. According to this arrangement the balloon will be held captive by means of a steel wire cable, running over vertical pulleys at the point of departure and arrival. These so-called pulleys are really large cylinders, or drums, on which the rope is wound backward and forward by means of a steam engine. To the cable, which performs the functions of a locomotive, is fixed a line, which conducts the balloon; this is the general idea of a system on which M. Moreaud has experimented with great success, employing small balloons. M. Seguin proposes to carry 250 persons at each trip, from the Place de la Concorde to the Bois de Boulogne, or about 600,000 persons per year."

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The result is a hydrogen-oxygen fuel cell system that is much lighter than any other known system. Pictured on the right is the 1-kw unit weighing just 50 pounds and measuring 20″ x 10″ in diameter. And, as the repeated demonstrations have proved, it is operational *right now!*

A further indication of confidence is the fact that the *Air Force Aeronautical Systems Division* has selected Allis-Chalmers to build a 50 watt hydrogen-oxygen system for the first orbital fuel cell flight. This system has successfully passed shock, vibration, acceleration, zero gravity and full power testing.

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1. We are studying mobile energy depot systems for the *AEC* and the *Army. Significance: These systems would use nuclear reactors to generate fuel. Fuel cells would power the vehicles, alleviating logistical problems of supplying fuel to a modern army on the move.*

2. Under development now — a fuel cell and the integration of a 5-kw hydrocarbon-reforming fuel cell system for the *Army's Engineer Research and Development Laboratories. Significance: This system will "crack" inexpensive hydrocarbon fuels to obtain hydrogen for the first major air-breathing fuel cell.*

3. Our 7-kw hydrazine-oxygen fuel cell powers an experimental, 2000 lb fork lift truck. Our 3-kw hydrazine-oxygen fuel cell powers an experimental golf cart. *Significance: Multiple kw fuel cell systems have been applied to vehicles like the experimental golf cart that have been demonstrated to thousands of people from coast to coast.*

4. We've announced discovery of nickel boride as the material to replace platinum for the anode catalyst. *Significance: This is the first inexpensive and efficient anode catalyst for fuel cells using hydrogen-oxygen or hydrazine-oxygen.*

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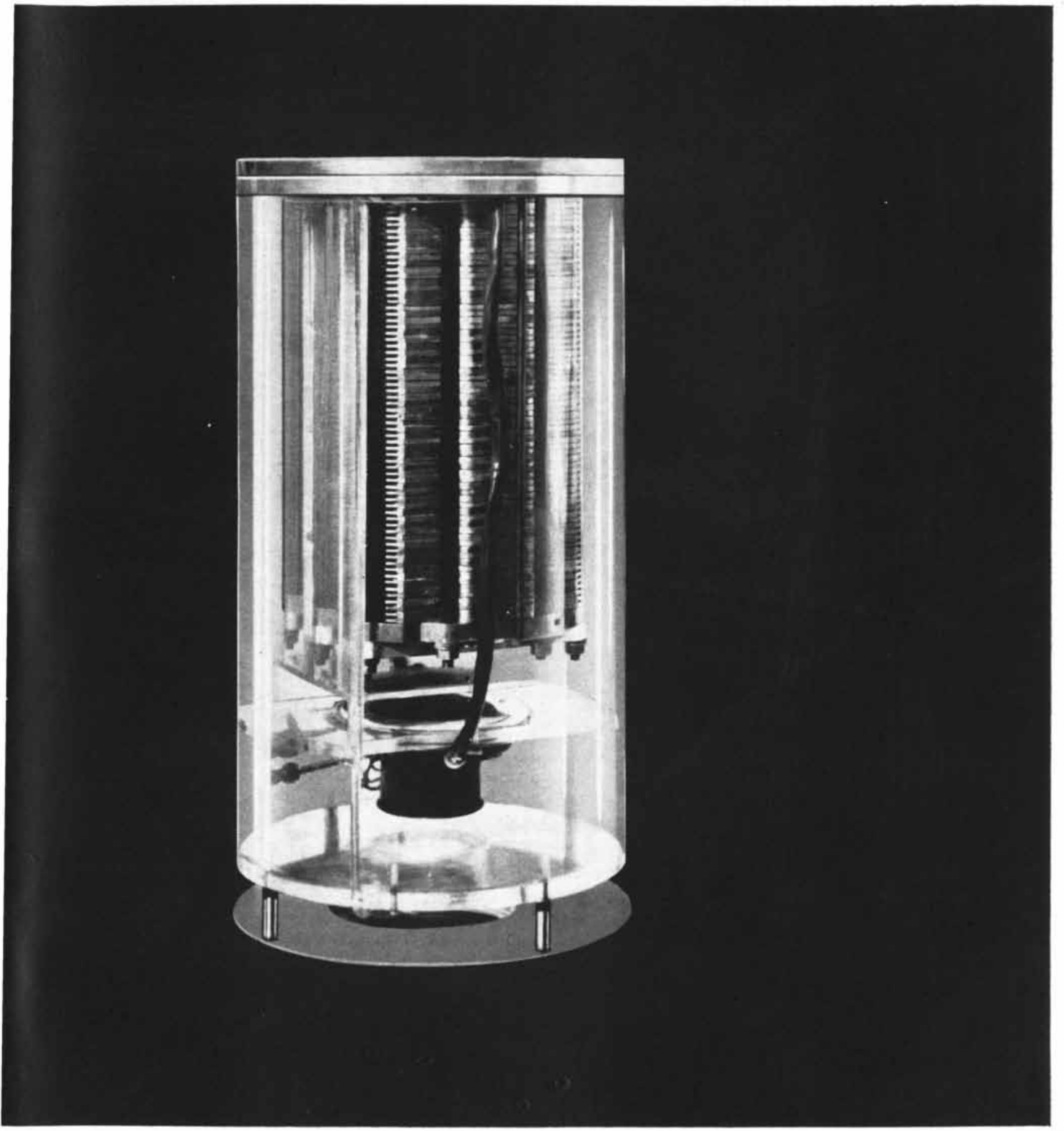

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Since the combination of Ling-Temco Electronics, Inc., and Chance Vought Corp. two years ago, LTV has become widely accepted as a leader in space, electronics and defense. The LTV name will identify the company's divisions as integral parts of this front-running team. Ling-Temco-Vought, Inc., Dallas, Texas.

*Kentron Hawaii, Ltd., and the Friedrich companies retain their identities as LTV subsidiaries.

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Biophysicists and biochemists

have been trying for years to pinpoint the precise role that the free radical plays in the processes of metabolism.

Thirty years ago, Leonor Michaelis hypothesized: "It will...be shown that all oxidations of organic molecules in biological systems, although they are bivalent, proceed in two successive univalent stages, *the intermediate being a free radical.*"

Like many other brilliant hypotheses, Michaelis' conclusions could not be verified at that time with existing equipment. Highly sensitive EPR spectrometer systems developed by Varian scientists provided the means for showing that Michaelis was, indeed, correct. The unique feature of EPR spectroscopy is, of course, that it responds only when free radicals are present. Quite recently, biochemists have been using EPR spectroscopy to study free radicals in biological systems. A growing reservoir of information is being formed.

One very promising application of this technique has been to study the mechanism of action of certain psychotropic drugs, the type used in treating mental illness. EPR shows that free radical intermediates are formed in the oxidation of these important drugs. It is possible that continued EPR study will delineate the exact role these intermediates play in the clinical activity of the drug.

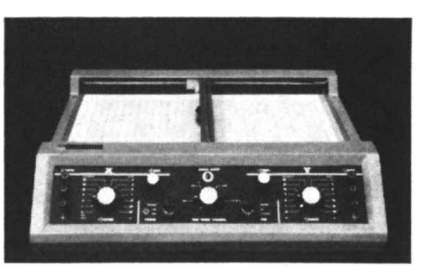
This study of psychotropic drugs is but one application of EPR techniques to the field of biochemistry. Other areas of research in biology, physics, and chemistry have applied this powerful analytical technique with equally dramatic results. We are interested in discussing with you the ways EPR spectroscopy might assist your present research. Please address your letter to Dr. William Landgraf, EPR Applications Laboratory, Analytical Instrument Division.

The scientific method entails observation, analysis, hypothesis and experimental verification.

Yet without permanent records permitting quantitative comparison, experiments may be merely qualitative transients. As an invaluable extension of the scientific hand and eye, Varian's new X-Y potentiometer recorder shown below combines a set of capabilities and specifications never before assembled in a single instrument.

Would you like to see for yourself what we mean? Your local Varian representative will be happy to show you our X-Y recorder. He'll demonstrate the unique full-platen vacuum hold-down that grips full-size 11" x 17" charts or 2" x 2" scraps without masking; seven time-base settings—50 sec/in to 0.5 sec/in; adjustable margins; manual or automatic cycling; an *instantly* removable, magnetically-held pen; rack or bench-top mounting; appearance and operating convenience that speak for themselves, with quality instrument specifications which invite comparison.

Get in touch with Tom McKerlie, Field Sales Manager, Recorder Division, for the whole story, or check EEM or EBG for your local source.



Oceanography is the chemistry and physics of the sea. It matches in scientific intensity of purpose, if not in public glamor or funding, the quest for complementary data from space.

Magnetism, along with such natural phenomena as gravity, depth, current, temperature, salinity, turbidity and others, is a basic variable sensed. And proton free precession magnetometers have become the oceanographer's accepted standard since Russell Varian's discovery of the principle.

The invariant natural relationship between ambient magnetic field and proton precession (23.4874 gammas per cycle) is harnessed in these systems to give rapid, absolute field data to ±1 gamma from a simple, rugged transducer virtually insensitive to orientation. Designed for 750-foot cables to reduce the anomaly created by the towing ship, some systems have been modified in the field under emergency circumstances to deliver original one gamma sensitivities through *four miles of cable.* This feat gains stature when you consider that the decaying proton precession signal (see oscilloscope trace) is at microvolt levels in the transducer—no pre-amplification is used except in the on-board console itself!

Varian proton magnetometers are mapping spatial variations of the earth's field in oceanographic vessels all over the world. The new higher-sensitivity, optically pumped magnetometers are opening research into magnetic-field time variations at sea. To learn more about either technique, for oceanography or other geophysical applications, write Lee Langan, Instrument Special Products.

THE AUTHORS

ROBERT HERMAN and KEITH GARDELS ("Vehicular Traffic Flow") are respectively head of the theoretical physics department and senior science writer in the technical information department of the General Motors Research Laboratories. Herman was graduated from the City College of the City of New York in 1935 and received an M.A. and a Ph.D. in physics from Princeton University in 1940. After successive one-year terms as a research associate at the University of Pennsylvania's Moore School of Electrical Engineering and as a physics instructor at C.C.N.Y., he joined the Applied Physics Laboratory of Johns Hopkins University in 1942. Except for a two-semester leave of absence as visiting professor of physics at the University of Maryland, he worked at the Applied Physics Laboratory from 1942 until 1956, when he joined General Motors as a consulting physicist. Gardels received a B.S. in physics from Colorado State University in 1954 and has been with General Motors since then.

ALEXANDER RICH ("Polyribosomes") is professor of biophysics at the Massachusetts Institute of Technology. A graduate of Harvard College, Rich obtained an M.D. from the Harvard Medical School in 1949. He did research in chemistry at the California Institute of Technology from 1949 to 1954, when he became chief of the section on physical chemistry at the National Institutes of Health in Bethesda, Md. Rich was visiting scientist at the Cavendish Laboratory in Cambridge, England, during 1955. He joined the M.I.T. faculty in 1958.

JESSE L. GREENSTEIN ("Quasi-stellar Radio Sources") is professor and head of the department of astronomy at the Mount Wilson and Palomar Observatories of the California Institute of Technology. After acquiring a Ph.D. in astronomy from Harvard University in 1937, Greenstein joined the staff of the University of Chicago's Yerkes Observatory. He left Yerkes in 1947 to spend a year at the McDonald Observatory of the University of Texas before taking up his present posts in 1949.

LEONARD V. GALLAGHER and BRUCE S. OLD ("The Continuous Casting of Steel") work for Arthur D. Little, Inc. Gallagher received a B.S. in chemical engineering from the Massachusetts Institute of Technology in 1954. Since joining the metallurgical engineering section of Arthur D. Little in 1956 he has worked on a number of projects involving the chemical and physical processing of ores and nonmetallic minerals to finished products. Old, who is senior vice-president of Arthur D. Little, received a B.S. in chemical engineering from the University of North Carolina in 1935 and an Sc.D. in metallurgy from M.I.T. in 1938. He is a past president of the Cambridge Corporation and also of Nuclear Metals, Inc., both former subsidiaries of Arthur D. Little.

P. F. SCHOLANDER ("The Master Switch of Life") is professor of physiology and director of the newly established Physiological Research Laboratory at the Scripps Institution of Oceanography. Scholander was born in Örebro, Sweden, in 1905 and received an M.D. from the University of Oslo in 1932. After two years as instructor in anatomy at Oslo he acquired a Ph.D. in botany there in 1934. He did research in botany and physiology in Norway until 1939, when he came to this country to join the department of zoology at Swarthmore College. During World War II Scholander served as an aviation physiologist in the U.S. Army Air Force, returning to Swarthmore in 1946 to continue his studies on the comparative physiology of diving. He investigated climatic adaptations of arctic and tropical animals and plants at the Arctic Research Laboratory in Point Barrow, Alaska, and in Panama from 1947 until 1949, when he became a research fellow in the department of biological chemistry at the Harvard Medical School. In 1952 he joined the staff of the Woods Hole Oceanographic Institution, and in 1955 he was appointed professor of physiology and director of the Institute of Zoophysiology at the University of Oslo. He joined the Scripps Institution in 1958.

RAYMOND V. SCHODER, S.J. ("Ancient Cumae") is professor of classical literature and archaeology at Loyola University in Chicago. Born in Battle Creek, Mich., in 1916, Schoder joined the Jesuit order in 1933 and studied at the Milford, Ohio, branch of Xavier University and at West Baden College in Indiana. He acquired an A.B. and an M.A. in classical languages from Loyola in 1938 and 1940 respectively and a Ph.D. in Greek, Latin and linguistics from St. Louis University in 1944. Before joining the Loyola faculty in 1960 Schoder taught at West Baden College and the University of De-

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troit. He was Fulbright Professor of Greek Art and Archaeology at the University of Nijmegen in the Netherlands during the academic year 1956–1957 and visiting professor at the American School of Classical Studies in Athens during 1961–1962. Since 1953 he has been director of the Vergilian Society's summer school at Cumae for American teachers of classical literature and history.

KENNETH W. FORD ("Magnetic Monopoles") is professor and chairman of the department of physics at Brandeis University. He was graduated from Harvard College in 1948 and worked for a year at the Los Alamos Scientific Laboratories before going on for his Ph.D. in physics, which he received from Princeton University in 1953. He taught physics at Indiana University from 1953 until 1957, when he returned for another year at Los Alamos. He joined the Brandeis faculty in 1958. During the academic year 1955–1956 Ford was a Fulbright Fellow at the Max Planck Institute in Göttingen. During 1961–1962 he did research at the Imperial College of Science and Technology in London and also at the Massachusetts Institute of Technology.

C. G. JOHNSON ("The Aerial Migration of Insects") is head of the entomology department at the Rothamsted Experimental Station in Harpenden, England. He was born in Southampton in 1906 and received a B.Sc. in botany from the University College of Southampton (now Southampton University) in 1930. For the next five years he was demonstrator in the botany department at Southampton. From 1935 to 1940 he studied the ecology of the bedbug *Cimex lectularius* at the London School of Hygiene and Tropical Medicine, obtaining a Ph.D. there in 1937. During World War II Johnson served as a major in the Royal Army Medical Corps, working on antimalaria measures, notably mosquito repellents and larvicides, for use in West Africa and Italy. He received a D.Sc. from the London School in 1943 for his work on the epidemiology of scabies in England. Since joining the staff of the Rothamsted Experimental Station in 1945 Johnson has been working on the aerial dispersal of insects and on the ecology of aphids in particular. From 1955 to 1959 he took time off from these studies to serve as deputy director and head of the entomology department at the West African Cocoa Research Institute in Ghana. He took up his present post in 1961.

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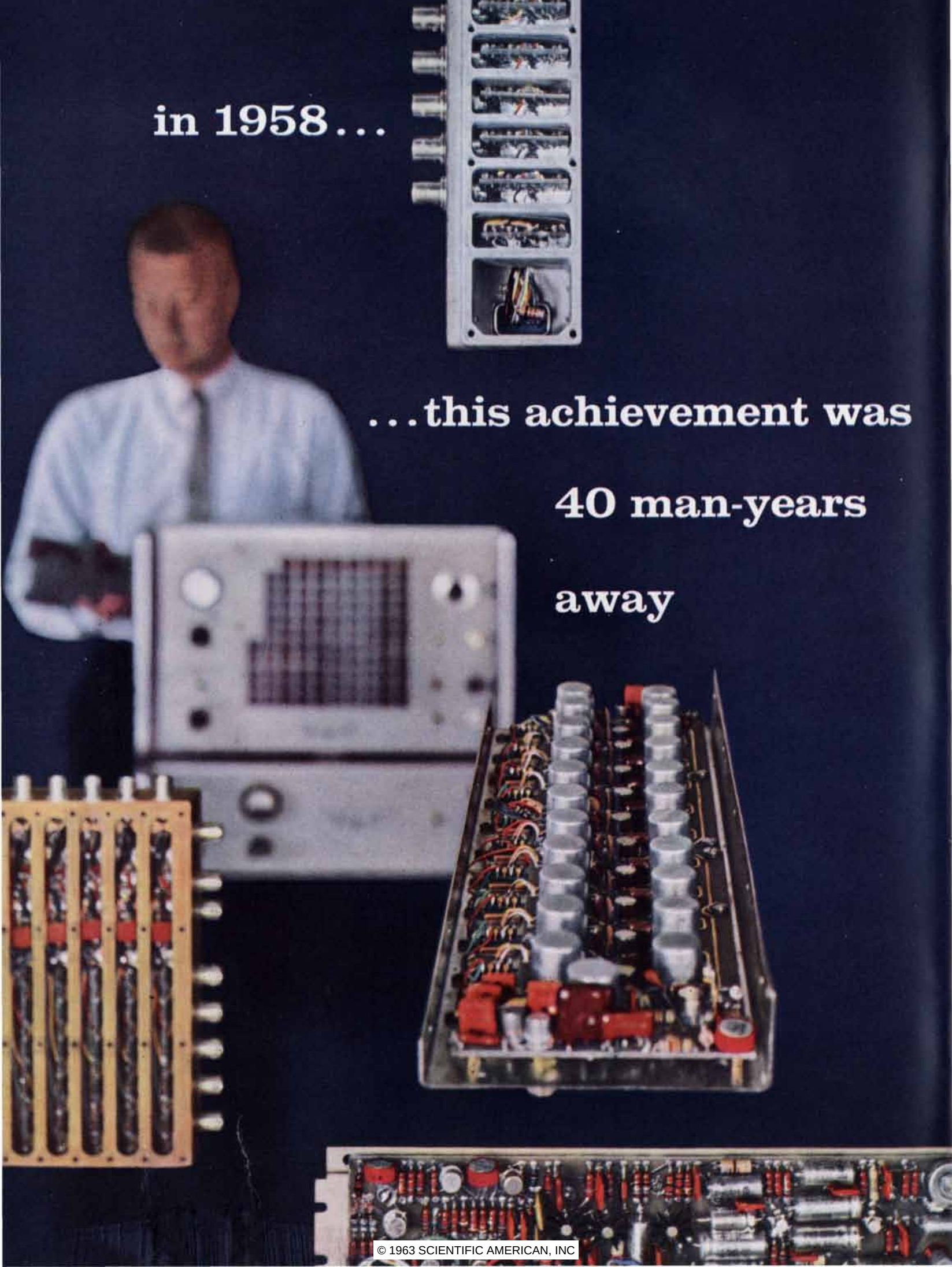

PROGRESS

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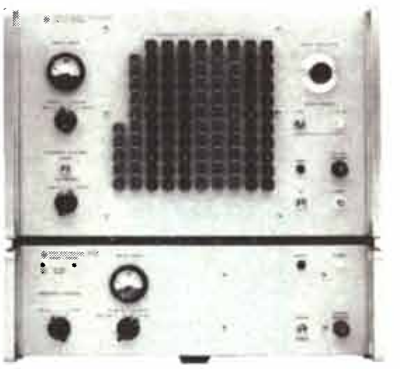

The 5100A Synthesizer (top) is driven by the hp 5110A fixed frequency unit (bottom), which provides a stability of 3 parts in 10^9 per day. The 5100A delivers signals from 0.01 cps to 50 mc in increments as small as 0.01 cps. Any discrete frequency may be selected conveniently by front-panel pushbutton, or remotely in less than 1 millisecond. Non-harmonic spurious signals are 90 db down. hp 5100A, $10,500; hp 5110A $5000.

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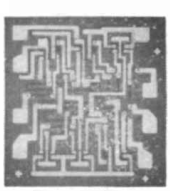

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Vehicular Traffic Flow

The interaction of driver-car units on roads is now being studied by physical and mathematical methods. The results have already been used in the solution of traffic problems

by Robert Herman and Keith Gardels

Science traditionally advances by the interaction of observation, theory and experiment, and the success of the scientific method has often recommended its application to problems of daily life. One such problem is the flow of automobile traffic. This problem has not lacked practical students: traffic engineers have obviously made important contributions to its solution. In recent years, however, it has become apparent that the flow of traffic lends itself to a more general kind of physical and mathematical analysis. The objective of this theoretical approach is to offer some insights that will give the practitioner something more than rules of thumb and graphs of vehicular flow for improving traffic systems.

Traffic theory, tested by experiment, has recently brought about a significant improvement in the large daily flow of vehicles between the state of New Jersey and the island of Manhattan. The achievement must be regarded as limited: virtually all the flow is carried by three arteries—the Holland Tunnel, the Lincoln Tunnel and the George Washington Bridge—and vehicles channeled through any such structure are conspicuously subject to analysis and control. Nonetheless, there is reason to believe that traffic theory can be applied successfully to more commonplace situations. It may be of fundamental value in helping to define the forces that act on a driver and to understand his responses to them. It may help to alleviate some of the problems that arise on crowded city streets and on multilane highways.

We wish to emphasize, however, that traffic theory in its present state of development has come about as far as astronomy had before Kepler. Much remains to be done, not only in acquiring and analyzing data but also in persuading theoreticians to correlate their thinking with reality and traffic engineers to accept the contributions that theory can make to their problems.

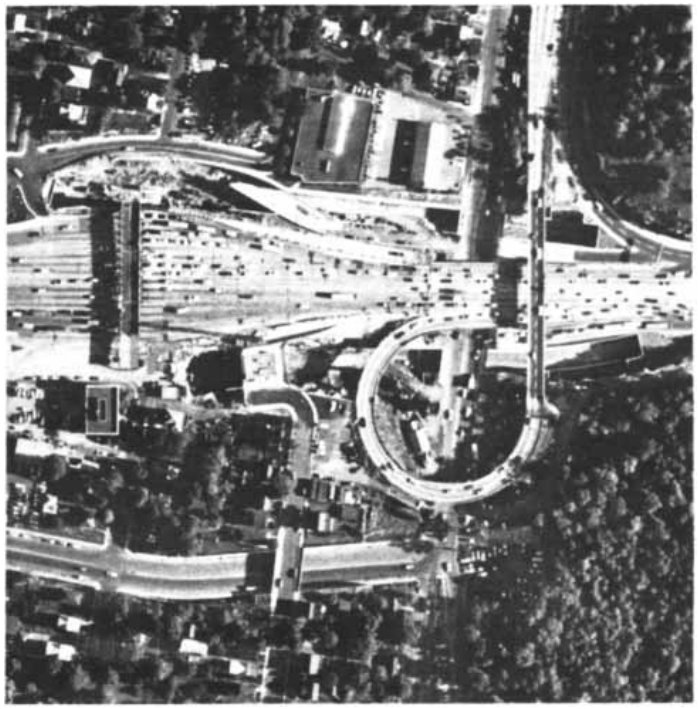
A theoretician is likely to take one of two conceptual approaches to traffic flow. One concept views the vehicular stream as either a compressible fluid (a single automobile is regarded as part of the fluid and is not considered individually) or the collection of molecules in a gas (the individual cars are regarded as discrete but are treated in a purely statistical manner). The second concept focuses primarily on describing traffic flow on the basis of the behavior of the individual driver-car unit.

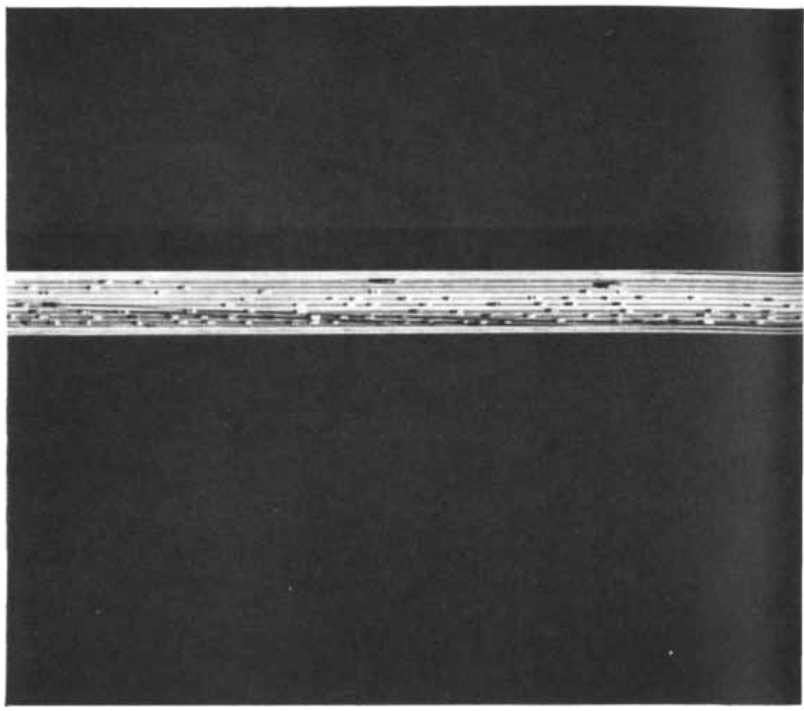
The first approach, with its macroscopic over-all viewpoint, has some appealing features. A traffic stream on a single-lane, no-passing stretch of road does indeed approximate a fluid whose rate of flow depends primarily on its density. Up to a point the rate of flow increases as the concentration of vehicles rises; thereafter the rate of flow decreases if the density continues to increase. Similarly, the analogy of traffic flow to the motion of molecules in a gas—an analogy in which automobiles are assumed to be isolated most of the time and interacting with each other only at intervals—has some application in reality.

One might well ask, however, if the resemblance of traffic to a fluid or molecules in a gas is only superficial. There seems to be little justification for assuming that the actual behavior of traffic is controlled by the same forces associated with liquid or molecular dynamics. Drivers, unlike molecules, make individual decisions.

The appropriateness of the first approach can be better judged by looking at the second concept dealing with the fundamental unit of traffic: the driver and his car. The behavior of the driver-vehicle unit has been extensively studied by a group of theoreticians and has developed into what we have called follow-the-leader theory. Among those who have worked most intensively on this approach are Elliott W. Montroll of the Institute for Defense Analysis, Renfrey B. Potts of the University of Adelaide, Denos C. Gazis of the International Business Machines Corporation and Richard W. Rothery and one of us (Herman) at the General Motors Research Laboratories.

We base follow-the-leader theory on an observable phenomenon that occurs whenever a driver draws fairly close to the vehicle ahead of him. The phenomenon is that within a region of about 200 feet he begins to interact with the leading driver. The distance is somewhat less





DENSE AND COMPLEX TRAFFIC FLOW characteristic of metropolitan areas appears in these aerial photographs by the Port of New York Authority showing the approaches to the George Washington Bridge and portions of the span at a peak period on a week-

if the follower has plenty of room to pass; on the Edsel Ford Expressway in Detroit, where there are three lanes each way with passing allowed, the region of interaction is about 175 feet. The distance is somewhat greater in a no-passing situation, such as that presented by the Holland Tunnel; there vehicles begin to interact within about 250 feet.

Follow-the-leader theory attempts to describe the behavior of a single lane of fairly dense traffic in terms of the detailed manner in which vehicles follow one another in the traffic stream. This condition of one-lane traffic with no passing is more common than the motorist accustomed to multilane turnpikes might think. No-passing situations still exist, in law or in actuality, on many stretches of two-way roads and streets, in tunnels and on bridges. Even on multilane highways dense traffic often forces a driver to stay in one lane.

The basic idea expressed in follow-the-leader theory is that a motorist driving along a highway behind another vehicle attempts to follow that vehicle in a stable manner. Therefore we assume that the motion of his car obeys what we might call a car-following law, which can be formally described by some mathematical relation.

Such an expression must take account of the fact that the behavior of the following driver-car unit is a result of some psychological phenomenon. With that in mind we have reduced the description of the behavior of the driver-car unit to an equation that says the driver's response, after a time lag, is a product of the measurable environmental stimuli and a factor we call the driver's sensitivity coefficient. Put another way, the equation says: A driver faced with a situation (the stimulus) does something about it (the response). How much he does represents his sensitivity coefficient. How quickly he does it determines the response lag of the man-machine system.

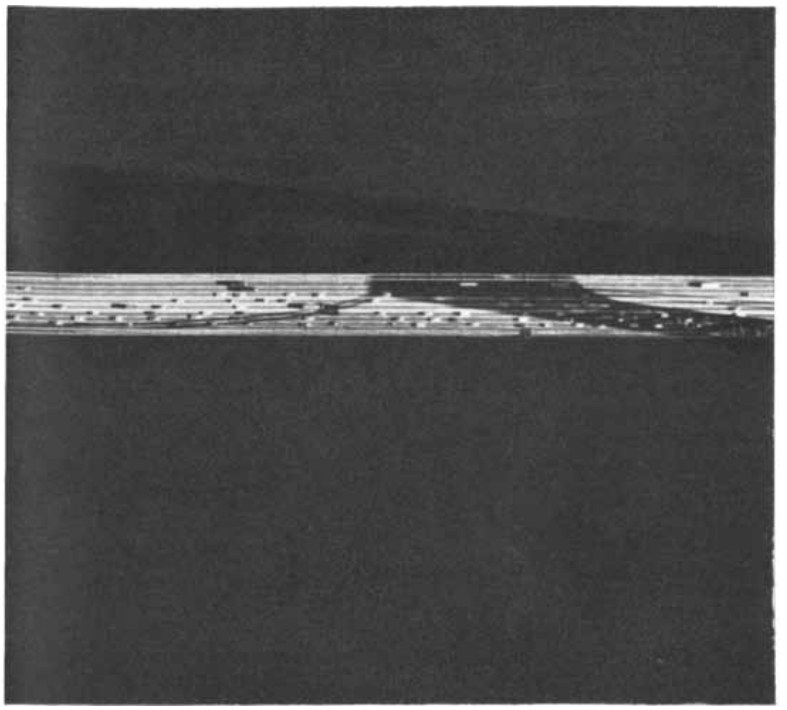
Necessarily such a car-following law is a grossly simplified description of a very complicated response to the world of stimuli that confronts a driver. The phenomenological approach taken in this theory lumps together a large number of mechanical and human characteristics that can be handled individually only with great difficulty. A complete stimulus-response description would have to distinguish, for instance, between a teenage driver with his arm around his female companion and a husband with his wife commenting from a somewhat greater distance. Nevertheless, we have been able to determine through a number of controlled experiments that the law represents a reasonable approximation of reality.

One might expect that if we were to attempt to supply the exact form of our equation, we would have to build a complicated mathematical structure in order to express something like the real traffic situation. Actually we have found through experiment that the ingredients of the equation—the response, the stimulus and the sensitivity coefficient—can be set out in relatively simple form. We shall discuss these ingredients one by one and at the same time describe the experiments by which we arrived at them.

The response is determined by a driver through his accelerator and brake. They provide his only practical means of responding to changing stimuli in a one-lane, no-passing situation. The equation describes the response as the acceleration or deceleration of the trailing car after a time lag. Acceleration, deceleration and time lag are easily and directly measurable quantities. The total time lag of both driver and vehicle is derived through a mathematical comparison of the response with the stimulus under study.

The main stimulus to which a driver responds might logically be expected to be the distance between him and the car ahead. Our experiments showed, however, that the dominant stimulus is instead the relative speed of the two cars. In other words, a following driver attempts to keep at a minimum the difference in speed between his car and the leading car.

We found this rather surprising stimulus-response behavior in follow-the-lead-



day morning. Almost all traffic between New Jersey (*left*) and Manhattan (*right*) is carried by this bridge or by the Holland or Lincoln tunnels. In heavy traffic all of the patterns are similar, but at the bridge it is possible to observe the entire flow at one time.

er experiments conducted on a test track at the General Motors Technical Center in Warren, Mich. We connected two cars with fine piano wire so mounted that a slipping friction clutch would keep it taut no matter what the two cars were doing [*see top illustration on next page*]. Mounted with the clutch were instruments that recorded such information as car spacing, speed and acceleration; originally that information was registered on an oscillograph but now it is recorded on magnetic tape and processed by means of an electronic computer. After the equipment was in place we said to several drivers in succession: "Follow the lead car in what you consider to be a safe manner." The various drivers of the lead car randomly varied their speeds from 10 to 80 miles per hour and included some drastic braking actions. Invariably in these tests it was clear that the governing stimulus for the following driver was relative speed rather than distance.

Between two interacting cars the distance will therefore vary, sometimes because of the nature of car-following behavior, which is accentuated by the time lag in the response of the follower, and sometimes because the follower decides that his speed should be somewhat greater or less than the leader's for some reason. Our laboratory has tried experiments in which the follower was asked to keep a constant distance, aided by spacing information on a dial in his car. It was found that in order to keep the pointer steady at, say, 100 feet as the speed of the leading car varied he had to accelerate and brake with distinct unevenness.

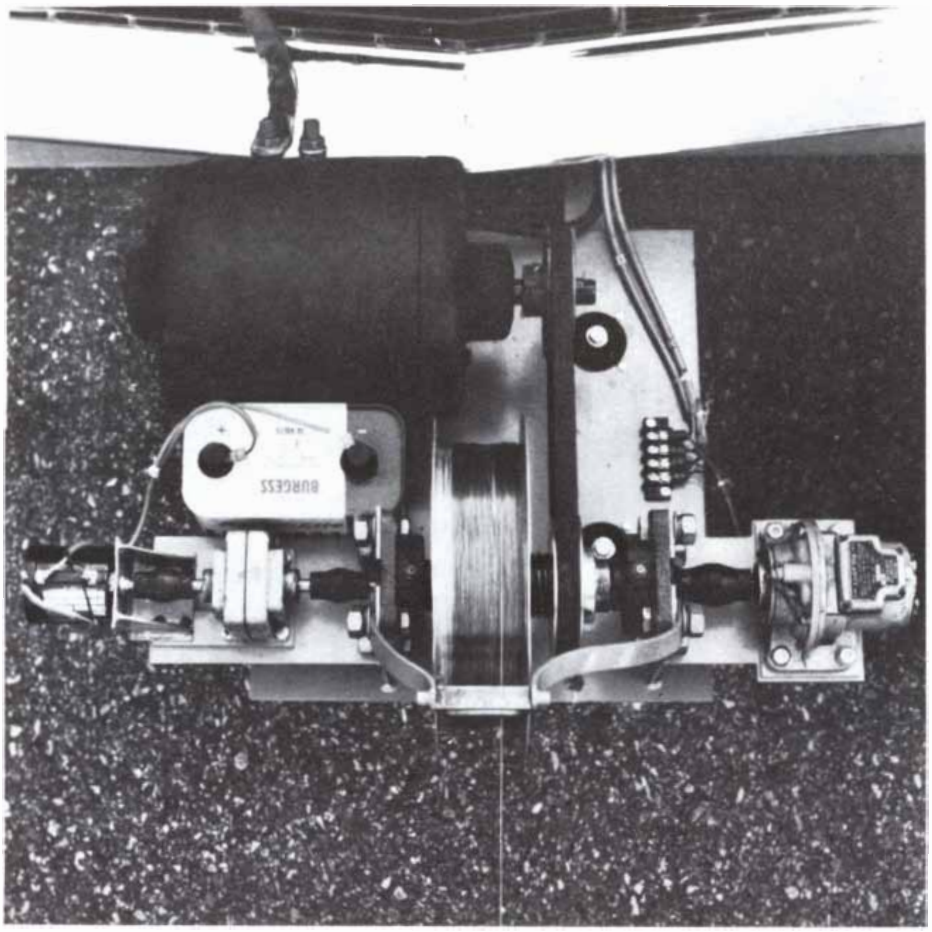
The final factor in the equation, the sensitivity coefficient, we took at first, for mathematical convenience, to be a constant. Our initial experiments indicated that the resulting values for this coefficient did give an equation that approximated reality. Later, however, we conducted experiments under real traffic conditions and the controlled conditions of the test track to see if the sensitivity varied with changes in the spacing or speed of the vehicles. These experiments indicated that the driver's intensity of response per unit stimulus—his sensitivity coefficient—varied inversely with the spacing. As the distance between cars decreased, the sensitivity of the following driver's reaction seemed to increase.

In sum, the follow-the-leader equation works out to show that a driver tries to keep the relative speed between him and the vehicle in front as small as possible, and that the closer he is, the more attention he pays to the problem [*see illustration on page 39*]. If he is far away, he drives in a manner that is more or less independent of what the driver in front is doing.

Armed with these findings about the interaction of two drivers, we turned our attention to the question of the interactions of several drivers. Our idea was that insights about such interactions, which occur in a stream of vehicles, would provide a basis for understanding traffic flow and perhaps for improving it.

Theoretically a condition of maximum flow would exist if all the cars in a stream proceeded bumper to bumper at the highest speed allowed by the nature of the road. What actually happens is of course different because of driver interactions. The manner in which drivers interact in a stream leads to a flow-concentration relation that can be expressed mathematically and might be called an "equation of state" for traffic. The equation reflects the fact that between the extremes of zero flow because there are no cars in a lane and zero flow because of a traffic jam there is a maximum flow. That steady-state flow is the product of the concentration and average speed of the traffic. We call the average speed of a traffic stream at maximum flow the characteristic speed. It has a value reflecting the total traffic situation: driver, vehicle and road characteristics as well as the impact of traffic ordinances, weather and the time of day or week.

On the basis of these calculations we undertook some studies of actual traffic situations in three tunnels in the New York City area—the Holland, the Lincoln and the Queens Midtown—all char-



CAR-FOLLOWING EXPERIMENTS, designed to demonstrate how one driver follows another, used this equipment mounted on front of following car. A clutch kept taut the piano wire connecting the two cars; instruments recorded such data as spacing and relative speed.

ACCELERATION AT (t+T) | SENSITIVITY COEFFICIENT | RELATIVE SPEED AT TIME t

$$\frac{d^2x_{n+1}(t+T)}{dt^2} = \frac{G}{s(t)}\left[\frac{dx_n(t)}{dt} - \frac{dx_{n+1}(t)}{dt}\right]$$

FOLLOW-THE-LEADER THEORY is expressed as an equation. It describes the manner in which one driver follows another in a stream of traffic. Symbol x is distance; t, time; T, a time lag; G, the following driver's gain constant; $s(t)$, spacing of the two vehicles at time t; n, the nth vehicle in a line of vehicles; $n+1$, the vehicle behind the nth. The d's represent differentials. The equation expresses experimental findings that a driver responds predominantly to changes in relative speed between his vehicle and the vehicle ahead.

RELAXATION TERM | COLLISION TERM | ADJUSTMENT TERM

$$\frac{\partial f(v,t)}{\partial t} = -\frac{f-f^0}{T} + (1-P)c(\bar{v}-v)f + \lambda(1-P)c\,[c\delta(v-\bar{v}) - f]$$

THEORY OF MULTILANE FLOW is similar in spirit to Boltzmann equation used in the kinetic theory of gases. The important difference is the incorporation of drivers' will into the traffic equation. Symbol f is the actual speed distribution; f^0, desired speed distribution; t, time; T, relaxation time; P, probability of passing another vehicle; c, traffic concentration; $\bar{v}$, average speed of traffic; v, speed of an individual car; λ, a weighting function that depends on the concentration of the traffic; δ, the Dirac delta function. The symbols resembling backward 6's are known as mirror 6's and represent partial derivatives.

acterized by heavy traffic moving in single-lane, no-passing situations. The Holland and Lincoln tunnels are under the jurisdiction of the Port of New York Authority, and in our studies we had the close collaboration of Port Authority staff members, particularly Leslie C. Edie and Robert S. Foote.

First, follow-the-leader experiments were conducted in the tunnels, again using two instrumented cars connected with piano wire. In the Holland Tunnel, for example, 11 different drivers made runs between Manhattan and New Jersey at randomly chosen times of day, including evening rush hours. As before, we studied the correlation between stimulus and response, between the relative speed of the two cars and the acceleration or braking of the rear car, thereby determining the time lag and sensitivity coefficient of the trailing driver. These experiments, however, differed from those on the test track in that both of the cars moving through the tunnel were necessarily influenced by the conditions of the traffic stream.

After these experiments were conducted, our next concern was to obtain some measurements of typical traffic in the tunnels. We would thus have data on the different quantities to be found for such variables as flow, concentration and vehicle speeds. In one of the measurements two photocells were mounted 12.9 feet apart on the ceiling above the center of a lane in the Holland Tunnel. Instruments connected with the photocells recorded the passage of each vehicle. This experiment collected data over 10 days at various times and under a variety of conditions, yielding a sample of about 24,000 vehicles, enough to establish the main characteristics of the traffic stream. For example, the data indicated that the characteristic speed in the tunnel—the speed at which maximum flow occurred—was 19 miles per hour.

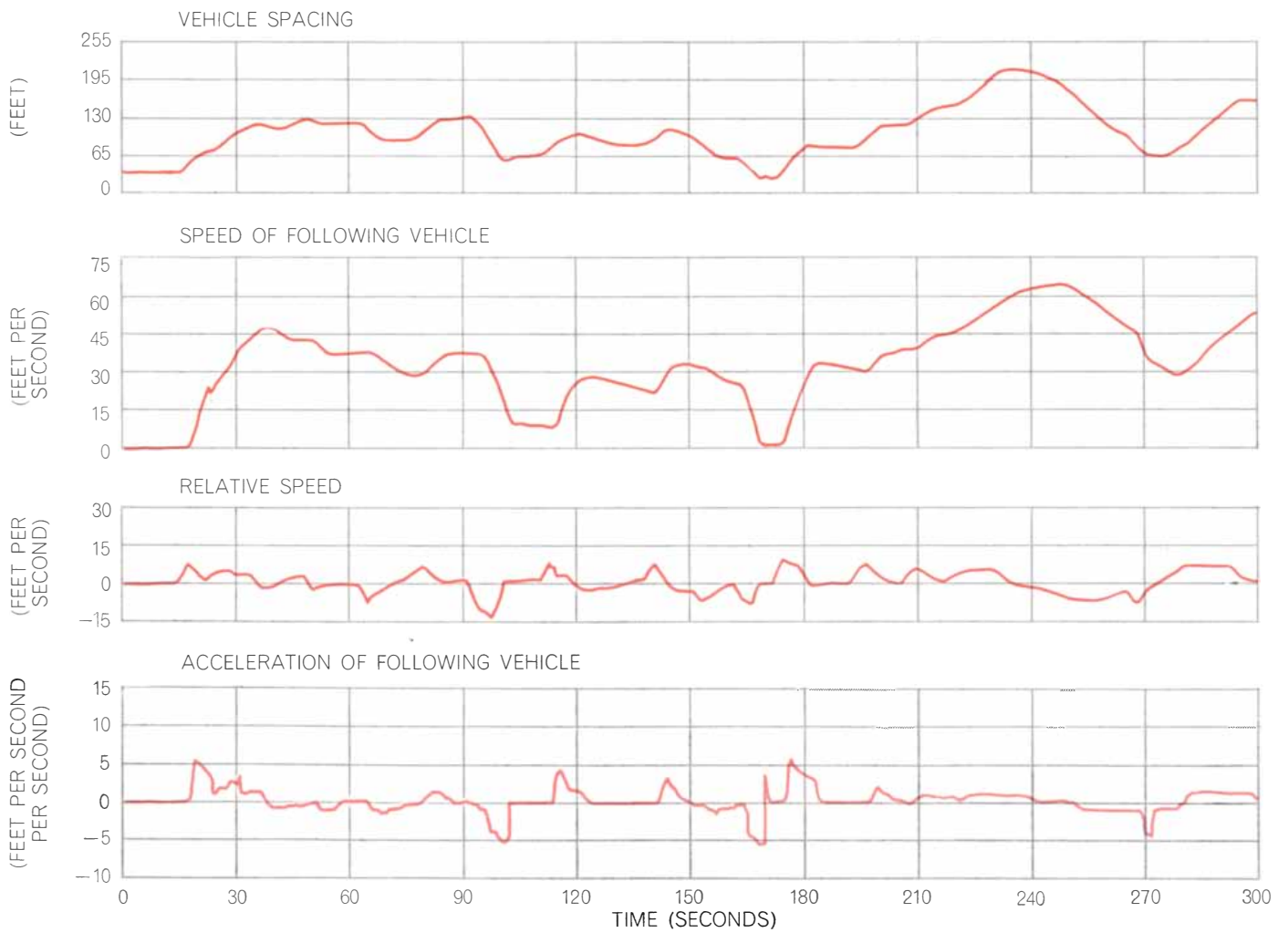
The results predicted by follow-the-leader theory closely approximated the characteristics derived from the traffic measurements in the tunnel. For example, the characteristic speed determined by the car-following experiments was 18.2 miles per hour. Plotted as curves, the data obtained from experiment showed a close fit with the results predicted by the car-following equation. Considering the complicated nature of actual traffic and the relative simplicity of follow-the-leader theory, we found it most gratifying to get results of the same order from observing two interacting vehicles as we had from looking at

24,000 in a given tunnel environment.

These tunnel studies have enabled us to understand something about the nature of the interactions of vehicles in a single lane of traffic. If the concentration of cars is low, a driver goes at what can be called his desired speed: the speed that seems most suitable to him in the circumstances. The flow through the lane will of course increase for a time as the number of vehicles in the stream increases. In other words, during this period there is an approximately linear relation between concentration and flow. Plotting the traffic through each of the three New York tunnels as a flow-concentration curve, we found that this linear relation was identical from tunnel to tunnel. Apparently a typical motorist drives through one tunnel in essentially the same way as he does through another up to a certain point of traffic concentration, no matter how the tunnel environments differ in such particulars as width, lighting and road profile.

When drivers have to interact with other cars, however, the situation changes markedly and with significant results for the flow. Motorists begin to react differently to the different tunnel environments. As a result the curves for the tunnels start to vary: they bend over at different rates and pass through different maximums for each tunnel. This maximum is lowest for the Holland Tunnel, the oldest of the three, and thus that tunnel's characteristic speed is also lowest. The Lincoln and Queens Midtown tunnels appear on the basis of somewhat less information to have characteristic speeds of 20 and 22 miles per hour respectively. As the traffic concentration increases sufficiently beyond the point of maximum flow in any tunnel, interactions cause disruptions in the flow and may even produce traffic stoppages. Stoppages occur in practice sooner than one might predict theoretically. As far as we know, no one has measured a moving traffic stream with a concentration of more than about 110 vehicles in a mile of lane.

Between maximum flow and standstill in a situation where the concentration of cars continues to rise, interactions produce disturbances best described as shock waves. A certain car in a lane slows down for some reason. So perforce does the next car, perhaps more abruptly because the driver reacts too slowly or too vigorously or both. In any case the disturbance is propagated back along the line for some distance [*see illustration on next page*]. The disruption may well reach a point at which one or more drivers have to stop, if only momentarily. Gradually the wave subsides as the first car and then the others regain their speed, but meanwhile some of the affected drivers may have had to perform extreme maneuvers of acceleration or braking. This is the accordion effect so familiar in crowded single-lane conditions. In a flow of high density it may occur repeatedly, considerably



TEST RESULTS are shown by graphs based on information printed by a computer during a follow-the-leader experiment in which the driver of the leading car varied speed randomly and the other driver followed in a manner that he thought safe. The cars were linked by piano wire as shown in top illustration on opposite page. A speed of 30 feet per second is approximately equivalent to 20 miles per hour; therefore in the period of five minutes shown here the speed of the leading car ranged from 0 to 40 miles per hour.

reducing the productivity of the lane.

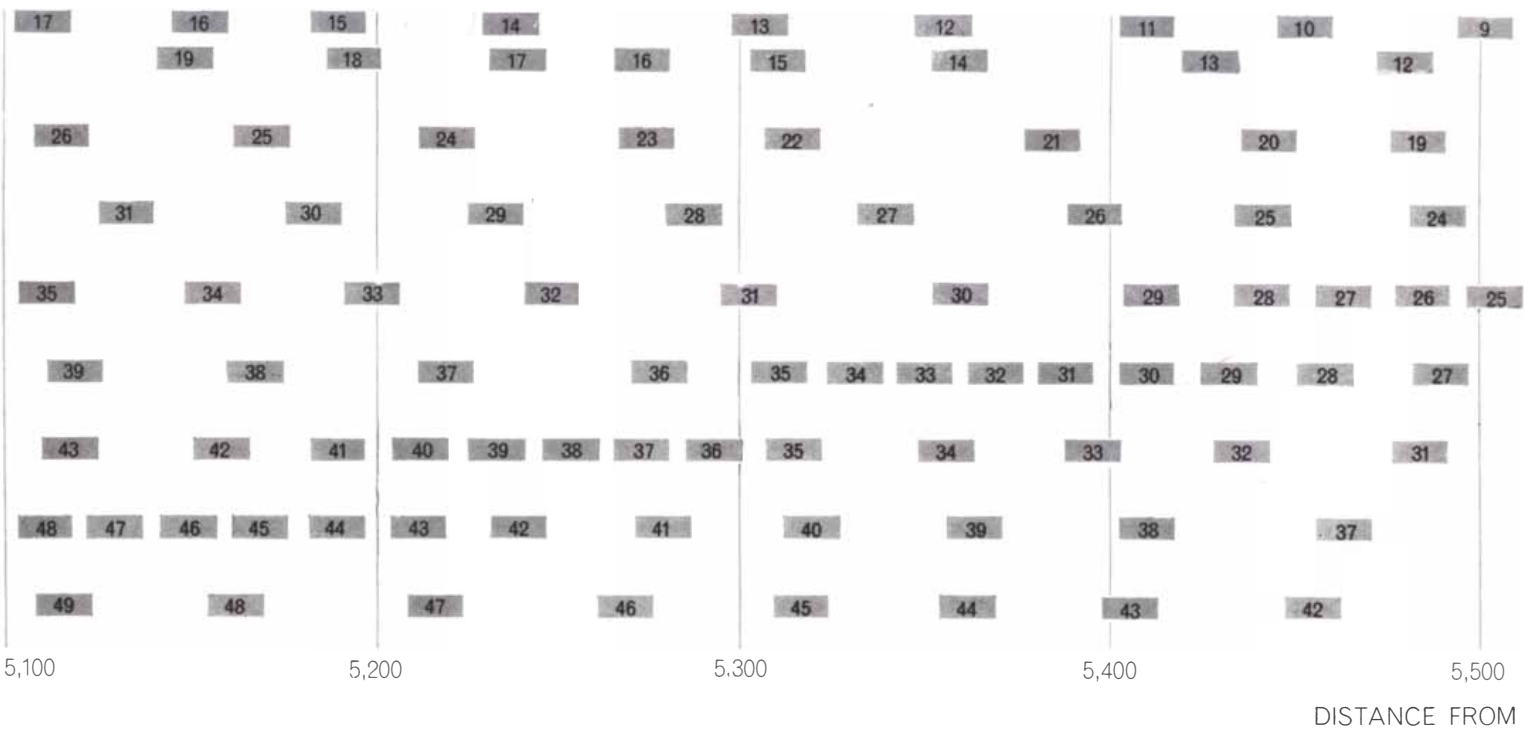
Often a shock wave is generated by some feature of the road, such as an upgrade. A motorist fails to realize he is on an upgrade or fails to accelerate in such a way as to maintain speed on the upgrade or has a car with poor acceleration. As a result he loses speed and a shock wave begins. In a crowded single-lane situation where passing is not possible such a feature becomes a chronic bottleneck.

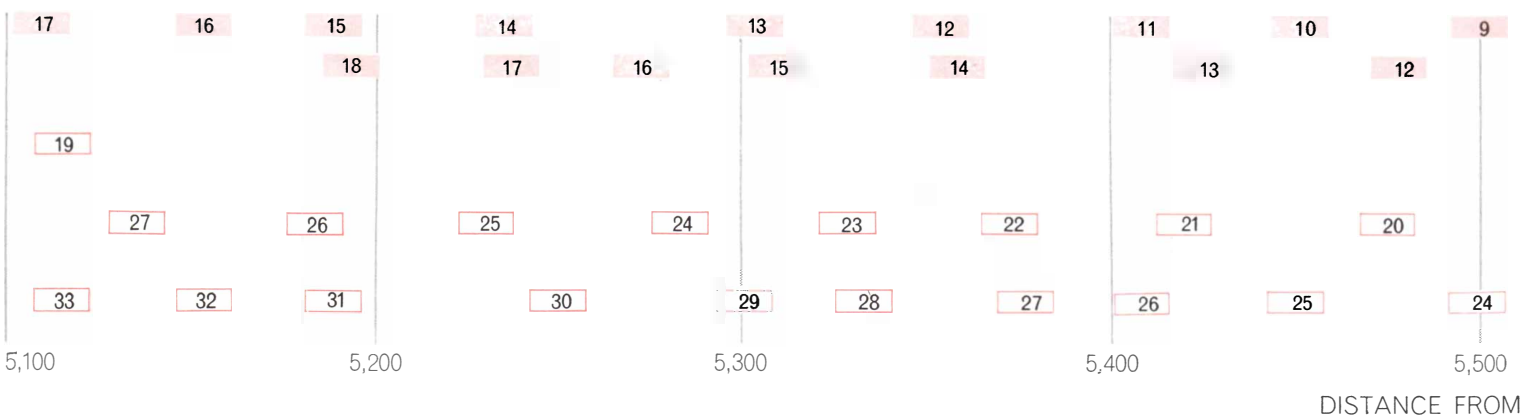
A typical bottleneck occurs on the upgrade of the Holland Tunnel's eastbound tube. Perhaps an added problem there is the fact that it is difficult to judge in a tunnel what sort of grade one is on. Whatever the causes, the area near the start of the upgrade is a frequent source of shock waves resulting from the interaction of following drivers after a leading driver has slowed.

Studying this effect of driver interactions, Harold Greenberg and other members of the Port Authority staff suggested that gaps be introduced into the traffic stream. The idea was that the gaps would provide a means of disrupting the propagation of a shock wave down a line of cars. Shock waves would still occur, but the vehicles would be moving in platoons that would have little effect on one another. Therefore each wave would be absorbed within a platoon and the over-all flow through the tunnel would be smoother. Perhaps with smoother flow the tunnel could carry more vehicles in peak periods of heavy commuter traffic.

Edie and Foote of the Port Authority conducted the first controlled experiments that confirmed this idea. They stationed an observer at the entrance of a lane to count the arriving vehicles. The aim was to keep the number of vehicles entering the lane at 44 or fewer every two minutes. These figures were based on the previous measurements of optimum flow through the tunnel. Whenever 44 vehicles entered in less than two minutes, a police officer stopped further entries until the two minutes were up. That action introduced gaps, usually of about 10 seconds' duration, in the traffic stream.

The results were dramatic. Average hourly flow, which had been 1,176 vehi-





EFFECT OF PLATOONING is depicted in these diagrams. At top a long line of cars is affected by a shock wave resulting from a momentary stopping or slowing down by car *1*; car *2* has to decelerate also, and the disturbance is propagated far back along the line, as shown in the diagram by succeeding lines representing the situation at 10-second intervals. Studying the effect of shock

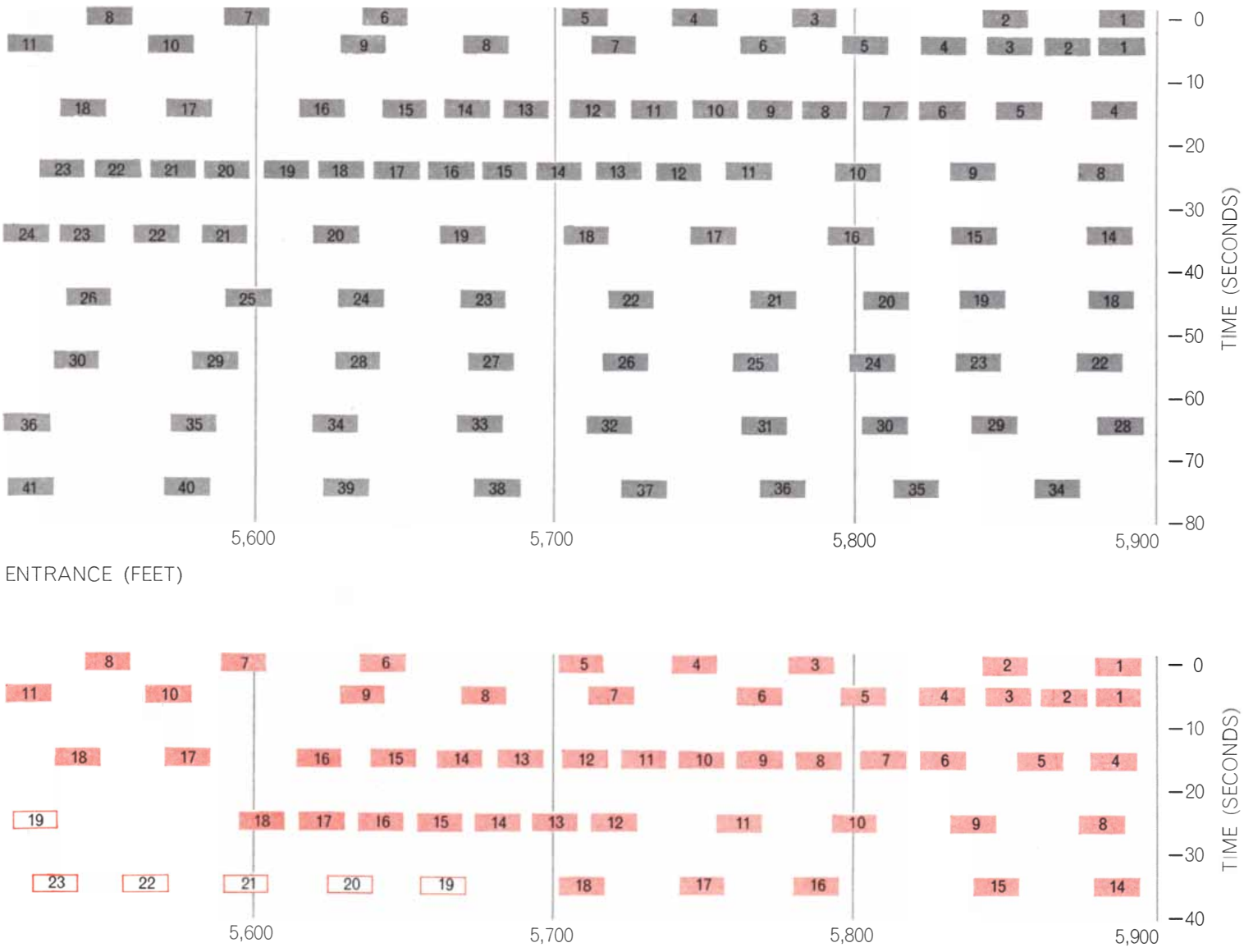
cles, rose to 1,248 vehicles with platooning. Occasionally the rate went as high as 1,320 vehicles an hour, which is about the maximum potential of the tunnel. Congestion on the tunnel approaches diminished because the flow through the tunnel was larger. Moreover, the elimination of stop-and-go driving reduced vehicle breakdowns by 25 per cent, opening the way for a still larger flow; breakdowns account for major losses in tunnel productivity. A largely unanticipated benefit was a marked reduction in tunnel ventilation requirements; there was less of the frequent acceleration that increases exhaust fumes.

This unique traffic-control system was originally tested by means of hand signals and then semiautomatically with signal lights. It is now evolving into a fully automatic electronic system being built by Port Authority engineers for installation in the Holland and Lincoln tunnels.

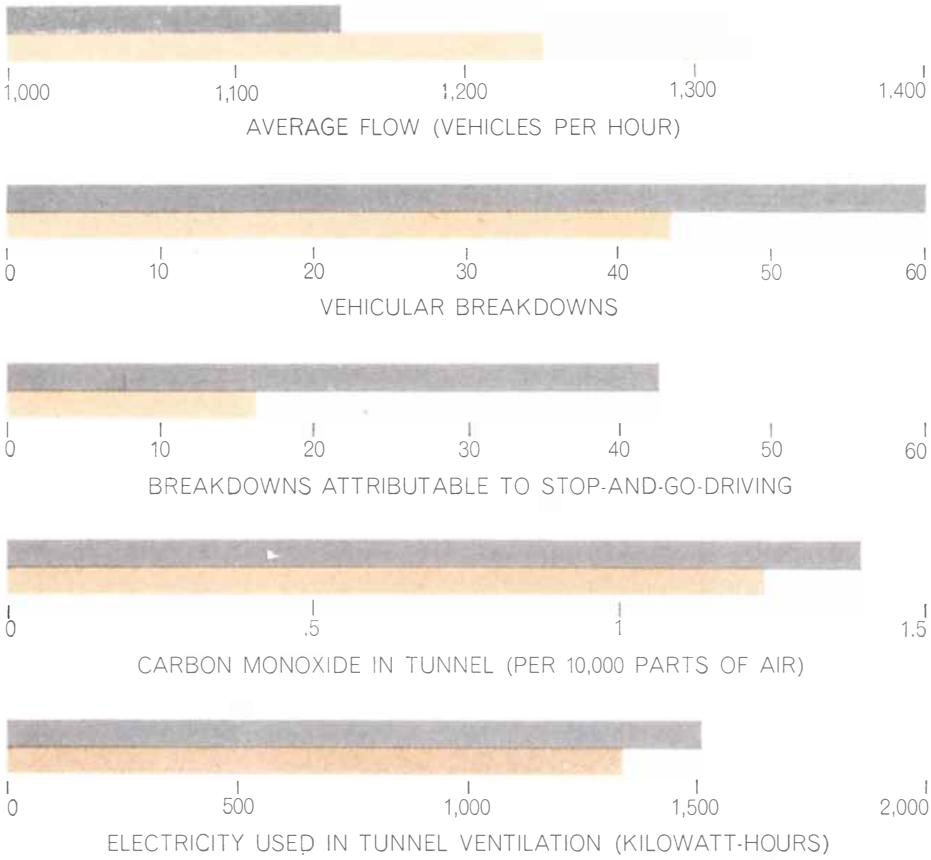
Another application of traffic theory is in the study of accidents and safety. In particular follow-the-leader theory has given us some quantitative limits to a driver's sensitivity and the time lag of his response. The limits calculated by the theory suggest a criterion for distinguishing the safe driver from the dangerous one. According to this criterion a dangerous driver is one who responds too slowly or too strongly to the stimuli he receives. A driver exceeding the limits creates a condition of instability in a lane of traffic; the result may be a collision and perhaps a chain of rear-end collisions of the kind that sometimes occurs on high-speed roads.

We deal with these variable characteristics of drivers as an instability factor that is the product of a driver's sensitivity coefficient and his reaction time. Assigning various values to this factor, we have made computer studies of stability. By means of these studies we have established criteria for various car-following situations that a motorist might face.

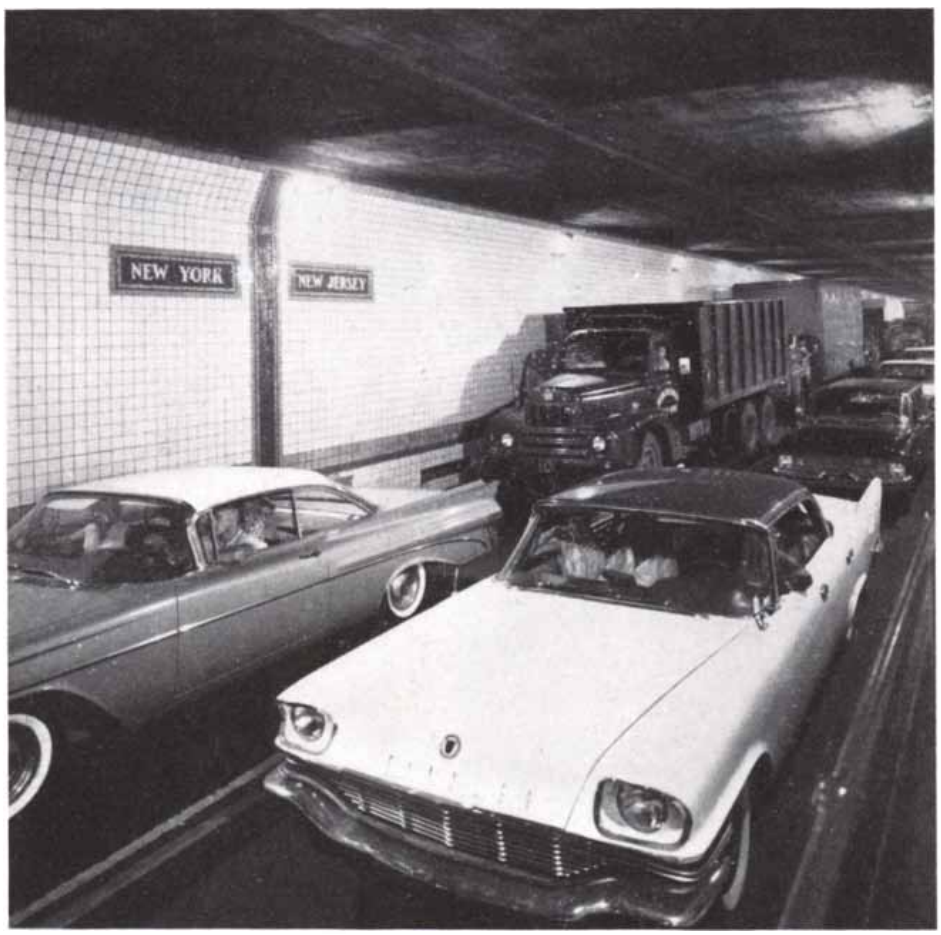
From these criteria it becomes plain that a driver with too high an instability factor—that is to say, a driver with excessive sensitivity or abnormally long reaction time—tends to amplify a deceleration pulse and to create a situation in



waves in the Holland Tunnel, officials of the Port of New York Authority devised a means of markedly reducing the disturbances. They formed cars into platoons by introducing gaps in the traffic. This usually confined impact of a shock wave to a single platoon, as depicted in bottom diagram, where gap appears between cars *18* and *19*. Platooning had dramatic results, illustrated on next page.



SIGNIFICANT IMPROVEMENTS in Holland Tunnel operations resulted from platooning. Colored and gray bars respectively indicate performance with and without platooning during approximately equal periods. Segment of open bar at top indicates occasional peak flow.



RUSH-HOUR LOAD typical of those carried by tunnels in the New York area is shown in the Holland Tunnel. The tunnels confront drivers with a single-lane, no-passing situation.

which an accident may occur farther back in a line of cars. Ironically it is likely that the first several cars that amplify a disturbance to accident proportions will not be involved in the actual collisions, having long since left the scene. Good drivers, for whom the product of sensitivity and reaction time is low, will tend to react in a smoother, more relaxed way to a deceleration pulse and will soak up much of the disturbance. To put the matter another way, there exists a potentially stable traffic situation if drivers control their spacing by the relative speed between vehicles, and a potentially unstable situation if they try to maintain a constant distance from the car ahead.

Our attempts to test this instability factor experimentally have been comparatively crude. However, we observed in our follow-the-leader experiments that the drivers pressed close to the outer limits of stability. It is probably true also that drivers in normal traffic are often operating on the very edge of stability.

Fortunately the instability of any single driver is counterbalanced somewhat by broader stabilizing influences that exist in highway traffic. For example, our calculations from a relatively simple car-following model indicate that the stability of a line of cars can be increased by as much as 50 per cent if each driver acts on the basis of what the car behind him as well as the one in front is doing. Moreover, as expert drivers have stressed, stability is found to increase even further when motorists watch several cars ahead and anticipate potential trouble.

Encouraged by the results of follow-the-leader theory in helping to clarify the behavior of single-lane traffic, we have begun to turn our attention toward the development of a theory relating to the behavior of multilane traffic. We proceed from the assumption, which seems safe and general enough, that automobiles in such a situation can be regarded as particles in which each driver is trying to do what he wants to but is subjected to boundary conditions.

The underlying idea of our work is a speed-distribution function: a mathematical expression that gives the distribution of speeds for all the cars and trucks on a multilane highway. In effect this factor expresses the competition between the wishes of each driver and the constraints that the environment, including other drivers, puts on him. This competition results in interactions of various drivers. The interactions can be explained mathematically by three processes.

First, the theory assumes that on a multilane highway there is a relaxation process. Given a chance, a driver does as he pleases. At low traffic concentration he will be free to do so because he will not have to interact with other drivers. All drivers, as long as they are in a position to do as they wish, will travel at their own desired speed. Traffic will achieve a desired speed distribution.

Second, if the traffic concentration is greater than zero, a vehicle will eventually come up behind another vehicle that is moving more slowly. Unlike a molecule, a driver cannot bump the driver in front up to a higher speed. He must either pass or, in heavier traffic, slow down. We describe this slowing down as a retardation, or collision, process. It leads to a decrease in the average speed of all traffic. Conversely, when a driver passes a slower car he is tending to "relax" back to his desired speed; in this instance the relaxation process has a speeding-up effect on traffic.

The third process relates to adjustment. It says that a driver is subjected to a kind of collective effect exerted by the local traffic. In heavy traffic he is forced to adjust his driving to the behavior of the cars in his immediate environment. This adjustment process, like the collision process, decreases the speed of the fast drivers. It also tends to increase the speed of the slow drivers. The net result is that it narrows the spread of the speed distribution.

From these processes we derive an equation that is similar in spirit to the fundamental Boltzmann equation of the kinetic theory of gases. Ilya Prigogine of the Free University of Brussels suggested the first form of the traffic equation and has been working closely with Robert L. Anderson and one of us (Herman) in its further development.

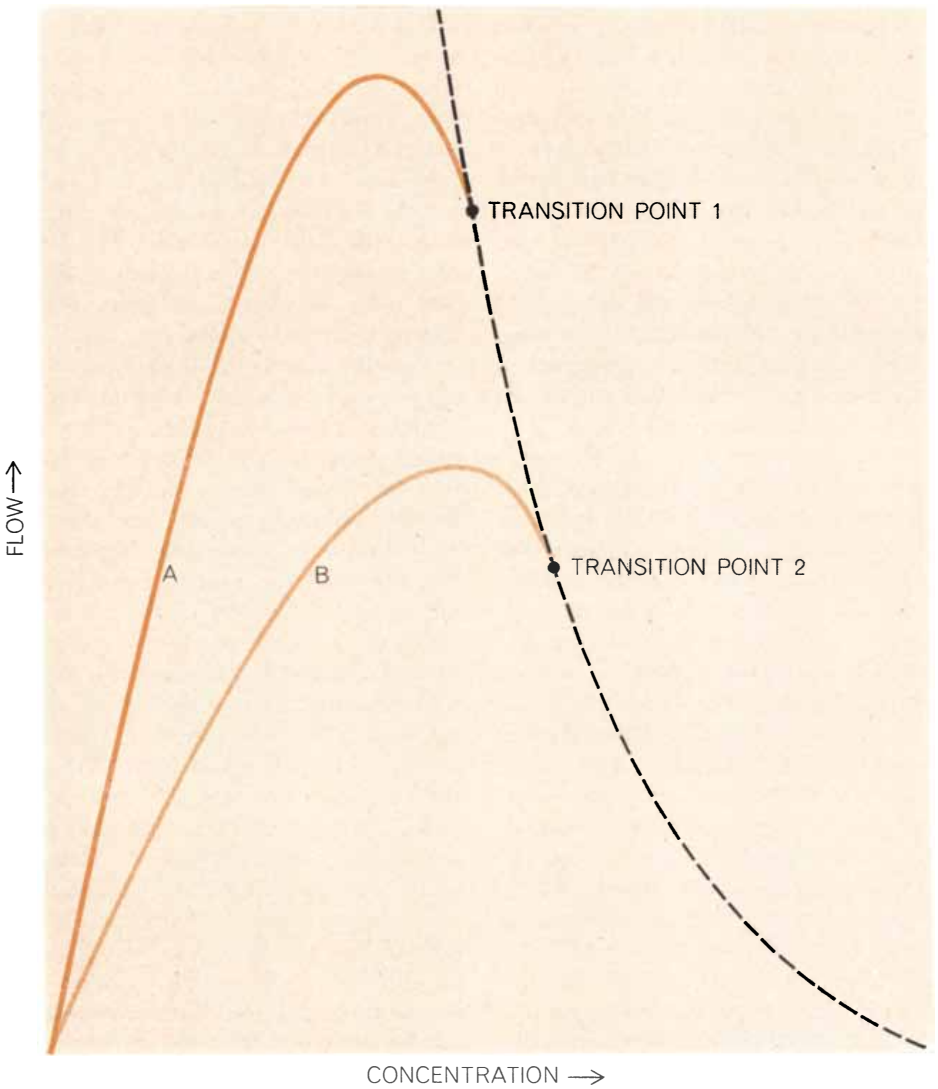
We are just beginning to collect some experimental information to compare with the predictions of this theory. Using special instruments, Rothery has assembled some preliminary data from traffic in Michigan between Detroit and Lansing on Interstate Route 96, a multilane, limited-access highway. In one section there is a five-mile stretch with no entrances or exits; it permits the gathering of data from undisturbed traffic flow.

So far we have ascertained the desired speed distribution for weekday traffic on this stretch of road; it is the distribution that occurs at virtually zero concentration. We plan to obtain data for speed distributions at various higher concentrations up to the point at which traffic is so heavy that individual cars can no longer pass because they are held to one lane.

A study of the way such a speed distribution varies with concentration predicts some interesting features of traffic. Beginning with a situation of light traffic, it is clear that a driver will do as he wishes—presumably within the limits of the law. But as the traffic concentration goes up, more and more restrictions are imposed on the driver. He must subjugate his wishes to what he can do safely—or to what he can do at all.

The theory predicts that at some critical concentration there will be a transition from individual flow to collective flow, in which traffic moves in a rather gelled state [*see illustration below*]. In that state every driver is doing what is forced on the community by the properties of this peculiar kind of fluid. During collective flow the average speed depends almost entirely on the concentration and the probability of passing. It is independent of the wishes of the drivers and therefore of the desired speed distribution. In collective flow the speed distribution is characterized by large fluctuations that indicate local traffic jams. It may be that a full understanding of speed distributions in the collective state will make it possible to predict such jams. That is a question we have not yet attempted to answer.

Indeed, there are many questions that traffic theory at its present stage of development cannot answer. We believe, however, that in time traffic theory—coupled with well-thought-out experiments and observations—will provide the basis for a science of traffic. Any insights that improve the productivity and safety of the highway complex, which represents a huge public investment, will more than repay the effort.



MULTILANE FLOW is described by an equation resembling the Boltzmann equation for a gas. Up to a point the flow is governed largely by the desires of individual drivers; here curve *A* represents a group of drivers with a higher average desired speed than group *B*. Initially the flow of both groups increases as the concentration rises; greater density restricts the flow and the curves bend. The theory predicts that at specified critical concentrations, points *1* and *2*, there will be a transition from individual to collective flow (*broken line*).

POLYRIBOSOMES

These collections of the particles called ribosomes appear to be the assembly lines on which the living cell manufactures protein molecules. How the assembly line works is just now becoming clear

by Alexander Rich

A typical mammalian cell contains instructions for making many thousands of different proteins and has the capacity to turn out thousands of protein molecules every minute. To a very large extent the living cell is an expression of the particular kinds of proteins it manufactures. It has been known for several years that the site of protein synthesis within the cell is the particle called the ribosome. Visible only in the electron microscope, ribosomes are approximately spherical and can be seen throughout the substance of all living cells. Although the internal structure of these particles is obscure, it has been established that they are composed of protein and ribonucleic acid (RNA) in about equal amounts.

Within the past 18 months experiments in our laboratory at the Massachusetts Institute of Technology and elsewhere have led to the hypothesis that the protein "factories" of the cell are not single ribosomes working in isolation but collections of ribosomes working together in orderly fashion as if they were machines on an assembly line. We have called such collections polyribosomes, or simply polysomes. As we shall see, the polyribosome is not the usual kind of assembly line. In such an assembly line the product moves down the line and component parts are added to it. In the polyribosome assembly line the ribosomes move down the line and each one makes a complete product. There is much evidence that the ribosomes are all alike, or at least interchangeable. They can move from one assembly line to another, making whatever protein a given line happens to call for.

How this specification of a protein takes place has been fully described in these pages, most recently in "The Genetic Code," by F. H. C. Crick [SCIENTIFIC AMERICAN, October, 1962] and "The Genetic Code: II," by Marshall W. Nirenberg [SCIENTIFIC AMERICAN, March]. The genetic code of the cell, which constitutes the instructions for the synthesis of the cell's proteins, is embodied in a double-chain molecular helix of deoxyribonucleic acid (DNA). The code itself consists of sequences of four different kinds of subunit called bases. The DNA of a bacterium may contain some five million pairs of bases, which are needed to specify several thousand different proteins. The DNA of a mammalian cell may contain nearly 100 times as many base pairs, which specify many more proteins.

Proteins consist of linear chains of amino acid subunits. Short chains or chains that lack full protein activity are called polypeptides. Polypeptide chains can be folded into a specific three-dimensional configuration, and they often combine to form complex proteins. For example, the protein hemoglobin, which carries oxygen in the blood, is composed of four polypeptide chains, each of which contains about 150 amino acid subunits. Protein chains are built up from about 20 different kinds of amino acid. Each chain must have the right sequence of amino acid subunits to make sense, just as a sentence must consist of the right sequence of letters, spaces and punctuation. It is evident that an enormous number of different polypeptide chains can be constructed from 20 different amino acids, just as an enormous number of different sentences can be composed from the 26 letters of our alphabet.

The kernel of the genetic coding problem was to discover how a sequence of four different bases in DNA could specify a sequence of 20 different amino acids in a protein. It now appears that a triplet code is employed: a sequence of three bases is needed to specify each amino acid. It has also been shown that DNA does not take part directly in protein synthesis. Instead the genetic code in the long double-chain molecule of DNA is transcribed into shorter single chains of RNA, which carry away the information needed to construct one kind of polypeptide chain, or perhaps in some cases several chains. Because these molecules of RNA bear the genetic code to the site of protein synthesis they are called messenger RNA.

How do the amino acid molecules get to the site of synthesis and find their proper place in the polypeptide chain? As a first step they must be "activated," a task performed by the energy-rich substance adenosine triphosphate (ATP). So activated, they can be "recognized" by still smaller RNA molecules, containing about 70 base subunits, called transfer, or soluble, RNA. There is a different kind of transfer RNA for each amino acid. The transfer RNA and amino acid are joined by a specific enzyme, a protein with catalytic activity. The transfer RNA then acts as an adapter for depositing a given amino acid at a position in the polypeptide chain specified by messenger RNA. Presumably the ultimate selection of an amino acid is determined by weak chemical bonds between a sequence of bases in messenger RNA and a complementary sequence in transfer RNA. By this mechanism, through the agency of the ribosome, the information coded in messenger RNA is translated into a polypeptide chain.

About a year and a half ago my colleagues and I began puzzling about one geometrical aspect of this system. Consider for a moment the problem of synthesizing one of the polypeptide chains of hemoglobin, which contains about 150 amino acid subunits. If each subunit is specified by a triplet code, the

messenger RNA must contain 450 bases merely to specify the sequence of subunits in one chain. In most RNA molecules the bases are stacked on top of one another more or less like a pile of pennies. Since the bases have a thickness of 3.4 angstrom units, the messenger RNA strand for the hemoglobin polypeptide chains should have a molecular length of at least 1,500 angstroms. In other possible arrangements of the RNA molecule the length might be almost twice as great. By comparison, the individual ribosome has a diameter of only about 230 angstroms, and so we wondered how the long messenger molecule interacted with such a small particle to manufacture a polypeptide chain. Some investigators thought that the RNA chain might be wrapped around the outside of the ribosome, but it was hard to visualize how intimate contact between the two could be maintained. The wrapping problem would be still more difficult for RNA chains 20,000 angstroms long, which are found in many viruses. Alternative suggestions that the messenger RNA might somehow be coiled inside the ribosome seemed to present even more formidable topological problems.

It occurred to us that proteins might actually be made on groups of ribosomes, linked together somehow by messenger RNA. There was already a little evidence pointing in this direction. Walter Gilbert of Harvard University, as well as other investigators, had found that when a synthetic RNA was added to a cell-free system of bacterial ribosomes, the ribosomes would tend to clump together. (In such experiments, initiated by Marshall Nirenberg at the National Institutes of Health, the ribosomes make synthetic polypeptides in accordance with instructions coded in the synthetic RNA. By comparing the base composition of the RNA with the amino acid composition of the polypeptide it is possible to compile a genetic code "dictionary.")

In some of the initial experiments in our laboratory Jonathan R. Warner, then a graduate student, tried to find in bacterial cells structures larger than single ribosomes. He was initially unsuccessful because, as we later realized, the vigorous grinding needed to break open the bacteria also destroys the delicate polyribosome structure.

At the same time Paul M. Knopf, a post-doctoral fellow in our group, was working with reticulocytes—the cells that make hemoglobin—from rabbits. Since the cells were readily available, we began looking for multiple ribosomal structure in them. The reticulocyte is a cell that has lost its nucleus but retains

LARGE POLYRIBOSOMES obtained from a culture of human tumor cells are enlarged 100,000 diameters in this electron micrograph made by the author and his colleagues. Individual globular units in the clusters are ribosomes, believed to be held together by strands of messenger RNA (ribonucleic acid). Polyribosomes are the site of protein synthesis.

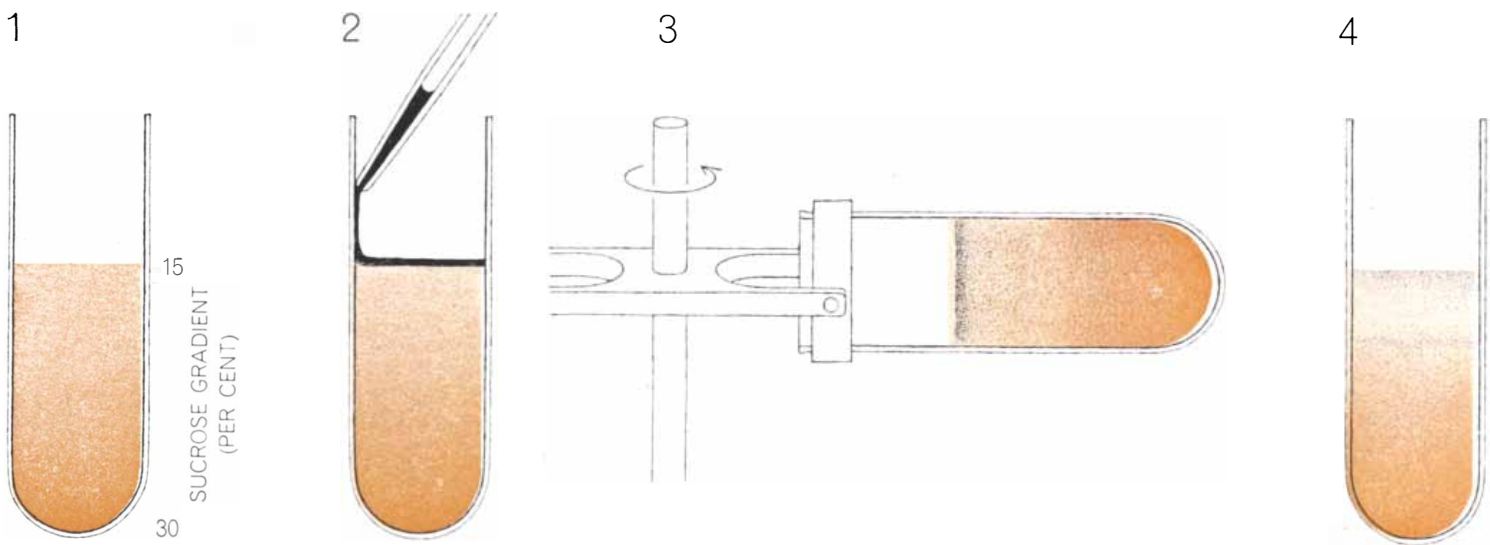
CELL COMPONENT	STRUCTURE	FUNCTION
DNA (DEOXYRIBONUCLEIC ACID)	A polymer molecule in the form of a double-strand helix containing many thousands of subunits.	Contains genetic information coded in sequences subunits called bases.
MESSENGER RNA (A FORM OF RIBONUCLEIC ACID)	A single-strand polymer molecule containing hundreds of subunits.	Transcribes from DNA the information needed to make a protein molecule and carries it to site of protein synthesis.
TRANSFER, OR SOLUBLE, RNA (A FORM OF RIBONUCLEIC ACID)	A single-strand polymer molecule containing about 70 subunits. May be folded into a double helix in some regions.	Conveys specific amino acids to site of protein synthesis. Each amino acid has its own type of transfer RNA.
RIBOSOME	A globular structure consisting of 40 per cent protein and 60 per cent RNA.	Collaborates with messenger RNA to link together amino acids delivered by transfer RNA, thereby creating proteins.
POLYRIBOSOME OR POLYSOME	Strings of ribosomes temporarily held together by messenger RNA.	Provides actual mechanism of protein synthesis.

GLOSSARY OF CELL COMPONENTS required for protein synthesis describes their structure, function and size. The end result of the collaboration among these components is to produce protein molecules whose composition has been specified by the genetic code

the molecular apparatus for producing hemoglobin molecules. It is also a highly specialized cell: hemoglobin is virtually the only protein it manufactures. For this reason the reticulocyte offers many advantages for studying protein synthesis. Using this cell, for example, Howard M. Dintzis was able to show at M.I.T. that the polypeptides in hemoglobin are assembled by the sequential addition of amino acids, starting at one end of the polypeptide chain and proceeding to the other.

The choice of reticulocytes for our search proved fortunate because they can be broken open by gentle methods. The cells are suspended in a medium whose salt concentration is lower than that within the cells. Water flows into the cell, making it swell until it bursts. A series of experiments demonstrated that protein synthesis is carried out not on individual ribosomes but on ribosome clusters. At about the same time Alfred Gierer, working independently at the Max Planck Institute in Tübingen, made similar observations with rabbit reticulocytes. A short time later F. O. Wettstein, Theophil Staehelin and Hans Noll of the University of Pittsburgh found ribosome clusters in liver tissues.

The basic technique we used in our work was sucrose-gradient centrifuga-



SUCROSE-GRADIENT TECHNIQUE provides a simple way to separate cell components that sediment at different rates when centrifuged. The gradient consists of ordinary sugar dissolved in a test tube (*1*). In a typical experiment rabbit reticulocytes (red-blood cells) are incubated 45 seconds with amino acids containing radioactive carbon 14. Ribosomes from the cells are layered on the sucrose gradient (*2*) and spun in a centrifuge (*3*). Separated fractions are removed in sequence (*5*) and analyzed. Ribosomes reveal their presence by strongly absorbing ultraviolet radiation at 2,600 angstrom units (*6*). A radiation counter determines the presence of newly synthesized polypeptide chains containing carbon 14 (*7*). These chains turn out to be in the faster sedimenting fractions.

SIZE
Diameter: 20 angstrom units Length: several thousand angstroms up to several millimeters
Diameter: 10 to 15 angstroms Length: 1,000 to several thousand angstroms
Length: 250 angstroms unfolded
Diameter: about 230 angstroms
Length: varies with length of messenger RNA holding ribosomes together

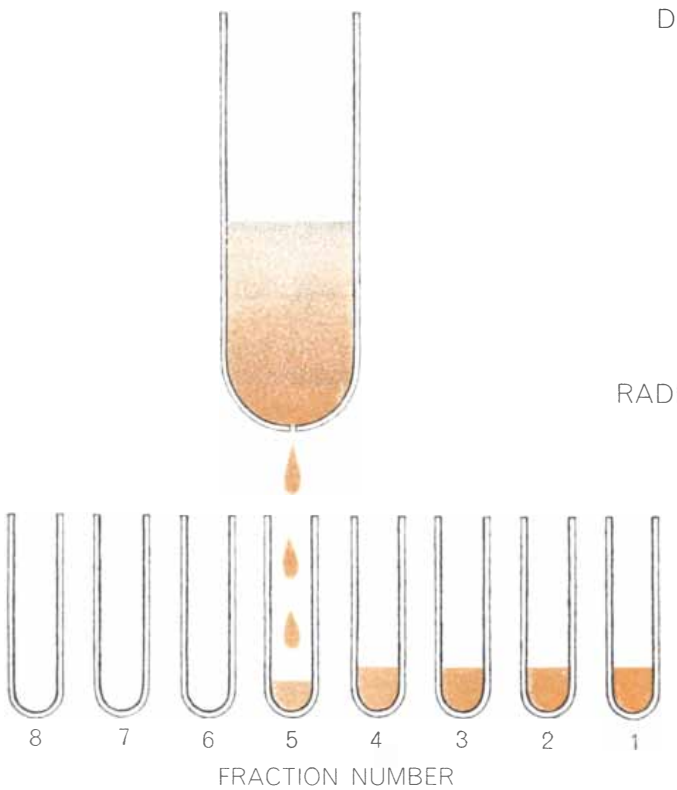
contained in DNA. Proteins are built up from about 20 varieties of amino acid.

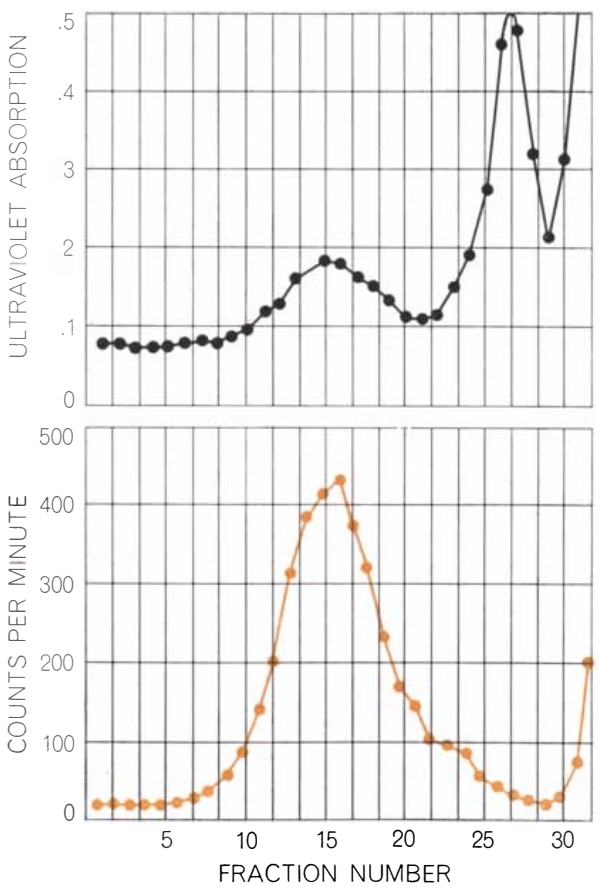
tion, which enables one to separate materials that sediment at different speeds in a strong gravitational field. In this technique a plastic centrifuge tube is filled with a sugar solution that varies smoothly from a concentration of 30 per cent at the bottom of the tube to 15 per cent at the top. The gradient is obtained simply by slowly filling the tube from two reservoirs containing 15 and 30 per cent sucrose. The sample material, containing molecules of different sizes, is carefully deposited in a layer on top of the sugar solution; the tube is then placed in a centrifuge with a swinging-bucket rotor. The sucrose gradient is preserved during the centrifugation and is still maintained after the run by gravity. During the run molecules that sediment at different speeds travel different distances and remain separated when the run is ended. The plastic tube is removed from the centrifuge and its bottom is punctured to allow the collection of a sequence of fractions from bottom to top. These fractions can now be analyzed in various ways.

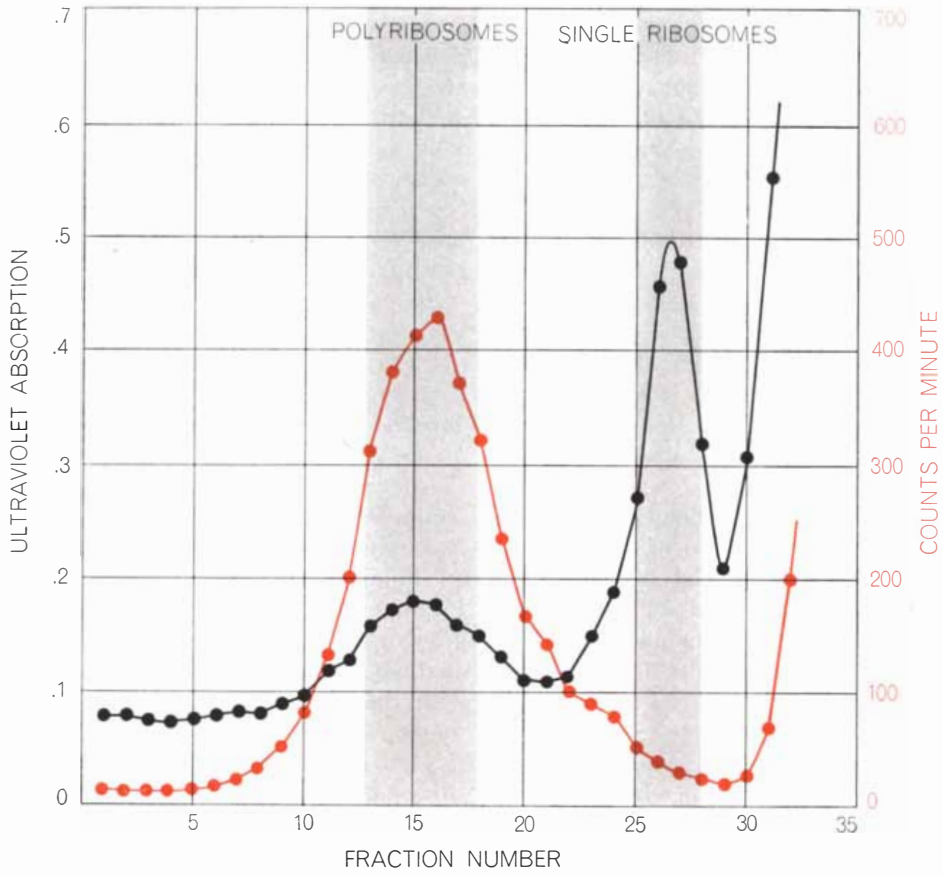
We designed the following simple experiment. A suspension of rabbit reticulocytes was incubated in a nutrient medium and then fed for 45 seconds with amino acids containing the radioactive isotope carbon 14. The time was kept short because we were interested in looking at the early stages of protein synthesis. After 45 seconds the cells were chilled to stop further metabolic activity, gently broken open and placed on a sucrose gradient. After centrifugation the fractions collected from the sucrose gradient were treated in two ways. The optical density, or amount of absorption, was read in the ultraviolet region at a wavelength of 2,600 angstroms, where nucleic acids strongly absorb radiation. Because ribosomes contain large amounts of ribonucleic acid, this is a sensitive method for determining their presence. In addition the radioactivity of the various fractions was measured. This measurement, by indicating the presence of amino acids containing carbon 14, told us which fractions contained polypeptide chains that were still growing.

The results are shown in the top illustration on the next page. It can be seen that two ultraviolet-absorbing peaks have migrated from the top of the tube. The first, or slow-moving, peak is typical of the peak for single ribosomes. Its speed of movement is represented by the sedimentation constant 74. The fast-moving peak has traveled about two and a half times farther and is much broader. Furthermore, the radioactivity in the growing hemoglobin chains was associated with the fast-moving peak and not with the peak containing single ribosomes. This clearly suggested that the fast-moving peak rather than the single-ribosome peak was the site of protein synthesis.

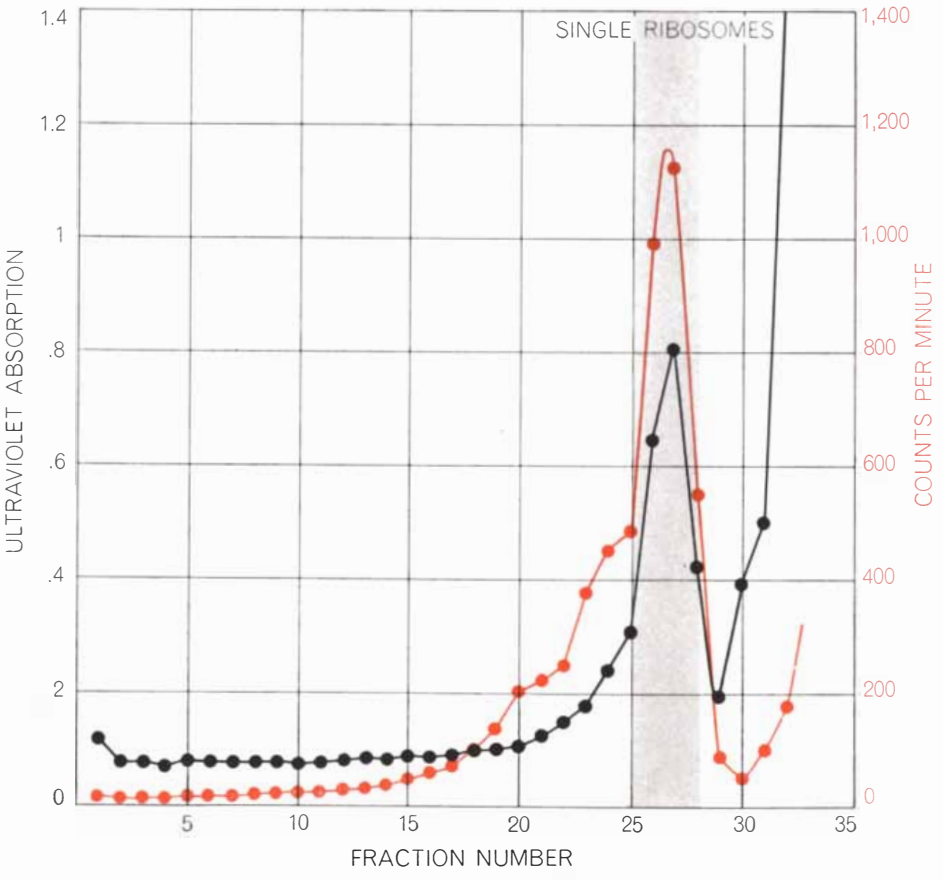
We then set about analyzing the fast-moving peak. It seemed plausible that it might contain clusters of ribosomes held together by one or more strands of messenger RNA. If this were so, it should be possible to free the ribosomes by subjecting the cell-free medium to ribonuclease, an enzyme that specifically







NORMAL RIBOSOME DISTRIBUTION in rabbit reticulocytes consists of a fast-sedimenting fraction of polyribosomes and a slow-sedimenting fraction of single ribosomes. High radioactivity (*color*) indicates that polyribosomes contain newly synthesized polypeptides.



AFTER ADDITION OF RIBONUCLEASE, an enzyme that breaks RNA chains, the ribosomes from reticulocytes no longer exhibit a fast-sedimenting fraction. This implies that polyribosomes are held together by RNA, which, on breaking, releases single ribosomes.

breaks RNA chains. In fact, when a very small amount of ribonuclease was added to the medium before centrifugation, the fast-moving peak did not appear. Both its optical density and its radioactivity were transferred to the peak containing single ribosomes [*see bottom illustration on this page*]. This confirmed the hypothesis that the fast-moving peak represented ribosomes held together by RNA.

Further experiments told us more about this fast-moving component. We learned, for example, that it is fairly fragile. When we subjected the gently opened cells to a modest amount of shearing in a homogenizer, the sucrose-gradient pattern changed dramatically [*see illustration on opposite page*]. The broad peak containing the fast-moving component disappeared and was replaced by a series of peaks. The sedimentation pattern again told us the slow-moving first peak contained single ribosomes. We speculated that the second peak might contain pairs of ribosomes, the third peak clusters of three and so on. This tentative hypothesis was readily confirmed by an electron-microscope examination conducted in the laboratory of Cecil E. Hall at M.I.T. A sample taken from the first peak showed single ribosomes. A sample from the third peak showed mainly clusters of three ribosomes, and the fifth peak showed mainly clusters of five. These initial observations showed us that hemoglobin synthesis is actually carried out on a group of ribosomes, which we named the polyribosome, or polysome.

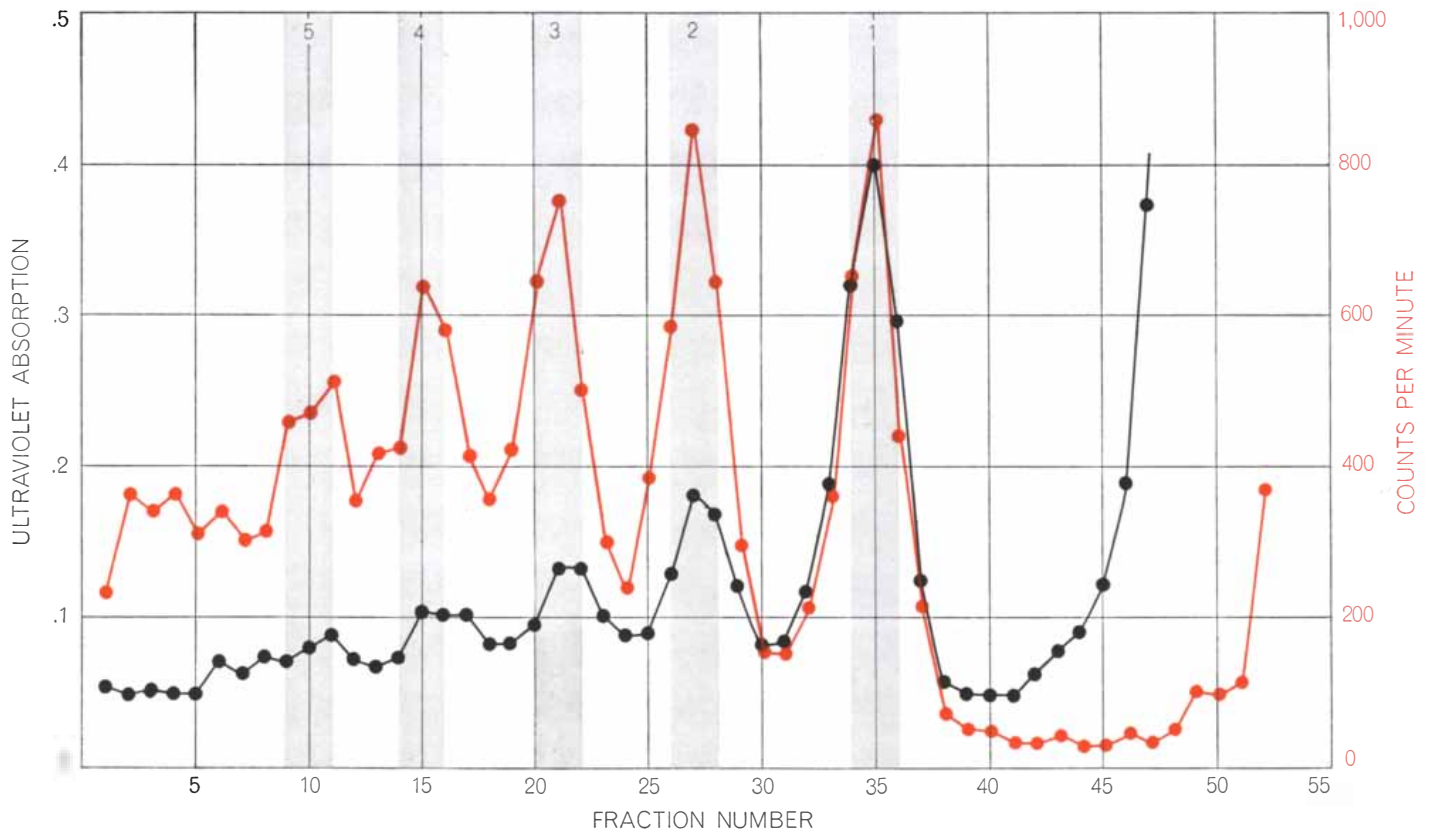
Further analysis showed that hemoglobin synthesis takes place primarily in a polysome containing five units, as shown clearly in electron micrographs. The micrographs also show, however, a fair number of four-unit and six-unit polysomes [*see top illustration on page 50*]. We were quite sure that these were not artifacts and that they must reflect the mechanism of protein synthesis.

The fragility of the polysome when subjected to mechanical forces, as well as its sensitivity to small amounts of ribonuclease, suggested that the ribosomes are held together by a single strand of RNA. This impression was strongly reinforced by more specialized electron micrographs made by Henry S. Slayter of M.I.T. The technique called negative staining shows that the ribosomes in a polysome are separated by gaps of 50 to 150 angstroms. Positive staining with uranyl acetate reveals that the ribosomes are connected by a thin thread 10 to 15 angstroms in diameter,

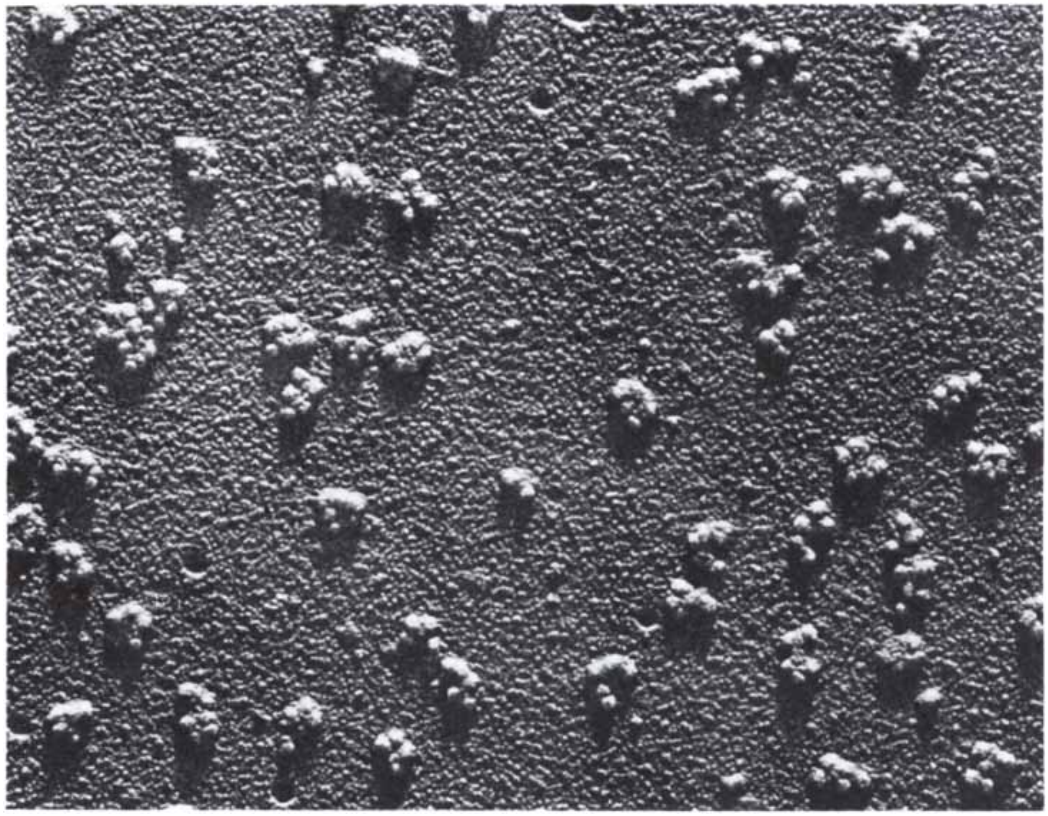
which is about the thickness of a single strand of RNA. From the size of the gap between ribosomes one can compute that the over-all length of a five-unit polysome is near 1,500 angstroms. (The five ribosomes have a total diameter of 5×230, or about 1,150 angstroms, and there are five inter-ribosomal gaps of 50 to 150 angstroms each.) These measurements of total polysome length are thus near the length that we concluded must be needed to specify the information in a hemoglobin polypeptide chain of 150 amino acid subunits. In other words, the messenger RNA for a hemoglobin polypeptide chain is about the right length to hold together a five-unit polysome.

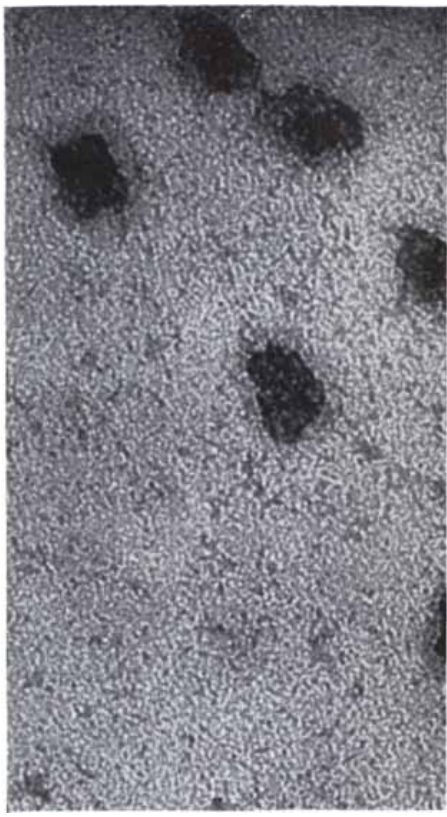
These various observations led us to the following picture of how the polysome functions. The fact that the ribosomes are separated by a considerable distance makes it seem unlikely that they cooperate in synthesizing a single polypeptide chain. Furthermore, if a ribosome is to have access to all the information coded in messenger RNA, it must "read" the strand from one end to the other. As it travels it must build up a polypeptide chain, adding one amino acid after another according to instructions. A similar conclusion was reached by Gilbert after he studied how transfer RNA is bound to the ribosome. The conclusion is also consistent with Dintzis' observation that hemoglobin synthesis proceeds in sequence.

Let us now imagine that the messenger RNA for hemoglobin contains not just one ribosome but five, all moving, say, from left to right [*see bottom illustration on next two pages*]. The ribosome at the extreme left has just attached itself to the strand and has started synthesizing a polypeptide chain. The other four ribosomes are proportionately further along in the synthesis process and the one at the extreme right has almost completed a polypeptide chain. Presumably the ribosomes are carried along by a ratchet-like mechanism that does not allow them to go backward. At each station along the way the appropriate amino acid, borne by transfer RNA, is selected from the cellular milieu and



EFFECT OF GENTLE GRINDING is to produce a series of sedimentation peaks, indicating that the polyribosomes from reticulocytes have been broken up into smaller units. Electron micrographs (*top*) were made of samples obtained from the first, third and fifth peaks from the left. They contained respectively five-unit polyribosomes, three-unit polyribosomes and single ribosomes.



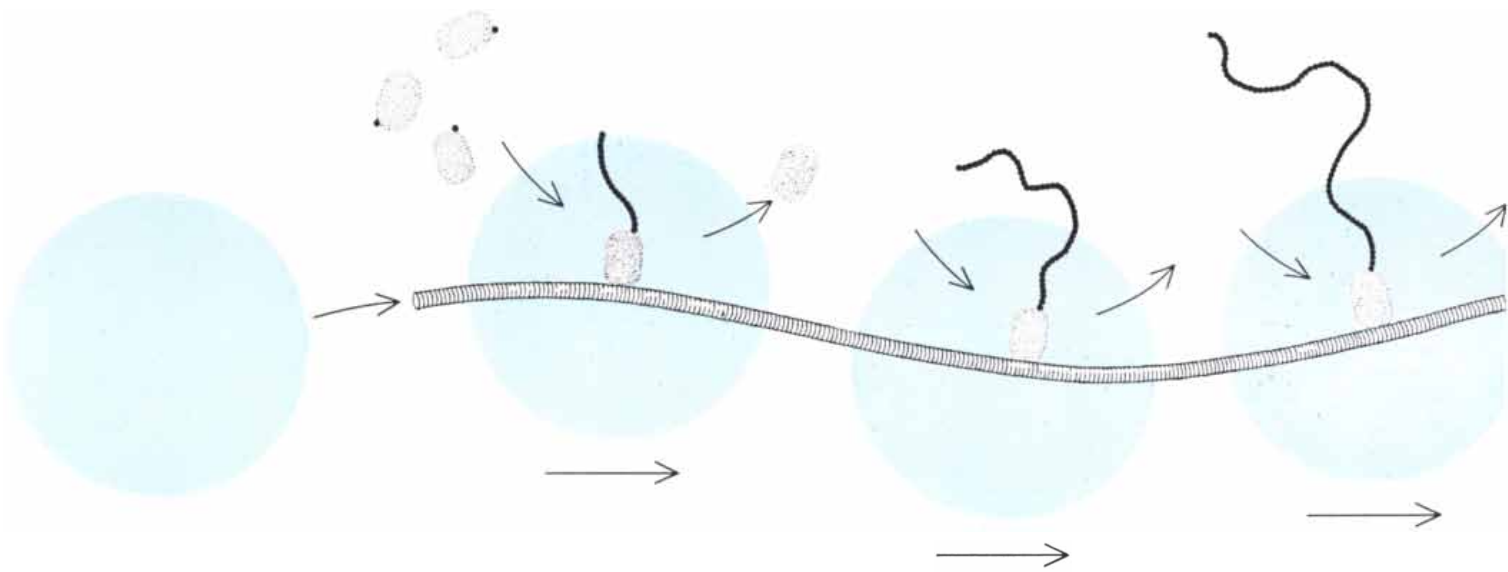


RETICULOCYTE POLYRIBOSOMES are shown at left shadowed with platinum and magnified 100,000 diameters in the electron microscope. Reticulyte polyribosomes at right have been positively stained with uranyl acetate and magnified 400,000 diameters by Henry

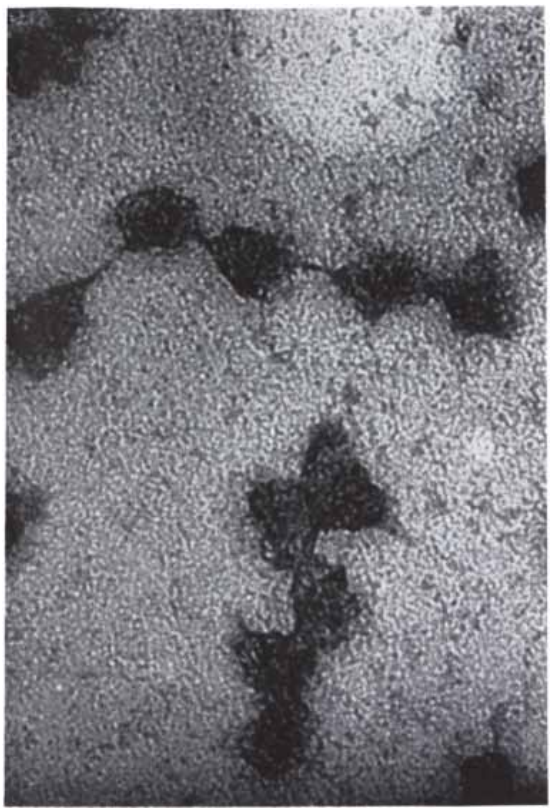
added to the growing polypeptide chain. When the synthesis is complete, the ribosome liberates the polypeptide chain and itself drops off the messenger strand. At about the same time another ribosome has found its way onto the messenger at the other end. The time needed for a single ribosome to traverse the messenger strand and produce a hemoglobin polypeptide chain has been estimated at one minute. In a bacterial cell the protein-synthesis time may be as little as 10 seconds.

In the reticulocyte the five-unit polysome is the most common species. The gaps between ribosomes vary somewhat, however, suggesting that the movement of ribosomes along the messenger strand has a statistical character. In some cases a ribosome will detach at one end before a new ribosome is attached at the other; this could account for the four-unit polysomes we see in some pictures. In other cases a ribosome may attach at one end before the fifth is released at the other end, thereby giving rise to a six-unit polysome. Such a statistical mode of operation would account for the distribution of polysome sizes observed in the reticulocyte.

Detroit might well envy the efficiency of the cell's protein factories. It is evident that protein synthesis is not really an



POLYRIBOSOME MECHANISM, as now visualized, consists of a long strand of messenger RNA to which single ribosomes attach themselves temporarily. As each ribosome travels along the strand it "reads" the information needed to synthesize a complete polypep-



S. Slayter of the Massachusetts Institute of Technology. Note the connecting threads.

assembly line process as it is normally understood. It would be more appropriate to compare protein synthesis with the operation of a tape-controlled machine tool. The tool will turn out an object of any shape within its range of capabilities, in response to information coded on the input tape. In factories where such tools are used each tool is provided with its own tape, but if it served any purpose a single tape could easily be fed through a battery of identical tools. The living cell evidently makes one tape serve for many tools because this is an efficient way to do the job.

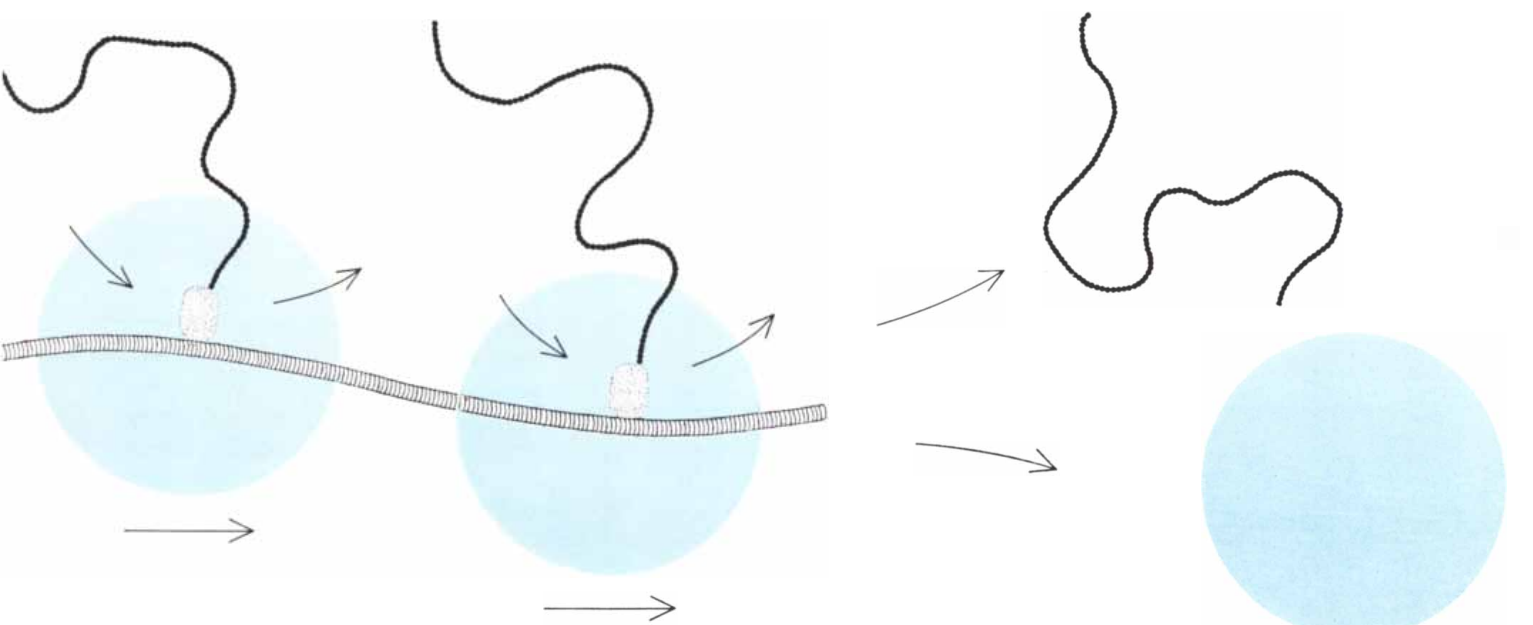
As the concept of the polysome became clearer we were naturally anxious to look for polysomes in other cells. It seemed likely that a variety of messenger lengths and polysome sizes would be found. This has turned out to be the case.

A human tumor cell known as the HeLa cell is widely grown in tissue culture and provides a convenient example of a mammalian cell that produces many kinds of protein. Polysomes from the HeLa cell were prepared at M.I.T. by Sheldon Penman, Yachiel Becker and James E. Darnell. When we subjected these polysomes to sucrose-gradient centrifugation, we obtained the curves plotted in the illustration at the top of the next page. The electron microscope shows that the most common polysome species is one containing five or six ribosomes, but the distribution is much broader than that in the reticulocyte. Some of the HeLa polysomes contain 30 or 40 ribosomes.

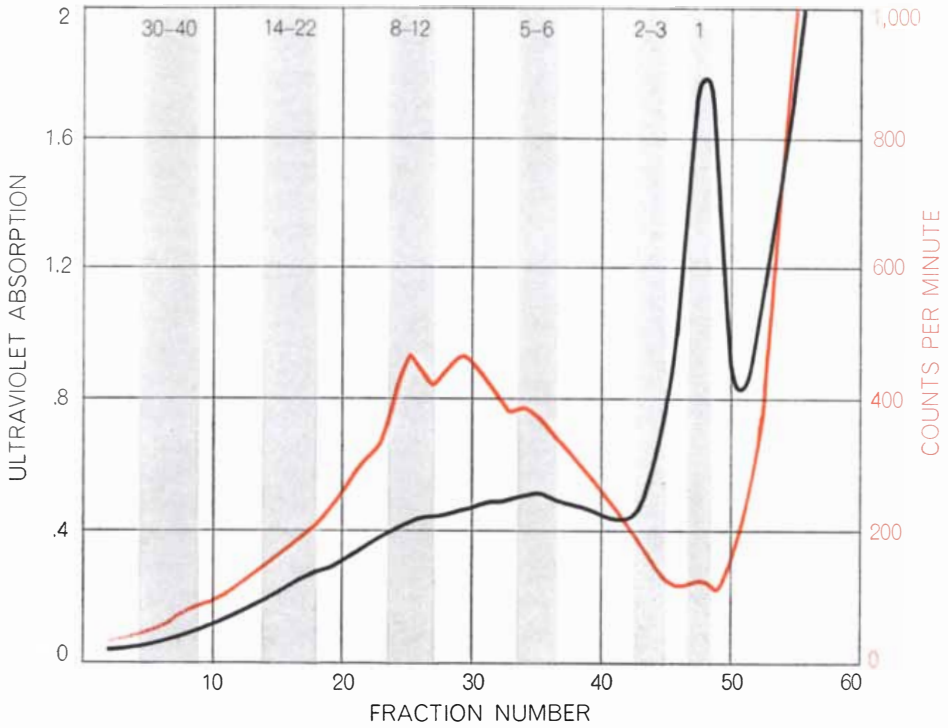
It is not surprising that the distribution of polysomes from another kind of mammalian cell is much broader than that found in the reticulocyte. The reticulocyte is highly specialized and predominantly makes a single protein. Other mammalian cells make a great variety of protein molecules to conduct a variety of metabolic activities. A broad distribution of polysome sizes implies that a cell contains messenger RNA of many different lengths. Presumably their length is proportional to the lengths of the polypeptide chains being synthesized, but this may not be the only interpretation. Some of the long messenger RNA strands associated with polysomes that contain 20 or more ribosomes may contain information for making more than one kind of polypeptide chain.

This is almost certainly true of polysomes consisting of 50 to 70 ribosomes, which are found in cells infected by the virus of poliomyelitis. The long chain of RNA that bears the genetic code of this virus evidently serves as a strand of messenger RNA when it enters a mammalian host cell. Experiments by Penman, Darnell, Becker and Klaus Scherrer have shown that the polysomes that occur normally in a mammalian cell in tissue culture decrease sharply when the cell has been infected by polio virus. The rate of disappearance of the polysomes can be hastened by feeding the cells actinomycin D, an antibiotic that prevents the manufacture of messenger RNA. Thus about three hours after poliovirus infection and treatment with actinomycin D few polysomes can be found in the cell. Half an hour later, however, a new class of polysomes appears. The proteins synthesized on these polysomes are characteristic of the polio virus rather than of the mammalian cell. These virus-induced polysomes are among the largest we have seen in the electron microscope. They undoubtedly manufacture more than one kind of protein molecule; hence some additional features may have to be added to the simple polysome model I have described.

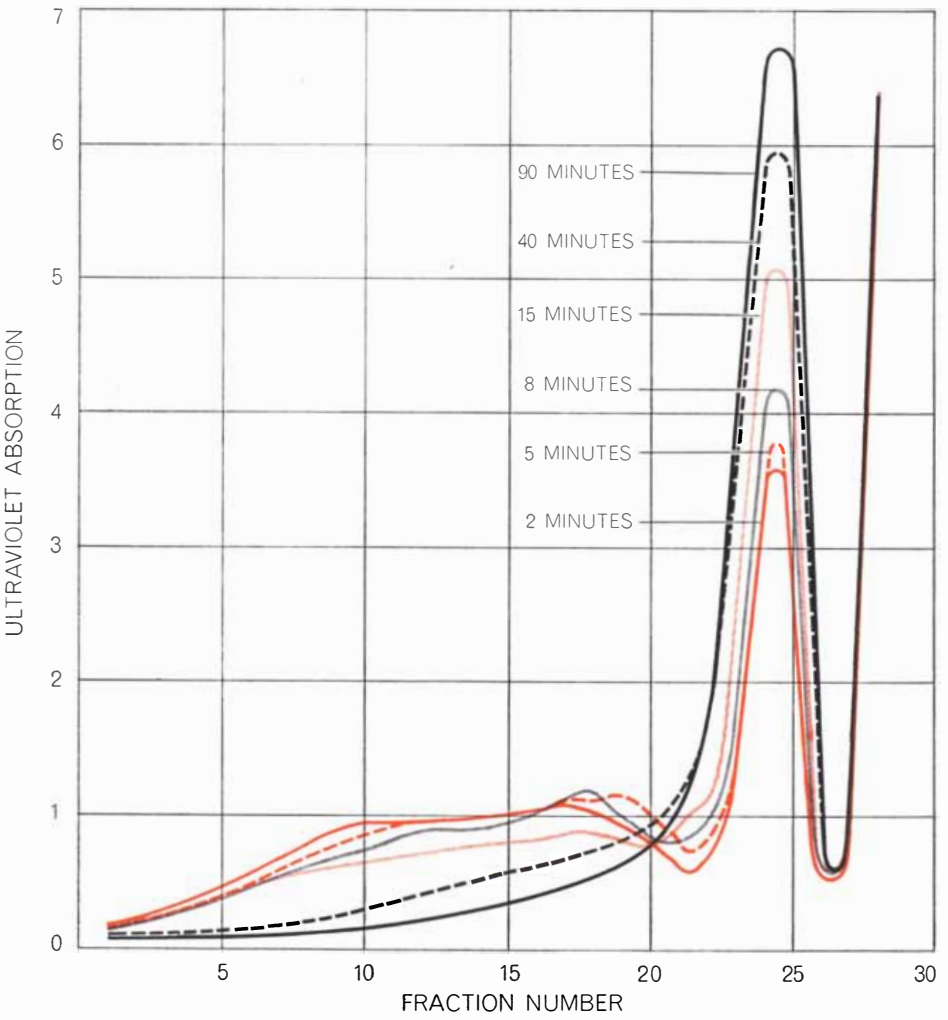
I shall mention briefly a few of the experiments we have designed to test our polysome model. The model as-



tide chain. The amino acids (*black dots*) for the chain are delivered by transfer RNA (*oblong shapes*). The polypeptide shown here contains 150 amino acid subunits, the number found in one chain of hemoglobin. The complete protein contains four chains.



MAMMALIAN POLYRIBOSOMES appear as a very broad peak of fast-sedimenting material when analyzed by sucrose-gradient centrifugation. Electron micrographs show that one peak of the ultraviolet absorption coincides with polyribosomes containing five or six units.



RELEASE OF SINGLE RIBOSOMES is demonstrated by incubating cell extracts with amino acids and an energy supply. Sucrose-gradient experiments show that the broad initial peak of polyribosomes gradually disappears and that the single-ribosome peak rises steadily.

sumes, for example, that an individual ribosome should be able to synthesize a polypeptide chain even though it normally works side by side with other ribosomes. This can be tested by saturating a reticulocyte extract with large amounts of external messenger RNA, such as the synthetic messenger RNA polyuridylic acid. This substance, which contains only one of the four bases normally found in messenger RNA, produces a synthetic polypeptide containing only one kind of amino acid: phenylalanine. By adding enough of the synthetic messenger to a reticulocyte extract one can obtain an extract in which there are as many messenger molecules as ribosomes. In this case most of the ribosomes should pair off with a messenger, leaving few ribosomes to form polysomes. The polysomes already in solution should be unaffected by the introduction of new messengers. Experiments of this type performed in our laboratory, as well as by Gierer in Tübingen, have shown that single ribosomes actively make the synthetic polypeptide polyphenylalanine when polyuridylic acid is added but that the polysomes themselves are inactive. Hence it is clear that individual ribosomes attached to single messenger strands can produce a polypeptide.

Our model also suggests that it should be possible to attach an additional ribosome to a polysome. We have postulated that a ribosome can attach itself to only one end of a messenger strand. If a ribosome could attach itself anywhere, chaos would result. In our simple model there should be only one attachment site on a polysome, whether it contains five ribosomes or 10. In two fractions containing equal numbers of ribosomes, however, there should be twice as many attachment sites in a fraction composed of five-unit polysomes as in a fraction composed of 10-unit polysomes.

Experiments to test this assumption were performed in our laboratory by Howard M. Goodman, a graduate student. Using a culture of HeLa cells, he produced single ribosomes labeled with the radioactive isotope hydrogen 3, or tritium. These single ribosomes were extracted and added to an unlabeled HeLa extract that contained a normal distribution of single ribosomes and polysomes. After a short period of incubation the extract was subjected to sucrose-gradient centrifugation. A test for radioactivity showed that some of the tritium-labeled single ribosomes had indeed become attached to polysomes. Moreover, in accordance with the prediction, twice as many single ribosomes were attached to five-unit polysomes as to 10-unit poly-

somes when the total number of ribosomes in each fraction was equal.

Our model also makes predictions about events at the terminal end of the messenger strand. It indicates that both ribosomes and polypeptide chains should be released from polysomes that are incubated under protein-synthesizing conditions. This can readily be tested in cell-free extracts because the extracts do not fully reproduce the functions of the intact cell. In particular, the messenger RNA is not replaced and other substances are destroyed, so that in the course of 90 minutes to two hours the cell extract gradually loses its ability to initiate the synthesis of protein. We are still, however, able to test for the release of ribosomes and polypeptide chains from polysomes.

To determine if single ribosomes are released from polysomes as protein synthesis proceeds we incubated cell extracts for varying periods before subjecting them to sucrose-gradient centrifugation. The results are plotted in the bottom illustration on the opposite page. At the beginning there is a large polysomal peak and a modest peak of single ribosomes, representing the normal distribution in the mammalian HeLa cell. As incubation proceeds there is a gradual decrease in the number of polysomes and a decrease in their size. At the same time there is an increase in the number of single ribosomes. At the end of 90 minutes of incubation most of the polysomes have disappeared, having been converted into single ribosomes. We have established that this release of single ribosomes takes place only if the energy necessary for protein synthesis is added to the reaction mixture. In other words, the system is not degraded simply by the passage of time.

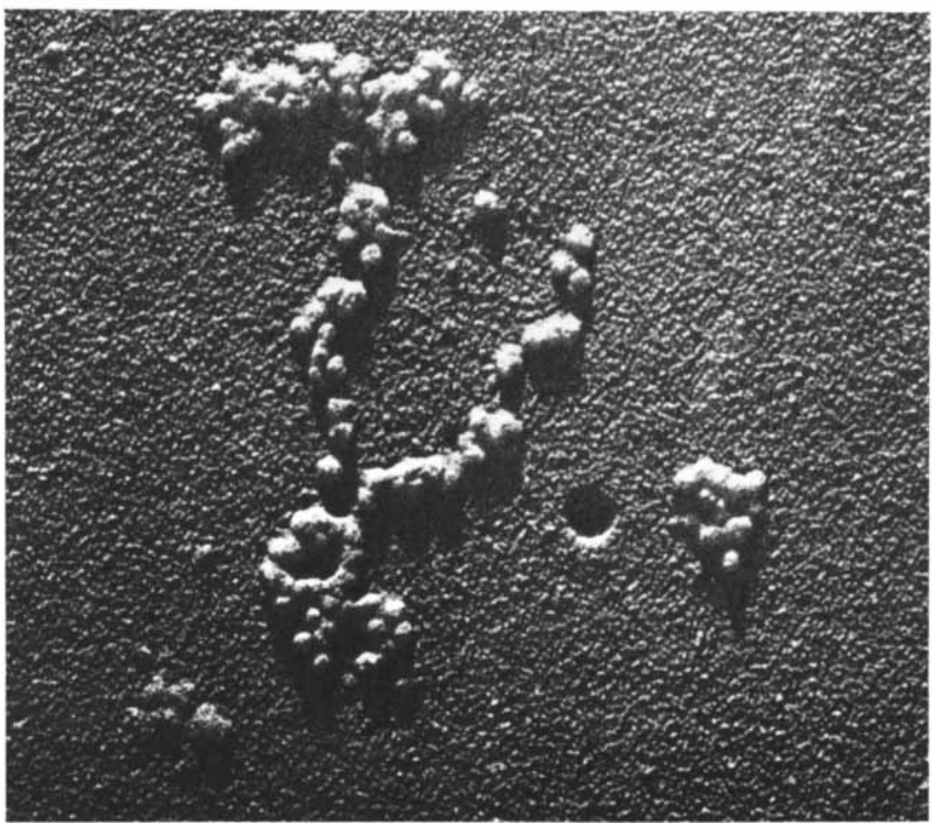
To determine if polypeptides are released as incubation proceeds we devised the following experiment. A suspension of living mammalian cells was incubated for a minute and a half with carbon-14-labeled amino acids and then the cells were chilled to halt protein synthesis. This process loaded the polysomes with labeled amino acids that were linked into still unfinished polypeptide chains. Now the cells were broken open and the ribosomes and polysomes were isolated by centrifuging them into a pellet. The liquid on top of the pellet was poured off in order to get rid of the labeled amino acids floating around in the cell extract. The ribosomes and polysomes were then resuspended in a fresh cell extract identical with that removed except that it contained normal rather than radioactive amino acids.

This suspension was incubated under protein-synthesizing conditions, and radioactivity was measured as a function of time in the polysome fraction as well as in the soluble-protein fraction floating at the top of the sucrose gradient. As incubation proceeded, the radioactivity decreased in the former fraction and rose in the latter, showing that most of the labeled amino acids, originally held in the polysomes, were ultimately released as soluble protein. In sum, these three groups of experiments show that it is possible to attach ribosomes to polysomes, to detach ribosomes from polysomes and to liberate polypeptide chains under the conditions of protein synthesis.

I shall mention just one more experiment that supports our polysome model. This experiment, performed in our laboratory by Warner, established the average length of the incomplete polypeptide chains in the polysomes of the reticulocyte. In a complete polypeptide chain found in hemoglobin there are 17 subunits of the amino acid leucine. Warner incubated intact reticulocytes with carbon-14-labeled leucine and determined the number of leucine subunits in the polysome fraction. Knowing the number of ribosomes per polysome, he could easily calculate the number of leucine subunits per ribosome. He found the average number was 7.4. This implies that on the average there is almost half of a complete polypeptide chain on each ribosome in the polysome region. This is consistent with our proposed mechanism, which suggests that there is one growing polypeptide chain for each ribosome in the polysome.

Whether or not polysomes exist in all living cells is still to be determined. To date polysomes have been isolated from several species of bacteria, from the primitive plantlike organisms known as slime molds, from unicellular protozoa and from much more complex cells, including those of man. Therefore I believe that polyribosomes may be the general method used by nature for assembling amino acids into most proteins, and that protein synthesis does not usually occur on single ribosomes.

The discovery of polysomes represents the latest addition to the rapidly growing body of knowledge that describes at the molecular level how genetic information coded in DNA is eventually expressed in terms of active proteins that govern the metabolism and structure of the cell. One of the key problems still to be explained is how complicated globular proteins are put together to form a biologically active molecule. Some of these proteins have more than one polypeptide chain, and it may be that the polysomes play an active role in this next step of protein synthesis.



POLIO VIRUS POLYRIBOSOMES, the largest yet observed in the electron microscope, contain at least 50 individual ribosomes. These have been enlarged 115,000 diameters.

QUASI-STELLAR RADIO SOURCES

Neither stars nor galaxies, they are perhaps the brightest objects in the universe, and among the most distant. Until their puzzling spectra were recently decoded they were mistaken for nearby stars

by Jesse L. Greenstein

Early this year astronomers discovered that five celestial objects, previously regarded as being faint and somewhat unusual stars in our galaxy, are perhaps the most bizarre and puzzling objects ever observed through a telescope. Not faint stars at all, they are extremely powerful sources of radio noise and, according to new estimates of their light output, are perhaps the brightest objects in the universe. The two objects that have been studied in detail may be 100 times brighter than our entire galaxy of 100 billion stars. They appear faint because they are so far away. One of the two is the second most distant object known; the other three, whose distances have not yet been established, may be more distant still. Heretofore the only objects that could be identified at such great distances were galaxies. The newly studied objects are almost certainly much smaller. Their diameters are estimated to be no more than a fifth and perhaps as little as a hundredth the diameter of a typical galaxy.

The dramatic recognition of these unusual objects was the result of a fruitful collaboration between radio and optical astronomers. The former provided precise positions of five radio sources, which were then identified with starlike objects on photographic plates made at the Mount Wilson and Palomar Observatories. Indeed, at first the objects were thought to be stars—the first stars, except for the sun, with a radio output strong enough to be detected on earth. Further study showed, however, that they were not individual stars but objects of a kind hitherto unknown. In recognition of their small size, and for lack of a better name, they are called quasi-stellar radio sources. The name will probably be changed when their true nature becomes clearer, but it will have to serve for this article.

The five quasi-stellar sources so far known are 3*C* 48, 3*C* 147, 3*C* 196, 3*C* 273 and 3*C* 286. The "3*C*" stands for "Third Cambridge," which is short for Third Cambridge Catalogue of Radio Sources, compiled by a group working under Martin Ryle of the University of Cambridge.

For almost two decades a major objective of radio astronomers has been to catalogue and provide precise locations of radio sources with the hope that they might ultimately be identified with objects visible on plates made with large optical telescopes. The 3*C* list provides positions for a few hundred of the brightest radio sources. Some of them are concentrated near the plane of the Milky Way and have been identified with gaseous nebulae. Their radio energy arises from the thermal motion of highly excited particles. A few sources have a large angular diameter and can be recognized as remnants of supernovae. Their radio energy is largely nonthermal in origin, and it is believed to be generated by high-speed electrons trapped in magnetic fields. The radio waves produced by such electrons are called synchrotron emission.

At higher galactic latitudes, that is, away from the plane of the Milky Way, the majority of the 3*C* sources are distant galaxies. About 50 have now been identified with objects visible in optical telescopes. The visible portion of a typical radio galaxy is unmistakably a vast assembly of stars, tens of thousands of light-years in diameter. The radio emission often arises in two much larger invisible regions, one on each side of the visible galaxy. The angular diameter of each region is from one to five minutes of arc, or about 10 times larger than the galaxy itself. In a few cases the radio-emitting region is centered on an optical galaxy and is smaller than it is.

The galaxies identified as strong radio sources frequently exhibit one or more peculiar features [see "Radio Galaxies," by D. S. Heeschen; SCIENTIFIC AMERICAN, March, 1962]. Some of the sources seem to be two or more distorted galaxies in near contact. In other cases there is an abnormal distribution of light across the surface of the galaxy. The majority of radio galaxies are elliptical or spherical in shape; they contain little or no gas and few high-luminosity stars, but they are themselves very luminous. A few unusual, gas-rich spiral galaxies are also radio sources.

Whatever gas is present in most radio galaxies is highly ionized, which means that the atoms of the gas have been stripped of one or more electrons. As a result spectrograms show strong, sharp emission lines of elements with ionization potentials of up to 100 electron volts. Ordinary ellipsoidal galaxies exhibit only weak emission lines of elements with ionization potentials no greater than 15 electron volts. High ionization potentials indicate that the interstellar gas is very hot, which in turn is evidence that energetic disturbances have taken place or may still be in progress in the galaxy.

In some cases the amount of radio energy emitted by a strong radio galaxy equals or even exceeds the amount of energy emitted as visible light by the stars of the galaxy. The radio energy is believed to be produced chiefly by synchrotron emission. That this process might account for the output of radio galaxies was first proposed by the Soviet astrophysicists I. S. Shklovsky and V. L. Ginzburg; their view is now generally accepted.

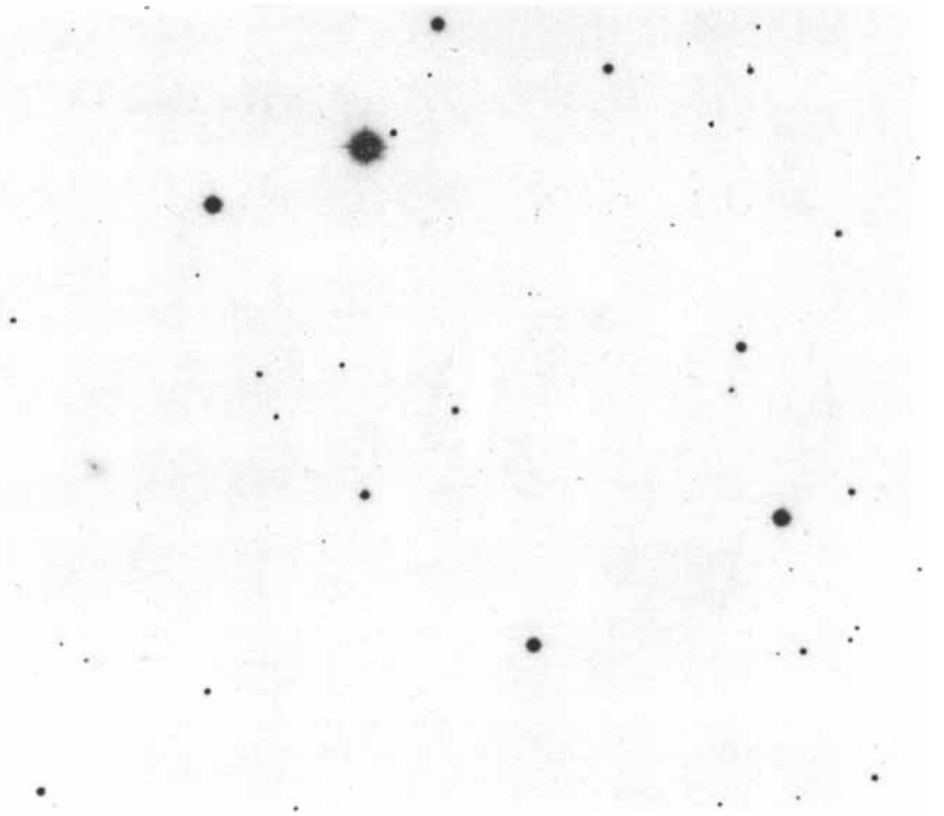
The mechanism that produces the high-speed electrons and the magnetic fields is not understood. It is commonly assumed, however, that both have been

created by titanic explosions inside the galaxy. A possible sequence in the life of a radio galaxy is illustrated on the next page. Following an initial explosion, high-energy electrons and magnetic fields are ejected from the galaxy, and the charged particles are trapped by the fields in the invisible regions from which radio noise emanates. By assuming that the regions have traveled away from the galaxy at almost the speed of light one can compute approximately when the initial explosion took place.

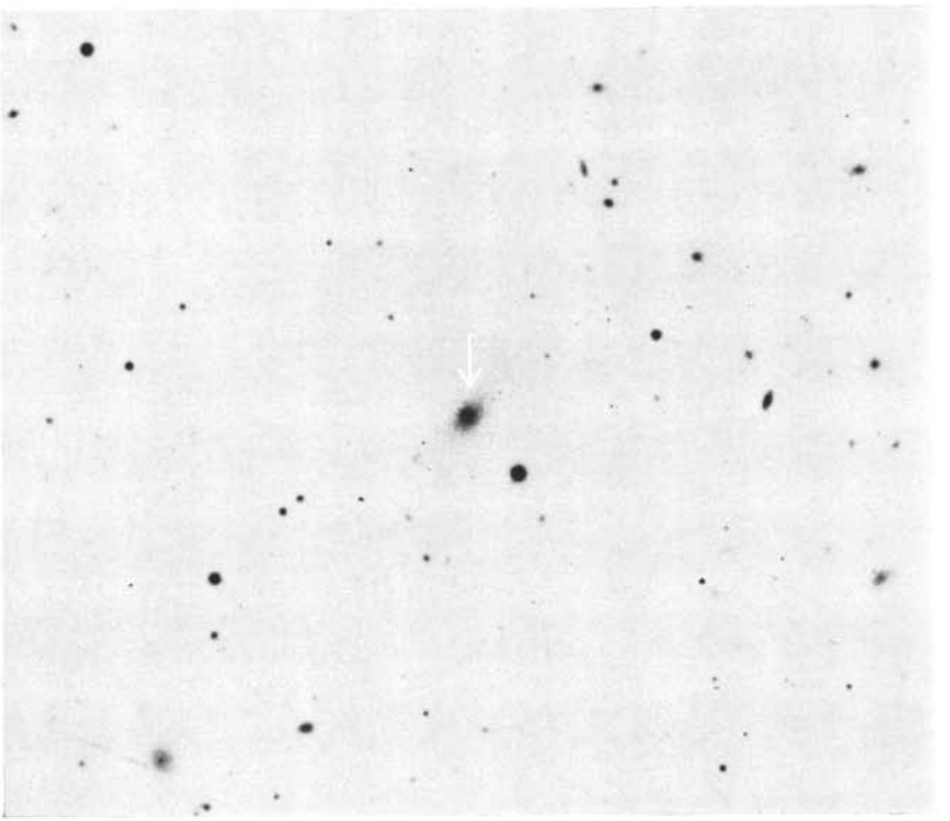
The most intense radio sources emit nearly 10^{45} ergs per second of radio-frequency power and an unknown amount of infrared radiation, ultraviolet radiation, X rays and gamma rays. If one assumes that a source has been radiating for a million years, a minimum value indicated by its distance from the galaxy, its cumulative output is more than 10^{58} ergs. Since the process that converts particle and magnetic-field energy into radiation cannot be very efficient, the total energy originally stored in the particles and the field must have been 10^{60} to 10^{61} ergs. For purposes of comparison, the nuclear energy that would be produced by the total conversion of a mass of hydrogen equal to the mass of the sun into helium is 10^{52} ergs. This implies that the driving force of the original explosion needed to create a strong radio galaxy was at least equivalent to the total nuclear-energy output of 10^{8} or 10^{9} (100 million or a billion) suns.

The question perplexing theoreticians is how 10^{8} or 10^{9} solar masses of hydrogen can be detonated in a single explosion. For the normal thermonuclear processes of the sun to release 10^{52} ergs of energy would require 10 billion years. More puzzling still, the sequence of events that results in radio emission seems to defy the second law of thermodynamics, which states that in a closed system energy can pass only from a higher to a lower form. In a radio galaxy the reverse seems to happen. The nuclear energy of the initial explosion (if it is indeed nuclear) produces rapidly moving particles and gamma rays, both of which have energies of a few million electron volts. Through collisions and interaction with surrounding matter their energy should be quickly degraded into thermal energy. Instead, by some unknown mechanism, it reappears in the form of high-grade energy, that is, in the form of 100-billion-volt electrons and large-scale magnetic fields. At this point one can only say that suitable conversion mechanisms do seem to exist in nature.

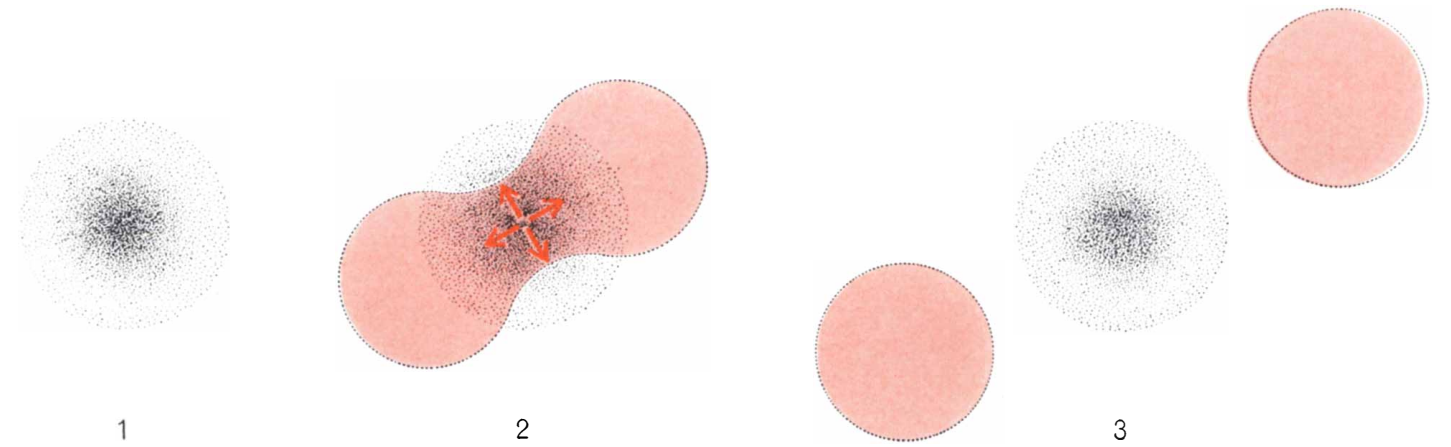
A major obstacle to identifying radio



QUASI-STELLAR RADIO SOURCE 3*C* 48, second most distant object known, appears at the center (*arrow*) of this photograph taken with the 200-inch Palomar telescope. The picture is printed as a negative to preserve detail. Until identified as a strong radio source, the object had been regarded as just another star of 16th magnitude. It is now said to be quasi-stellar because it is almost certainly not a star. On the other hand, if it were the size of a typical galaxy, it would produce a diffuse image on a photographic plate, as shown below.



TYPICAL RADIO GALAXY, M23–1*12* (*arrow*) is about equal in apparent brightness to 3*C* 48. M23–1*12* is about .8 billion light-years away compared with four billion for 3*C* 48. In this Palomar plate M23–1*12* appears brighter than 3*C* 48 (actually darker, in this negative print) because it has been exposed about three times longer and printed with increased contrast. The same treatment when applied to 3*C* 48 fails to reveal a comparable galactic structure.



BIRTH OF A RADIO GALAXY may involve a titanic explosion that releases the energy equivalent to the fusion of 10 million to a billion solar masses of hydrogen. Before the explosion the galaxy may be of the standard elliptical or spheroidal type (*1*). The explosion (*colored arrows*) creates a source of radio noise in a dumbbell-shaped region (*2*). The radio source, propelled outward by the explosion, often separates into two regions, which can travel hundreds of thousands of light-years from the optical galaxy (*3*).

sources with visible objects is that radio telescopes have an inherently low resolving power; precise locations are therefore hard to establish. A 200-foot parabolic antenna, when used by itself, cannot pinpoint the location of a radio source with an accuracy greater than several minutes of arc. In a region of this diameter an astronomical photograph will contain dozens of objects.

To increase resolving power the radio astronomer can use a multielement antenna, for example two parabolic dishes separated by several thousand feet. The waves from a radio source reach the two dishes slightly out of phase, thereby creating an interference pattern from which the source's location and size can be calculated much more accurately than when only a single dish is used.

Using this technique, called interferometry, observers at the University of Manchester and the California Institute of Technology have made detailed studies of the structures of the stronger radio sources. The Manchester group consisted of L. R. Allen, B. Anderson, R. G. Conway, H. P. Palmer, U. C. Reddish and B. Rowson; the Cal Tech observers were Per Maltby, Thomas A. Matthews and Allen T. Moffet. The Manchester group recorded emission from some 200 radio sources at wavelengths longer than one meter. Using an interferometer with simple movable elements, which were separated by distances of up to 61,000 wavelengths (nearly 75 miles), they obtained a limiting resolution of one second of arc. Among the 200 sources surveyed four are now classed as quasi-stellar. Two of the four consisted of a small, bright core near the limit of resolution, surrounded by a weak halo perhaps 20 seconds of arc in diameter. The other two sources were bright points smaller than one second of arc. One of these was the radio object 3*C* 48, a quasi-stellar radio source since studied extensively.

The other extensively studied quasi-stellar source is 3*C* 273, whose precise location was provided early this year by the Australian observers C. Hazard, M. B. Mackey and A. J. Shimmins. The Australians used the excellent 210-foot parabolic radio telescope of the Commonwealth Scientific and Industrial Research Organisation near Sydney. They also took advantage of the existence of a large natural disk that traverses an appreciable fraction of the sky and in the process blacks out a number of radio sources. This disk, the moon, which most optical astronomers consider a nuisance, has enabled radio astronomers to determine very accurate positions for radio sources and to observe small details in their structure.

The moon can be considered as being equivalent to a sharp knife-edge, which produces simple diffraction fringes as a bright object disappears behind it or emerges [*see illustration on page* 58]. Moreover, since the moon's position at any time is known with considerable accuracy, the precise moment of occultation and reappearance can be established. The Australians examined several of the 3*C* sources known to be of small angular diameter, confirmed their small size and provided better positions. In this group was one of the five small objects now classed as quasi-stellar radio sources: 3*C* 273.

Armed with precise new positions, Thomas Matthews of the Cal Tech Radio Observatory and Allan R. Sandage of Mount Wilson and Palomar inspected astronomical photographs looking for objects that might coincide with the small radio sources. No unusual galaxy coincided with any of them. Matthews and Sandage were able to find, however, a stellar image within the circle of probable error computed for each source. These images were on first inspection indistinguishable from any of the hundreds of thousands of stars on the plate. Perhaps the coincidence in position was merely an accident; perhaps none of the visible objects accounted for the radio emission. This was conceivable because it has often been assumed that most radio sources are objects too distant and faint to be photographed even with the 200-inch Palomar telescope.

Nevertheless, I was one of many observers who felt it was important to investigate the coincident stars. We thought that they might be the first true radio stars. In the early days of radio astronomy it was assumed that many sources might be identified with stars, until closer study of the problem made this seem unlikely. At the distance of the nearest star the radio emission of the sun would be reduced by a factor of 10^{11}, which would place the star far below the threshold of sensitivity of existing radio telescopes. There have been reports that radio signals have been detected from a few nearby "flare stars" at the time of flare-up, but the evidence is still uncertain.

In any case, Sandage made a new series of photographs with the 200-inch telescope and discovered faint features not previously seen in two of the quasi-stellar sources. One plate shows faint, reddish wisps of nebulosity, about five by 12 seconds of arc in size, surrounding the stellar image coincident with 3*C* 48. Another photographic plate shows a still fainter nebulosity associated with an ob-

ject possibly identifiable with 3C 196.

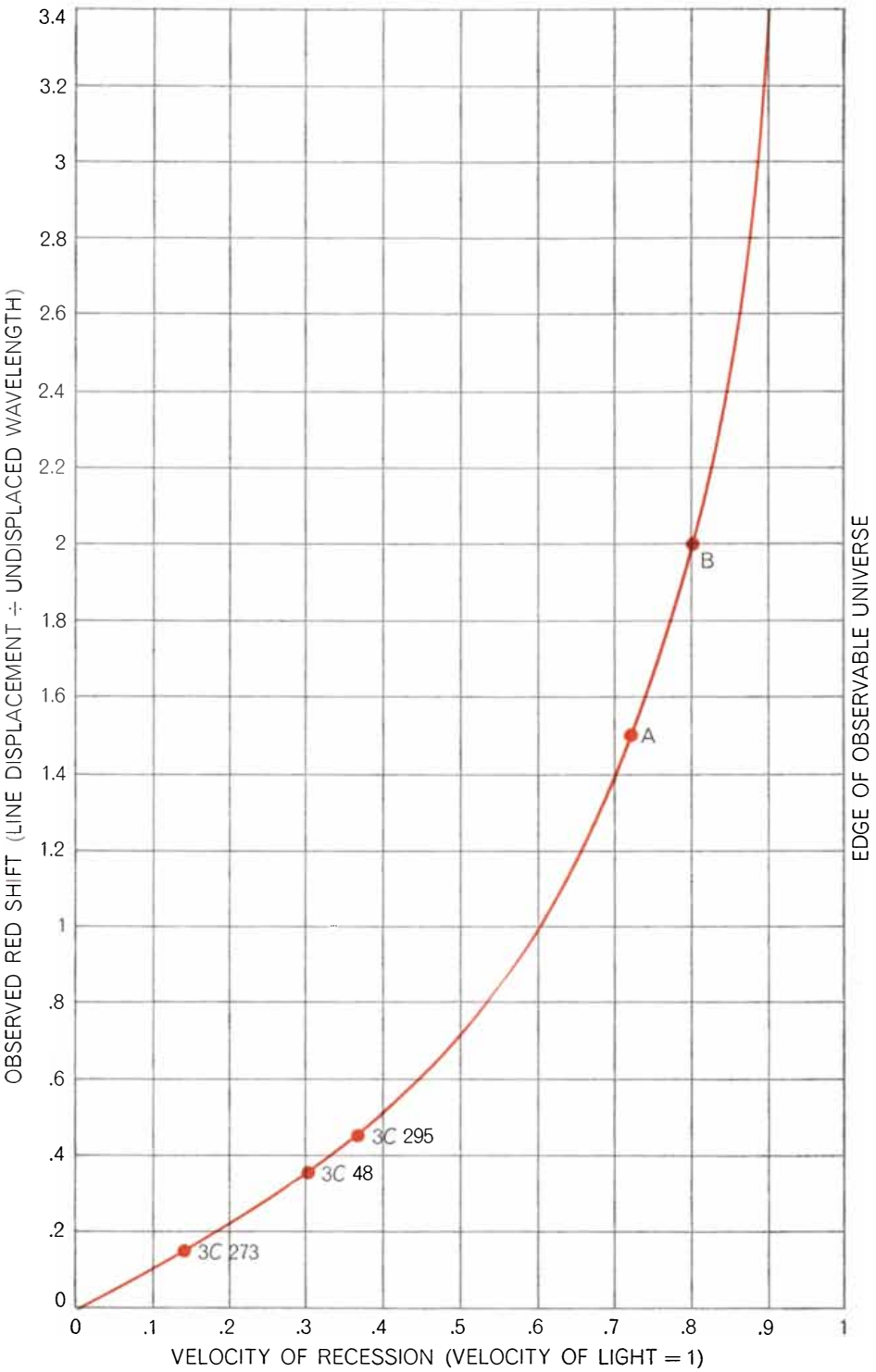
The accurate position and peculiar radio structure of 3C 273 enabled Maarten Schmidt of Mount Wilson and Palomar to make a beautiful identification of the radio source. The Australian radio observation, made with the help of the moon, showed that 3C 273 is made up of two small components designated A and B, whose centers are separated by 19.5 seconds of arc [*see illustration on page 59*]. Component B is slightly elliptical and much weaker than component A, which is markedly elliptical. Schmidt obtained photographs showing that a faint jet of nebulosity overlaps the radio position established for component A. At the location of component B his photographs show what appears to be a 13th-magnitude star. There is no uncertainty about the identification of the two components, because there is nothing else interesting on this part of the plate.

At this writing 3C 48 and 3C 273 remain the best identified and most successfully studied of the five known quasi-stellar radio sources. In optical astronomy a direct photograph of an object is only a prelude to a detailed study of its spectrum, which can provide clues to the object's temperature, composition and distance. The first low-dispersion spectra of 3C 48 were made by Sandage more than three years ago. The plates showed several diffuse emission lines superposed on a continuous spectrum. The position of the lines did not seem to coincide with any of the well-established lines of atomic spectra.

In an effort to solve the mystery, spectra with higher dispersion (that is, a greater separation between spectrum lines) were made, first by Guido Münch of Mount Wilson and Palomar and then by me. The object is so faint that exposures as long as seven hours were required with a spectrograph of focal ratio $f/1$. In such long exposures the dominant features on the spectrogram are the lines emitted by excited atoms and molecules in the earth's atmosphere. The faintest of these night-sky lines produce a background "noise" that sets the present limit to the spectroscopy of distant or faint objects. (This limitation will be overcome eventually by placing observatories outside the atmosphere.)

By careful measurements of seven plates made by various observers I was able to establish the positions of six lines that seemed to be real features of 3C 48. The lines lay between a wavelength of 3,500 angstrom units at the ultraviolet end of the spectrum and 6,000 angstroms at the red end. They fell into no simple pattern and did not correspond with those observed in other stars or supernovae, nor with the prominent lines of bright nebulae.

The spectroscopist is always aware that the census of spectrum lines is incomplete and that he may be seeing atoms under some freakish condition of excitation. The census includes just about all the lines that can be produced under laboratory conditions. Astronomical objects, however, frequently show "forbidden" lines that are not easily produced in the laboratory. They arise from



RED SHIFT OF DISTANT GALAXIES is interpreted to mean that the galaxies are receding. The curve shows how the observed red shift is related to the velocity of recession, which can never quite reach the velocity of light. The radio galaxy 3C 295, about five billion light-years away, is the most distant known object. The quasi-stellar radio source 3C 48 is the next most distant; 3C 273, also a quasi-stellar source, is about half as distant as 3C 48. *A* shows where a spectrum line normally in the ultraviolet at 2,800 angstrom units would shift into the infrared region at 7,000 angstroms. *B* shows where the Lyman-alpha line of hydrogen at 1,216 angstroms would shift into the visible near-ultraviolet at 3,647 angstroms.

rare atomic transitions that occur only when the atoms are in a gas of low density. Fortunately the wavelengths of forbidden lines can be predicted from theory, and their census for the common elements is fairly complete.

The attempt to identify the emission lines in 3*C* 48 led me through the spectroscopic literature and left me with the conviction that the lines might be emitted by highly excited ions, notably helium stripped of one electron and oxygen stripped of five. In fact, one of the lines coincided with one produced for the first time in a British experimental thermonuclear device, and it added to my confidence. Lines still unidentified, I told myself, might belong to the yet-unknown spectrum of an ion such as neon in a highly excited state.

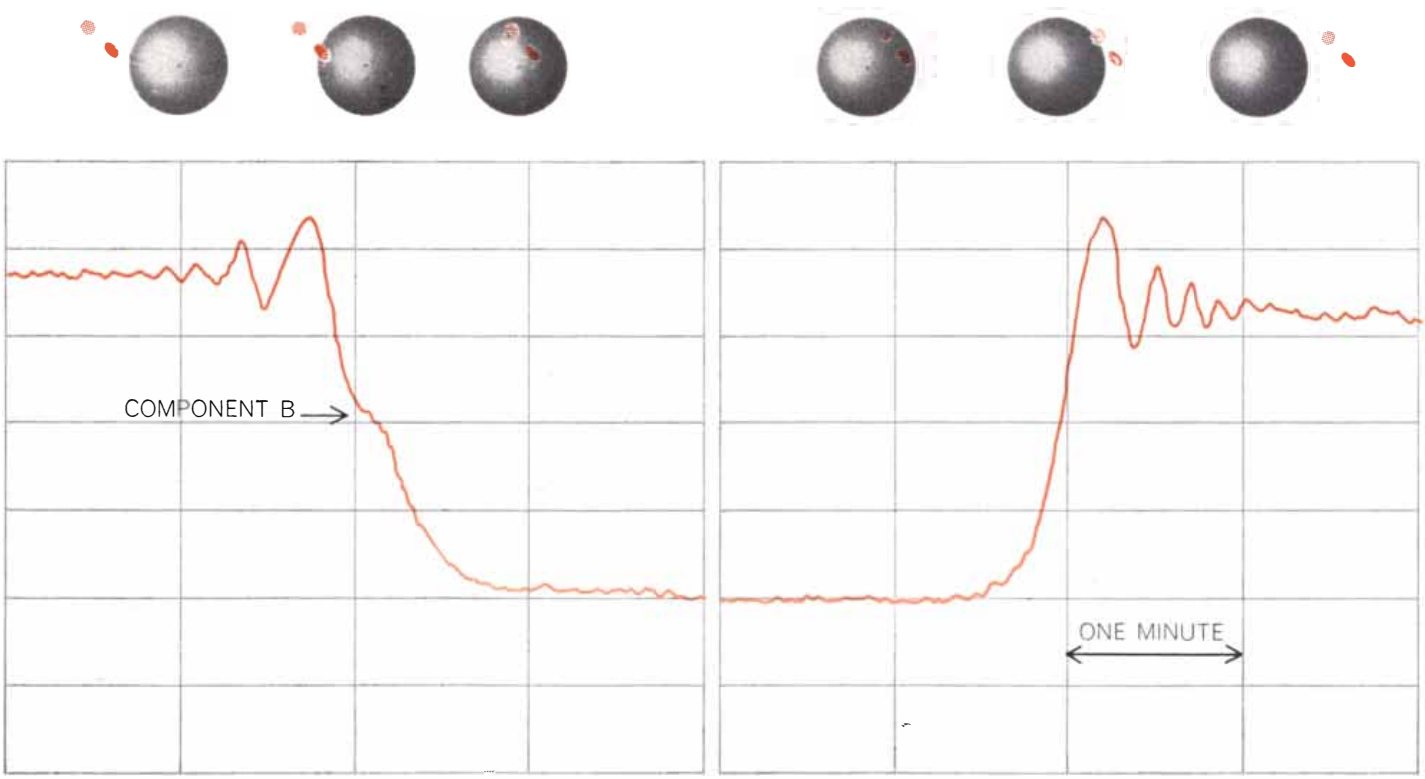
The mystery deepened when Schmidt was successful in recording a few weak emission lines from the very faint sources 3*C* 147, 3*C* 196 and 3*C* 286. He found that none coincided with any of the lines in 3*C* 48. Of the possible interpretations the only one then surviving was that these were stars of extraordinary composition and that all of them were different. I speculated that they were rich in rare elements, representing the remnants of supernovae caught in various stages of element-building. But the requirement that no two objects have even one spectral line in common seemed rather "sticky."

There the matter rested uneasily for more than two years until Schmidt began studying the spectrum of 3*C* 273. This time nature was kind. Four of the six emission lines from 3*C* 273 formed a simple harmonic pattern with separation and intensity decreasing toward the ultraviolet. The lines obviously belonged to a series of the type expected from hydrogen or any other atom that had been stripped of all electrons but one. But which atom and which series?

Schmidt soon concluded that no atom gave the observed wavelengths. If he assumed, however, that the spectrum lines had been shifted toward the red by 16 per cent, four of the observed wavelengths agreed with those of hydrogen. One of the remaining lines was then easily identified as a forbidden line of doubly ionized oxygen (oxygen stripped of two electrons) shifted by the same amount. The last line was at 3,239 angstroms, near the ultraviolet end of the spectrum. Before being shifted toward the red it must have originated at 2,800 angstroms, in the ultraviolet part of the spectrum that is normally unobservable. We remembered that two lines of ionized magnesium lie side by side at 2,800 angstroms and that they were the strongest emission lines found when the solar spectrum was recorded above the earth's atmosphere by rocket. Subsequently, using a photoelectric scanning spectrograph, J. Beverly Oke found that the first line of the hydrogen series, H-alpha, which has a "rest" wavelength of 6,563 angstrom units, had been shifted to about 7,590 angstroms in the infrared. Schmidt's important discovery was the clue that unlocked the puzzle.

I immediately re-examined my spectra of 3*C* 48 to see if application of a red-shift factor would make sense of the observed lines. The strongest line in my spectra of 3*C* 48 was at 3,832 angstroms. If this were the 2,800 line shifted by more than 1,000 angstroms, it would imply a red shift of 37 per cent. By assuming the same shift throughout the spectrum Matthews and I were able to identify five other lines, but curiously none of them coincided with a hydrogen line. They proved to be forbidden lines of singly ionized oxygen and of neon ionized two times and four times. If hydrogen lines are present, they are too broad and have too little contrast to emerge from the background.

To produce quadruply ionized neon requires 100 electron volts of energy, so



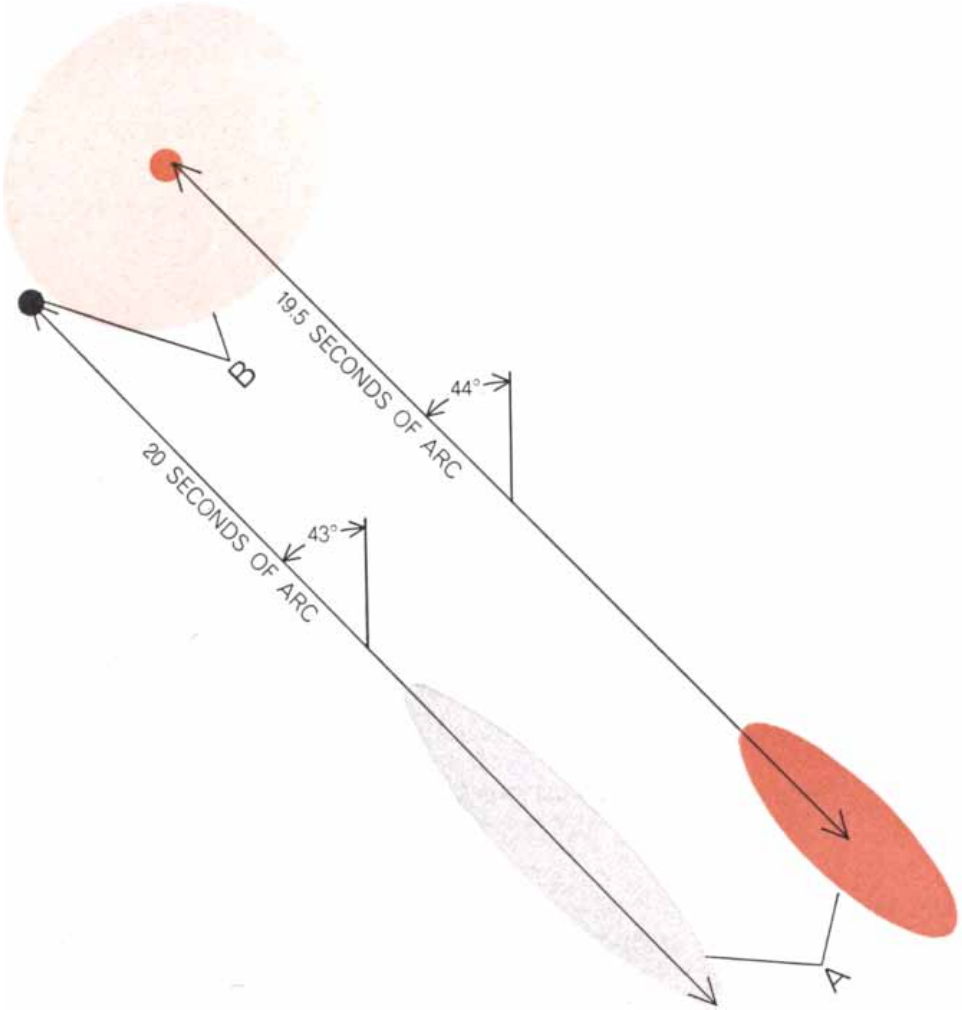
LUNAR OCCULTATION of a radio source can provide extremely precise knowledge of its position and structure. The curve shows how the radio signal from the two-component quasi-stellar source 3*C* 273 was blacked out by the moon on August 5, 1962, as recorded by Australian workers using the 210-foot radio telescope at Parkes, near Sydney. The step in the descending curve (*left*) indicates where component *B* started to disappear. Because of their orientation with respect to the moon both components emerged together.

that its appearance implies that the gas clouds in 3C 48 are hotter and of lower density than those in 3C 273. Moreover, Oke finds that the background continuum of the two objects is different, which suggests that it has a different origin. Whether or not the compositions are the same and whether or not they resemble normal stellar material is not yet known.

The large red shifts of 3C 273 and 3C 48, respectively 16 and 37 per cent, came as a complete surprise. Heretofore red shifts of this magnitude had been observed only in the most distant galaxies. The largest known red shift, measured at Palomar by Rudolph Minkowski, is that of the faint galaxy 3C 295. Originally found as a radio source, 3C 295 has a red shift of 46 per cent. Since the pioneer work of Edwin M. Hubble of the Mount Wilson Observatory in the early 1920's it has been known that the more distant the galaxy, the greater the red shift. The commonly accepted explanation for this shift in frequency is that the galaxies are in general recession, from us and from each other.

The red shift of galaxies has been related to a velocity of recession and to a scale of distances. When the red shift is small, its value in per cent is roughly equal to the velocity of recession expressed as a per cent of the speed of light. This relation is not linear, however, because a recession velocity equal to the speed of light can never be reached no matter how large the red shift. The relation is plotted in the graph on page 57. The graph shows that a red shift of 46 per cent for 3C 295 corresponds to a recession velocity of about 36 per cent of the speed of light. The red shifts of 16 and 37 per cent for 3C 273 and 3C 48 respectively correspond to recession velocities of 15 and 30 per cent. On the currently accepted galactic-distance scale a red shift of 46 per cent for 3C 295 corresponds to a distance of about five billion light-years. The comparable distances for 3C 273 and 3C 48 are two billion and four billion light-years.

Perhaps the most astonishing thing about 3C 273 and 3C 48 is that they do not look like distant objects. An ordinary bright galaxy at a distance of four billion light-years has a visual magnitude of 20 to 22 and can be observed only with the largest telescopes. The visual magnitude of 3C 48 is 16; of 3C 273, 13. The latter can easily be observed with any good amateur telescope. By the same token an ordinary galaxy close enough to be of the 16th magnitude, let alone the 13th magnitude, is easily recognized as a complex stellar system [*see bottom illustration on page 55*]. It is mystifying how 3C 273 and 3C 48 can be so far away and look so bright. On the other hand, if they are not distant objects but are actually stars of the 16th and the 13th magnitude —in which case they would have to lie within our own galaxy—how can one account for the great red shift?



STRUCTURE OF 3C 273 as determined by Maarten Schmidt from Palomar photographs (*left*) is very close to that determined by lunar occultation of its radio signal (*right*). The two views are shown here side by side, although they actually overlap. Component *A* provides about 90 per cent of the radio energy emitted by this quasi-stellar source. In the visible region of the spectrum component *B* is much the brighter and *A* is almost invisible.

Red shifts can have causes other than the "cosmological" expansion of the universe. According to the theory of relativity photons of light must do work to leave a gravitational field. The work expended shows up as a decrease in frequency, or a red shift in wavelength. One can therefore postulate that the red shift of 37 per cent for 3C 48 could arise if the source were extremely dense or extremely massive. For example, an ultradense star with a mass equal to that of the sun and a radius of less than 10 kilometers would exhibit such a red shift, as would a star with 200,000 times the mass of the sun and the same radius.

The densest objects known are the white-dwarf stars, which have less than solar mass and a radius of about 1 per cent that of the sun. The pressure of closely packed ("degenerate") electrons is sufficient to prevent further collapse of the white dwarf even at a temperature of absolute zero. It is conceivable that under extraordinary and transient conditions, not yet studied in detail, the core of a massive star might be crushed to much higher densities than the matter in a white dwarf. If the outer envelope of such a star could then evaporate, a residue of solar mass and a density 10^7 to 10^{13} times that of a white dwarf would be left. At such densities neutrons and hyperons (particles heavier than a neutron) are the stable form of matter.

There are, however, persuasive reasons for believing that the quasi-stellar radio sources cannot be neutron or hyperon stars. In brief, the gaseous envelope of such a star could not be more

SPECTROGRAMS OF 3C 48, made by the author, show three weak emission lines at 3,832, 4,575 and 4,685 angstroms. The illustration actually consists of two spectrograms placed side by side to increase the visibility of faint lines. Even so, the three lines labeled are almost submerged by the continuum radiation of the object. Also visible are a number of prominent night-sky lines produced by air glow in the upper atmosphere. Close inspection of these and other spectrograms disclosed three more very faint emission lines at 4,066, 5,098 and 5,289 angstroms. The six emission lines were identified by assuming that their rest wavelengths had been red-shifted approximately 37 per cent, as illustrated on the opposite page.

SPECTROGRAM OF 3C 295, the most distant known object, shows a single faint emission line (*arrow*) at about 5,450 angstroms. It is believed to be produced by a red shift of 46 per cent in two closely spaced emission lines of oxygen that normally occur at about 3,727 angstroms. In this spectrogram the air glow has produced many bright vertical lines; the brightest is the green auroral line of the night sky. (The bright horizontal line was probably produced by a star.) If the emission line of 3C 295 had happened to coincide with any of the bright night-sky lines, it would never have been seen. Because only one emission line can be seen its identification with oxygen at 3,727 angstroms is at best an informed guess.

than a few hundred meters thick or the gravity effect would progressively vary throughout the envelope and make the emission lines broader than those actually observed. Moreover, the envelope could not exceed a certain low density or forbidden emission lines would be suppressed. The amount of energy that could be radiated from such a small, low-density envelope would be negligible on an astronomical scale. In fact, emission lines from a neutron star could not be observed if it were located much outside the solar system.

There are also grave difficulties with the alternative possibility that the observed red shifts are produced by stars that have 100,000 times or more the mass of the sun. The conventional theory of stellar interiors indicates that a star of more than 100 solar masses would be unstable and thus could not condense from the interstellar gas. Recently, however, Fred Hoyle of the University of Cambridge and William A. Fowler of Cal Tech have speculated about conditions in enormous objects of a million to a billion solar masses.

Setting aside the problem of how so large a mass could collect and successfully traverse a series of unstable configurations of a mass between that of 100 and a million suns, they originally hoped that temporary stabilizing tendencies might arise for very massive stars. Subsequent theoretical studies by Hoyle, Fowler and their associates at Cal Tech seem to show that objects of extreme mass would undergo gravitational collapse so rapidly that stable configurations may not exist. The gravitational red shift in such massive objects would probably prevent photons or neutrinos from leaking out, so that the star would eventually be closed off from our universe except for the influence exerted by its gravitational field.

It is unlikely that we have been able to catch one of these supermassive stars in its collapse phase, just before it has disappeared from view. Still, the attractive feature of the Hoyle-Fowler idea is that an enormous gravitational energy release, far larger than any possible nuclear explosion, occurs when the core of such a star implodes. The gravitational energy available is possibly 10^{62} to 10^{64} ergs, enough to propel a large fraction of the star's mass into space at a velocity approaching that of light. The source of the high-energy particles carrying 10^{60} or 10^{61} ergs of energy in the strong radio galaxies has long presented a difficult theoretical problem. The superexplosions postulated by Hoyle and Fowler could produce the physical processes that lead, by alternate pathways, both to the large, intense radio galaxies and to the quasi-stellar radio sources.

If the quasi-stellar sources are neither hyperdense stars nor hypermassive ones, what are they? Let us assume that their large red shift is indeed evidence of a high recession velocity and that they are therefore objects billions of light-years away. If this is accepted, one can easily compute from the image size on photographic plates that the stellar components of 3C 48 and 3C 273 have a maximum dimension of about 16,000 and 3,000 light-years respectively. The jet of 3C 273 and the faint wisps near 3C 48 are about 200,000 light-years across. The jet and wisps are truly of galactic scale; the stellar component of 3C 48 is at most a third the size of a typical galaxy, and the stellar part of 3C 273 is less than a tenth galactic size.

There is little doubt that their great radio output is due to synchrotron emission. Their light output, however, presents a difficulty without precedent. The presence of sharp emission lines makes it virtually certain that we are looking not at a galactic assembly of stars, which would show few, if any, emission lines, but at a massive cloud of gas heated to more than 10,000 degrees Kelvin. Such temperatures are observed in the bright gaseous nebulae within our own galaxy.

More curious still, Sandage and Matthews have found by photoelectric observations that the light from 3C 48 varies as much as 30 per cent within the span of a year. Old photographs from the Harvard College Observatory, studied by Harlan J. Smith and E. Dorrit Hoffleit of Yale University, show similar long-term variations in both 3C 48 and 3C 273, and some flarelike brightenings seem to occur within a month.

Such variations could be explained if 3C 48 and 3C 273 were merely stars, but if they are several thousand light-years in size, it is difficult to see how a general brightening could take place in a tiny fraction of the time needed for light to travel from one side of the object to the other. In other words, it seems impossible to explain a systematic variation in brightness without a pulse-transmitting signal, and this could not travel faster than light. The possibility that the brightness variations may be due to random fluctuations in the brightness of small individual components has been examined by Schmidt and found no more satisfactory. If there were more than a few hundred randomly pulsating components, their individual fluctuations would average out and never produce a large brightening of the whole quasi-stellar source. But if there are only a few hundred fluctuating components, each would have to be about a tenth to a fifth

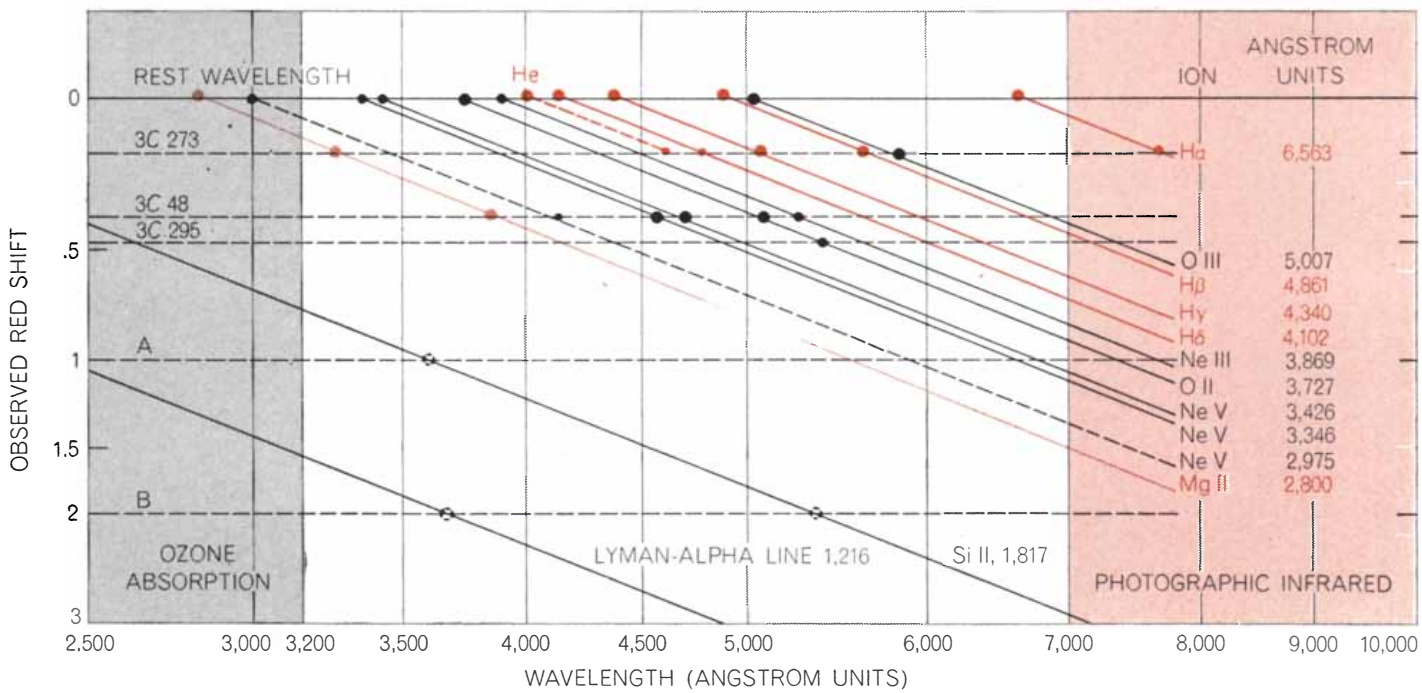
as bright as a normal galaxy. While such extraordinary objects may exist, they present more theoretical problems than they solve.

Turning to the radio emission of 3*C* 48 and 3*C* 273, one finds fewer puzzles beyond those associated with any strong radio source. Making certain assumptions—particularly that the objects are near the upper limit of possible size—it appears that the total energy stored in the magnetic field of these quasi-stellar sources can lie between 10^{56} and 10^{60} ergs. Of this energy about 10^{52} ergs per year is poured out into space in the form of synchrotron radiation. This implies a maximum lifetime of between 10^4 and 10^8 years. And since it is clear that not all the magnetic energy can be converted into radiation, the upper age limit must lie in the range between 10^3 and 10^7 years. On the age scale of the universe—13 billion years—the quasi-stellar sources can have only a fleeting existence. This would explain, incidentally, why they are so few and so hard to discover.

An interpretation of the nature of these strange objects is now being made by Schmidt and me. They may well be stranger than we think. But let me summarize one preliminary viewpoint. According to this analysis the diameter of 3*C* 48 can lie between one and 6,000 light-years, and its total mass between 10^4 and 10^9 solar masses. For 3*C* 273 a similar analysis shows a size range between six and 6,000 light-years and a mass range between 10^6 and 10^{10} suns. It is my impression, however, that 3*C* 48 is larger, older and less luminous than 3*C* 273, so that for 3*C* 48 the higher radius and mass limits seem preferable. The spectrum of 3*C* 48 resembles that of a planetary nebula near a very hot star, whereas that of 3*C* 273 is more abnormal. In both cases the emission lines seem to originate in great masses of highly ionized gas. The source of ionization in these giant gas clouds is unknown, but it is probably not stellar. No conclusion on the abundance of the various elements in the gas can be drawn; they appear to be normal, except for an apparent hydrogen deficiency in 3*C* 48.

As a concrete model (leaving the light variations unexplained) one can picture a quasi-stellar source as an excited cloud of gas with a diameter of about 600 light-years and a mass equal to 10^9 suns. At present it seems likely that the energy source in a quasi-stellar source must be ascribed to a titanic explosion involving the release of either nuclear or gravitational energy. It is uncertain whether or not it contains any stars. If the gas has been flying outward at 1,000 kilometers per second, it has taken 100,000 years to reach the size observed. The total energy released in the explosion was 10^{58} to 10^{59} ergs, which is slightly larger than the present expansion energy. If the explosion were nuclear, it would require 10^7 to 10^8 solar masses of hydrogen. Geoffrey R. Burbidge of the University of California at La Jolla has suggested that a rapid release of this much energy could be achieved by a chain reaction of supernova explosions in a crowded region of a galaxy. Alternatively, the required energy could be provided by the gravitational collapse of a single star of 10^8 solar masses, as suggested by Hoyle and Fowler. The presence of the jet of 3*C* 273 suggests that an essential feature of the explosion was that a small amount of matter was ejected with nearly the velocity of light, and that a much larger amount (that constituting the central component) traveled at only about one three-hundredth the velocity of light. In the case of 3*C* 273 the faster moving component—the jet—emits about 10 times more radio energy than the central component does.

There is no definite proof for or against Burbidge's multiple supernovae hypothesis. Such a chain-reaction explosion might be possible in the high-density core of a giant elliptical galaxy



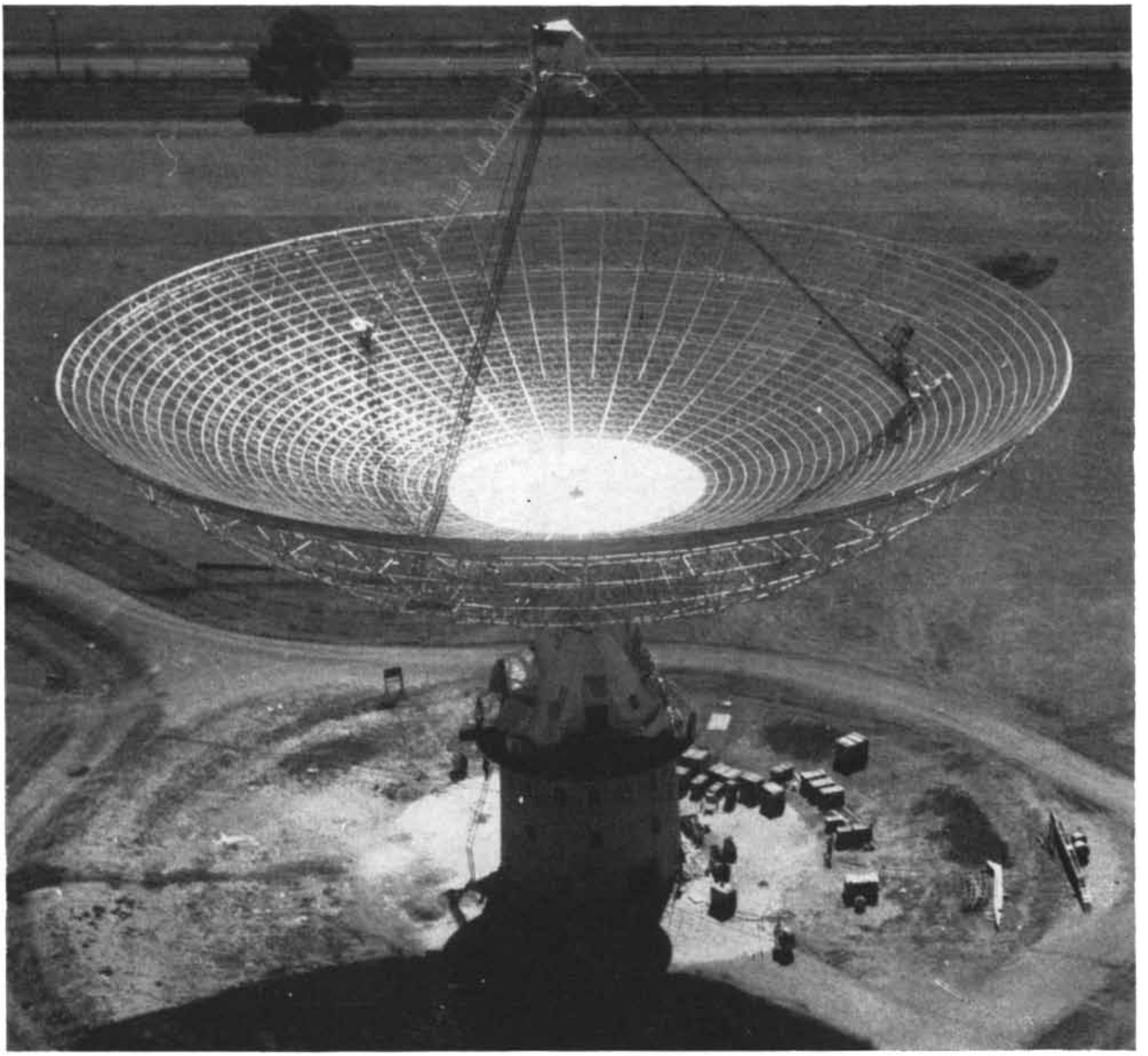
RED-SHIFT DISPLACEMENT is shown for spectral lines recorded from two quasi-stellar radio sources, 3*C* 273 and 3*C* 48, and from the most distant galaxy, 3*C* 295. The top horizontal line shows the rest wavelengths of "permitted lines" of hydrogen (*dark color*) and ionized magnesium (*light color*). Black dots are "forbidden" lines of ionized neon (*Ne*) and oxygen (*O*). Roman numerals indicate the state of ionization of the element: a number that is one greater than the number of electrons missing from the ion. The slanting lines connect spectrum lines observed in the radio sources with presumed rest wavelengths of ions responsible for emission. Horizontal line *A* represents a red shift equal to one and line *B* a red shift equal to two, neither yet observed. Spectra with such red shifts could contain lines for singly ionized silicon (*Si II*), which has a rest wavelength of 1,817 angstroms in the ultraviolet. A spectrum with a red shift of two could contain the Lyman-alpha line of hydrogen, normally found in the far ultraviolet at 1,216 angstroms.

in which the spacing between neighboring stars is only a few light-months. If the core contained an aging population of stars reaching a critical evolutionary stage, the explosion of one might trigger off the explosion of others. But for known objects the actual crowding and total mass of central regions seems insufficient to satisfy Burbidge's hypothesis.

The Hoyle-Fowler hypothesis is even more speculative, since no one knows how a star of 10^8 solar masses can be formed. The total interstellar gas observed in our entire galaxy is not much more than 10^9 suns, and ours is a spiral galaxy, rich in gas. In an elliptical galaxy the interstellar gas seldom exceeds 10^8 suns. In a rapidly rotating spiral system the gas has so much angular momentum that it is hard to see how 10^8 solar masses could contract into a single object. In fact, the quiescent conditions required for so much gas to collect are unlikely to be found within any galaxy.

One place where great masses of gas might assemble is in intergalactic space. The gas density could be relatively high (say one atom per million cubic centimeters) without being observable or affecting the expansion of the universe. Moreover, the net angular momentum of large regions could average out to a small value. In the intergalactic hypothesis the quasi-stellar sources would have no evolutionary connection with the giant radio galaxies, a possibility favored by another bit of evidence. The quasi-stellar source is both smaller than a radio galaxy and supplied with less energy. If the quasi-stellar source represented an early stage in the evolution of a large radio galaxy, one would have expected the quasi-stellar source to have more energy.

In any event, we have encountered a most baffling group of astronomical objects. Whether fundamental new processes lie behind their brilliant but ephemeral appearance, or whether our imaginations are still too limited, remains for the future to determine.



AUSTRALIAN RADIO TELESCOPE, near Sydney, was used to pinpoint the location of the quasi-stellar radio source 3C 273. The 210-foot dish, which went into service last year, is operated by the Commonwealth Scientific and Industrial Research Organisation.

Kodak reports on:

air-conditioned brilliance for 8mm movies... sweat in glass... what came of the litmus idea

Action safely frozen, slowed, or reversed

This new 8mm movie projector is designed for use in the home, and we would not pretend otherwise. In addition to the now familiar reversing feature of home movie projectors that has always so delighted Uncle Henry, the family clown, when he shows those friends of his riding backward on the horse, the KODAK CHEVRON 8 Projector, Model 10, can show film at less than half normal running speed without flicker, and it can project single frames just like slides at the same high brightness as for the normal speed. Because of a constant blast of air through internal pipes to cool the film gate, single-frame viewing fails to sauté the film. Flicker fails to appear at low speed because the shutter then automatically increases from three to six blades, in order to keep above what is known in physiological optics as critical flicker frequency.

While this message is timed to inspire serious consideration of the projector as a Christmas gift for the household, you may find some pleasure in outwitting our little plot. You may decide to get along yet a while with the old family movie machine, to buy them a color television set instead, and to slap down on some nearby camera counter a couple of income-tax-deductible $100 bills, more or less, for a CHEVRON 8, Model 10, as a perfectly satisfactory device for detailed examination of quite unfunny 8mm motion-picture studies exposed in the pursuit of your profession.

To make a laser, use a laser

As of this writing, alas, very few routine uses for lasers exist. As far as the eye can see, the present market is nearly all R&D. In this business, unlike some others we are in, product uniformity is hardly worth millions per annum. R&D customers have no objections if a KODAK Laser Rod shipped this week is quite a bit better than one shipped six weeks ago.

We don't make KODAK Laser Rods with the same tooling philosophy we use for KODAK INSTAMATIC Cameras. Each rod is individually handcrafted. This suggests tradition. There *is* a tradition of optical craftsmanship, and we even have it; but we do not go so far as to claim we have men who were taught how to fashion laser rods by their grandfathers. A six-month-old tradition in the laser craft is pretty hoary.

KODAK Laser Glass has acquired a much envied reputation in the last six months for optical quality. Optical quality is worth having in a laser rod, not so much for feelings of serenity it may induce in the owner as for minimizing beam divergence and internal losses. It is bought with chemical and glass-working sweat and in turn buys very low threshold in small rods and very high efficiency in big ones. Up to the time this ad was written, we had made them as long as 30 inches and had obtained efficiencies as high as 2¼ %. Without sly tricks, we calculate efficiency as simply the energy in the capacitor bank, $\frac{1}{2}CV^2$, divided into what the calorimeter measures.

One item of special tooling we have found most valuable for maintaining optical quality in long rods and in more ingenious configurations that customers have devised. This gadget Grandpa never had in *his* optical shop. It is a helium-neon gas laser. Here, then, is one of the still very rare routine, day-in, day-out uses of a laser.* Day in and day out the hand-craftsmen keep trotting over to it to use with or without Twyman-Green plates as a light source of fantastically long coherence length for interferometrically establishing optical parallelism of the two ends of a KODAK Glass Laser Rod. If the ends happen to be separated by a million or so wavelengths, it is no more trouble to see what touching-up is still needed than it ever was to check the Newton's ring pattern on an aerial photo-lens component through a test glass.

Correspondence on this subject is conducted by Apparatus and Optical Division, Eastman Kodak Company, Rochester, N. Y.

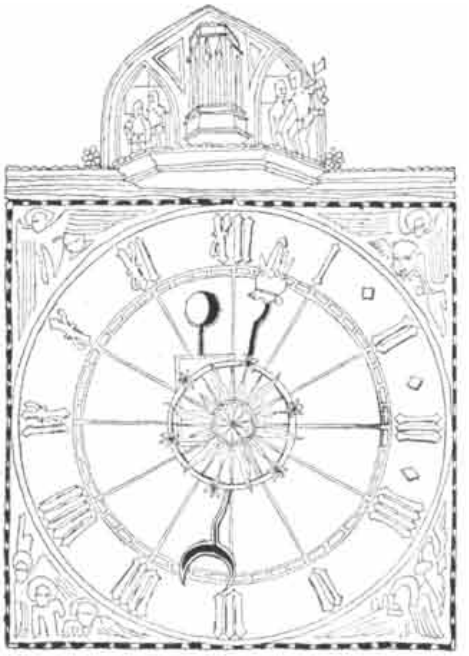
*And not even our own type!

pH 0 to 14

Blue litmus paper turns pink in acids. Pink litmus paper turns blue in alkalies. To know these facts is as much a part of general culture as it is to know that Aristophanes wrote *The Frogs*. Neither type of information calls for any particular course of action. Persons of whom is actually required some responsible decision in selecting a dye that will undergo a known change of color over a well defined range of pH now have better compounds than litmus for the purpose. Indeed they have 61 such. All are EASTMAN Organic Chemicals. The dyes range from *Methyl Violet* (EASTMAN 1309), which starts turning from yellow to blue at an intensely acidic pH 0 and completes the change at pH 1.6 (still pretty dad-blasted sour), to *1,3,5-Trinitrobenzene* (EASTMAN 639), which starts losing its orange color at a blistering caustic pH 14 and has lost it all by the time the alkalinity has moderated to pH 12.

A new chart of these color changes with pH, bearing suggestions for preparation of indicator solutions from each of the 61 dry dyes, will be supplied on request by Distillation Products Industries, Rochester, N.Y. 14603 (Division of Eastman Kodak Company). It can contribute little to one's general cultural background. Nor does it include litmus.

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



SCIENCE AND

The Nobel Prizes

The Nobel prizes in science, which in recent years have increasingly come to reflect currently active themes of investigation, were this year awarded for (1) the study of the transmission of the nerve impulse, (2) the application of symmetry principles in modern physics, (3) the study of the structure of the atomic nucleus and (4) the synthesis of giant molecules.

The award in physiology and medicine was shared by A. L. Hodgkin of the University of Cambridge, A. F. Huxley of University College London and Sir John Eccles of the Australian National University. Hodgkin and Huxley (who is a younger half-brother of Julian and Aldous Huxley) collaborated in showing the intimate relation between the chemical and electrical events that take place when a nerve impulse is transmitted along a nerve fiber. Eccles is considered one of the world's leading students of communication among nerve cells.

The prize in physics was shared by Eugene P. Wigner of Princeton University, Maria Goeppert Mayer of the University of California at La Jolla and J. H. D. Jensen of the University of Heidelberg. Wigner will receive half the cash award; Mrs. Mayer and Jensen share the other half.

Wigner, who was born in Hungary, has made major contributions to quantum mechanics, the theory of solids and the theory of nuclear chain reactions. As early as 1927 he emphasized the importance of symmetry principles, which have become increasingly useful in understanding the behavior of elementary particles. Early in World War II he helped to bring the discovery of uranium fission to the attention of President Roosevelt; later he played a major part in the design of nuclear reactors for producing plutonium.

Mrs. Mayer, who was born in Poland, and Jensen were honored for their work on the structure of the atomic nucleus. In 1949 they independently put forward theories supporting the concept that the nucleus has a shell structure in which neutrons and protons occupy specified orbits analogous to those occupied by electrons outside the nucleus (see "The Structure of the Nucleus," by Maria Goeppert Mayer; SCIENTIFIC AMERICAN, March, 1951).

The award in chemistry was shared by Karl Ziegler, director of the Max Planck Institute for Coal Research in Mulheim, and Giulio Natta, director of the Institute of Industrial Chemistry at the Polytechnic Institute of Milan. Ziegler devised a low-pressure process for making the important industrial plastic polyethylene, which previously had been synthesized commercially only at high pressures. Natta devised novel methods for precisely controlling the structure of polypropylene and similar polymers to obtain a wide range of useful properties (see "Precisely Constructed Polymers," by Giulio Natta; SCIENTIFIC AMERICAN, August, 1961).

Another expert in molecular structure, Linus Pauling, had earlier been awarded the Nobel peace prize, thereby becoming the first person to win two full Nobel awards. (Marie Sklodowska Curie had received a full award in chemistry and shared an award in physics.) Pauling had received the Nobel prize in chemistry in 1954.

End of the Race?

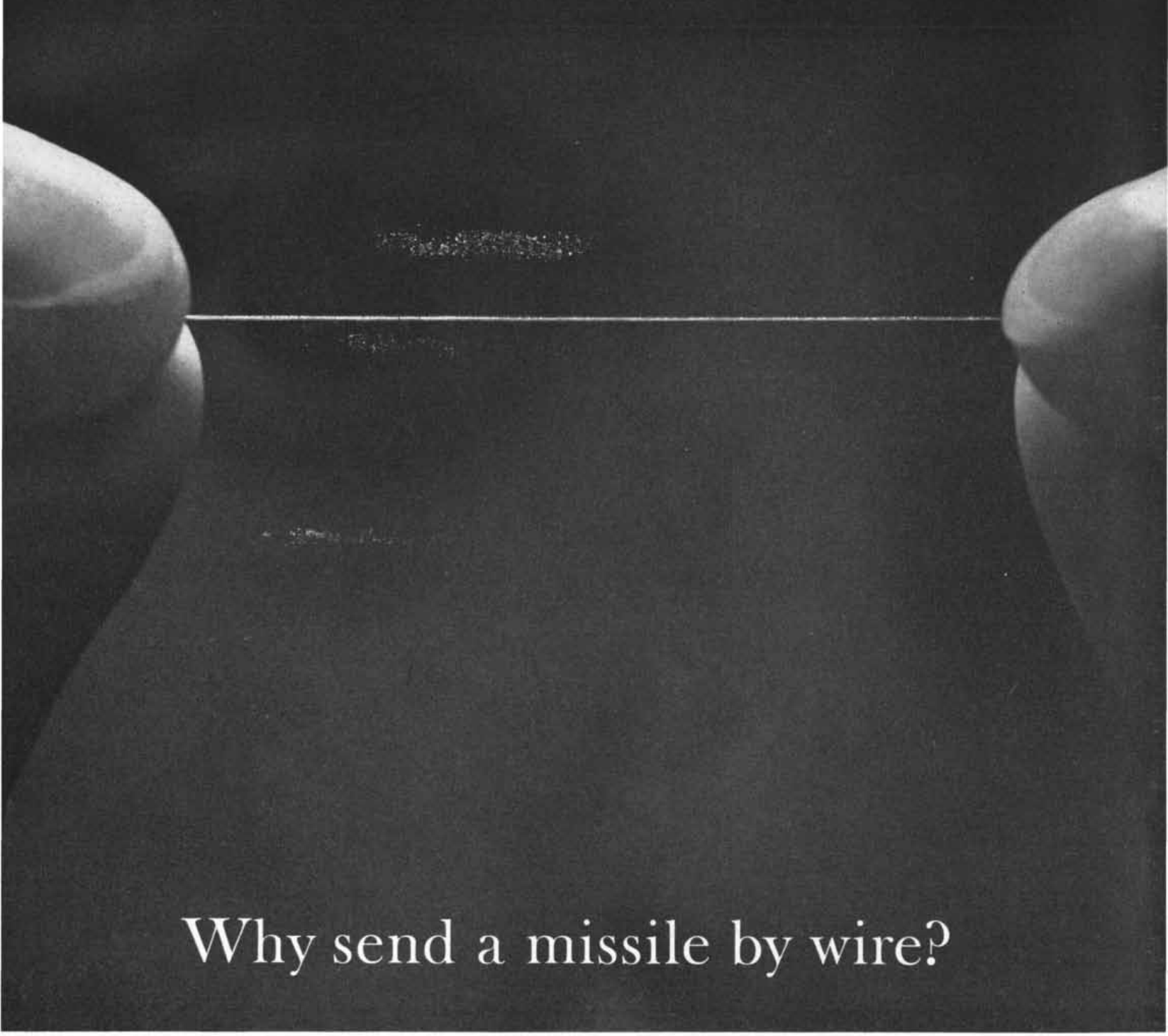
Premier Khrushchev's October statement that the U.S.S.R. is "not at present planning" a manned flight to the moon widened the debate over the U.S. program to land men on the moon before 1970. When President Kennedy announced Project Apollo in May, 1961, it was in terms of a race against the U.S.S.R. for national prestige. When it became less certain that the U.S.S.R. was engaged in a similar project, the Administration began to emphasize the

THE CITIZEN

broader benefits of Apollo rather than its competitive aspect. In September, President Kennedy appeared to be dropping the idea of a race when he proposed before the United Nations a joint U.S.-U.S.S.R. moon expedition. To that suggestion the U.S.S.R. gave no official response. The race still appeared to be on when Anatoly F. Dobrynin, the Soviet Ambassador to the U.S., said that the U.S.S.R. did plan to send men to the moon by the end of the decade.

Only 10 days later Premier Khrushchev said at a news conference that, although "it would be very interesting to take a trip to the moon... I cannot say this will be done.... We do not wish to compete in sending people to the moon without careful preparation." His words were interpreted as taking the U.S.S.R. out of the moon race—if there had been a race. In the U.S. the Soviet "withdrawal" was cited as an argument in favor of at least slowing the pace of Project Apollo. A number of groups have urged such a slowdown, including certain scientists who feel that the $20 billion project takes too large a share of the nation's scientific and economic resources, and congressmen who oppose heavy Government spending or believe that the "moondoggle" is diverting funds from military space activities. Some Government space officials, on the other hand, argued that if the U.S.S.R. was not in a race to the moon, the U.S. should press its advantage to make certain of getting there first. Others insisted that most of the technology developed for Apollo would advance the country's manned space program in general and its military space capability in particular. At the end of the month President Kennedy said he would not assume that the U.S.S.R. "was out of the space race at all" on the basis of Premier Khrushchev's "Delphic" statement. Again emphasizing the broad aspects of the U.S. program, he said: "It is not a question of going to the moon, it is a question of having the confidence to master this environment.... I think we ought to stay with our program."

That program, however, has already been slowed down by cuts in the National Aeronautics and Space Administration's budget and by technical and administrative problems. Now, with the competitive spur dulled by doubt about



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This was the scope of the problem faced by Hughes engineers working with the U.S. Army. The solution—almost paradoxically simple in this day of complex weapons—is the new TOW missile system.

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Because these steering commands are sent by wire, they are undetectable. Thus, the enemy cannot use the guidance commands to locate the launcher.

The lightweight TOW anti-tank missile system offers other important advantages. Its simplicity of operation reduces training requirements. It can be used either by dismounted troops or it can be carried on various types of vehicles, such as jeeps and armored personnel carriers, or on helicopters.

TOW is characteristic of Hughes approach to scientific and technological challenge—where every requirement is

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Soviet intentions, there may be broader discussion of the basic question raised by the scientific community: Exactly how important is a manned flight to the moon in the context of finite U.S. resources for the support of all research in science and technology?

Two Cultures Reaffirmed

Sir Charles Snow, central figure in the four-year controversy stirred by his essay *The Two Cultures and the Scientific Revolution,* has replied to his critics with a reaffirmation and expansion of his thesis. Writing in *The Times Literary Supplement,* he holds out the hope that a "third culture" may bridge the gap, with important consequences for mankind.

Snow's original thesis, delivered as the Rede Lecture at the University of Cambridge in 1959, was that Western intellectual leadership has become dangerously divided, with "literary intellectuals at one pole—at the other scientists.... Between the two a gulf of mutual incomprehension." He called this polarization a "practical and intellectual and creative loss" and asserted that the remedy lay in a revision of Western educational systems. Only thus, he said, can any society "think with wisdom" and, more importantly, turn the benefits of "the scientific revolution" to the vital task of closing the chasm between rich and poor nations. Snow writes now that "the sheer volume of comment" on his lecture led him to "see what modifications I should make if I were going to give the lecture again." He finds that for the most part he would say the same things. He says, however, that he is convinced that "a third culture... is coming" and that "when it comes some of the difficulties of communication will at last be softened."

The members of this group, Snow says, are "intellectual persons in a variety of fields—social history, sociology, demography, political science, economics, government (in the American academic sense), psychology, medicine and social arts such as architecture." They constitute a "mixed bag," but "all of them are concerned with how human beings are living or have lived." And "in their approach to cardinal problems—such as the human effects of the scientific revolution, which is the fighting point of this whole affair—they display, at the least, a family resemblance."

Restating his "major theme," Snow says: "It is dangerous to have two cultures which cannot or do not communicate. In a time when science is determining much of our destiny, that is, whether we live or die, it is dangerous in the most practical terms. Scientists can give bad advice, and decision makers cannot know whether it is good or bad. On the other hand, scientists in a divided culture provide a knowledge of some potentialities which is theirs alone. All this makes the political process more complex and in some ways more dangerous than we should be prepared to tolerate for long."

X-ray Astronomy

The existence of a powerful X-ray source outside the solar system has been confirmed in a series of experiments employing rocket-borne detection devices. The new discovery has raised the possibility that a whole range of celestial phenomena invisible to the most powerful optical and radio telescopes can be observed by X-ray techniques.

Since the earth's atmosphere is opaque to all electromagnetic radiation from space except for two "windows" in the optical and radio regions of the spectrum, instruments for measuring X radiation must be lifted above the atmosphere by rockets or placed in artificial satellites. Rockets have been used to detect X rays from the sun; more recently they have been used to explore the night sky for other possible sources. Three such rockets have been launched at the White Sands Missile Range in New Mexico over the past 18 months by a group of investigators from American Science and Engineering, Inc., in Cambridge, Mass. All were Aerobee rockets with X-ray-sensitive Geiger counters as their principal detection devices. The first rocket was launched in June, 1962, and was above an altitude of 50 miles for about six minutes. The data recorded by the Geiger counters indicated the presence of an extremely strong source of X rays somewhere in the direction of the center of the galaxy. A launching in October, 1962, could not confirm this particular observation because the galactic center is not visible from New Mexico in the fall, but two possible weaker X-ray sources were detected. A rocket launched in June of this year succeeded in detecting powerful X radiation from the same general region that produced the recording of the preceding June.

In *Physical Review Letters* Herbert Gursky, Riccardo Giacconi and Frank R. Paolini of American Science and Engineering and Bruno B. Rossi of the Massachusetts Institute of Technology discuss the significance of the findings. They reject as unlikely the possibility

that the observed radiation is corpuscular rather than electromagnetic, that it results from purely local auroral activity or arises from any source within the solar system. They identify the radiation as consisting of "soft" X rays with a wavelength of about three angstrom units.

A strong X-ray source near the galactic center has also been detected recently by Herbert Friedman, Stuart Bowyer, Edward Byran and Talbot A. Chubb of the Naval Research Laboratory's Rocket Group. Their instrumented rocket, launched this past spring from the White Sands Missile Range, succeeded in locating the source in the direction of the constellation Scorpio. The rocket's field of view was restricted to eight degrees in diameter and the source appeared not larger than the field of view. At the time the galactic center itself was below the horizon and therefore invisible to the rocket. The radiation detected by this group was mostly in the three- to eight-angstrom range.

Various theories as to the origin of the galactic X rays have been proposed, but so far none enjoys wide acceptance. Meanwhile both groups plan to fire more rockets to look for X rays of longer wavelength and to locate the known sources more precisely.

Elusive Pigments

A year of experimenting under a photographer's red light has yielded new evidence for the existence of two of the three color-sensitive pigments believed to be involved in human color vision. Moreover, data from the study, which was conducted by Paul K. Brown and George Wald of Harvard University, strongly suggest that one of the two pigments is a substance identical with or very similar to iodopsin, a red-sensitive pigment in the retina of the chicken.

Since Thomas Young first advanced the three-color theory of color vision a century and a half ago little headway has been made in efforts to demonstrate and identify the three pigments—one for each of the primary colors red, green and blue—presumably involved in man's ability to perceive colors. Some investigators have proposed the existence in the human eye of as many as seven pigments; others have sought color-vision mechanisms that eliminate pigments entirely. Recently, however, W. A. H. Rushton of the University of Cambridge has obtained evidence for the presence of red-sensitive and green-sensitive pigments in the retina by studying light entering the living human eye and coming back out of it after passing through the

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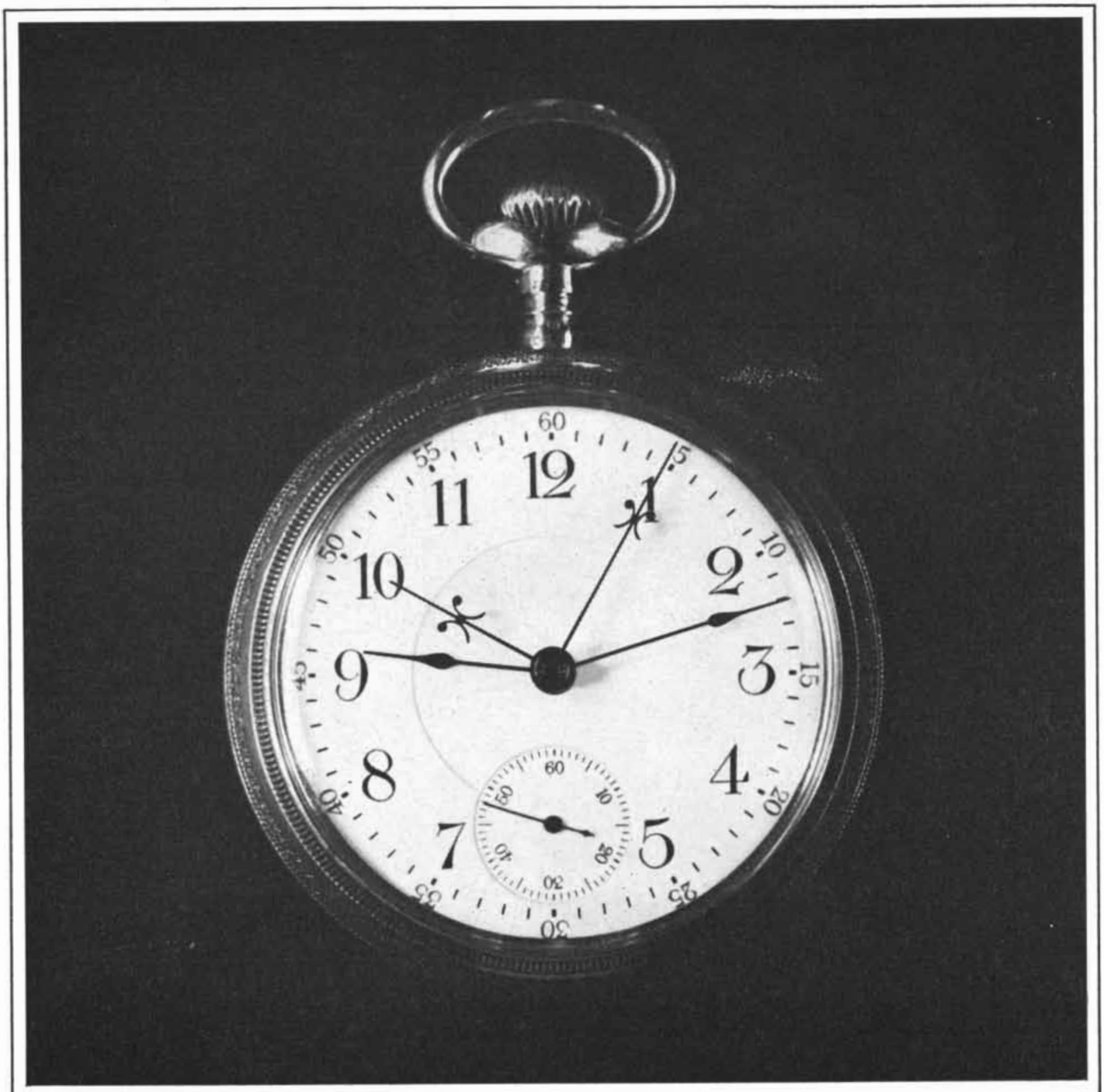

Time Sharing

Co-op Computers?

As computers become more common in large organizations, the question arises as to whether one large computer or a number of smaller ones should be obtained. For many applications, it is desirable to make the computer itself accessible to the individual user, engineer, or manager. Normally, economy of operations dictates that the large computers are used in a centralized facility where they are unavailable to the potential user. Thus, many organizations are forced into procuring several small computers to service them. A potential answer to this dilemma lies in the time-sharing approach, wherein computer programs are so arranged that several individual users may have simultaneous access to the computer. Substantial man-hours can be saved by on-line checking of new computer programs, and certain functions become feasible when users are in direct communication with the computer. SDC is developing such a time-sharing system within the Command Systems Department, and a large computer, the AN/FSQ-32, is currently in operation in a time-sharing mode at SDC. The technology of time sharing is but one of many aspects of tomorrow's information systems now under scrutiny by SDC scientists and engineers. This broadening spectrum of systems technology will create a wide range of unusually attractive positions at SDC. Human factors scientists, operations research scientists, systems-oriented engineers, and computer programmers interested in joining a rapidly expanding technology are invited to write Mr. A. M. Granville, SDC, 2430 Colorado Ave., Santa Monica, California. Positions are open at SDC facilities in Santa Monica; Washington, D.C.; Lexington, Massachusetts; and Dayton Ohio. "An equal opportunity employer."

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retina (see "Visual Pigments in Man," by W. A. H. Rushton; SCIENTIFIC AMERICAN, November, 1962).

Brown and Wald took a different tack. Retinas were obtained from human eyes willed to an eye bank and also from rhesus monkeys sacrificed in other experiments. The richest concentration of cones, the color-sensitive cells of the eye, is found at the center of the retina in the fovea; the foveal area of the retina was mounted on the stage of a microscope coupled to a recording spectrophotometer. General illumination was provided by a photographer's red light to minimize bleaching of the visual pigments. The foveal area of each retina was then scanned several times with a beam of light whose wavelength could be varied systematically from one end of the visible spectrum to the other, and the absorption of light at different wavelengths was measured. During the first scan the intensity of the beam was held at a low level so that no detectable bleaching of the fovea occurred. This yielded a curve for light absorption by the unbleached fovea, that is, the fovea with all its visual pigments unaltered. Individual foveas were now exposed to monochromatic bleaching lights of various colors and their light absorption was measured again. A comparison of the "before" and "after" curves revealed which wavelengths of light had been absorbed.

Working in this way Brown and Wald, who describe their work in *Nature*, identified the absorption spectra of two distinct light-sensitive foveal pigments. One has its maximum sensitivity, as measured in both man and monkey, to light with a wavelength of 565 millimicrons, in the red region of the spectrum. The other pigment has its maximum sensitivity in the green: at 535 millimicrons in man and slightly lower in the monkey, probably because of contamination of the monkey preparations with rods, the cells involved in night vision. A blue-sensitive pigment may also have been detected; the retina, however, contains a nonvisual pigment that also absorbs in the blue and masks the visual pigment.

The absorption figures for the green-sensitive pigment found by the Harvard investigators and Rushton agree closely, but Rushton obtained a maximum absorption for the red-sensitive pigment farther into the red (590 millimicrons). Brown and Wald note, however, that their red-pigment spectrum is nearly identical with that of iodopsin, the color-vision pigment of the chicken. Consequently, although color-vision processes in the chicken and man are quite dif-

ferent (the chicken retina contains droplets of colored oil that appear to act as color filters), iodopsin may be the red-sensitive pigment in man.

Synthetic Insulin

A University of Pittsburgh group has produced the first synthetic insulin to exhibit biological activity. Consisting of 51 amino acid units, this substance is the largest protein-like molecule yet synthesized in the laboratory. Synthesis of the pituitary hormone ACTH, consisting of 39 amino acid units, was achieved only this past summer.

The insulin synthesis was announced at a conference on proteins and polypeptides sponsored by the Upjohn Company in Kalamazoo, Mich., and was accomplished by Panayotis G. Katsoyannis, Andrew Tometsko and Kouhei Fukuda. The insulin molecule consists of an "A" chain of 21 amino acid units and a "B" chain of 30. The chains are joined at two points by pairs of sulfur atoms; a third pair of sulfur atoms forms a secondary link between segments of the A chain. A few months ago the Pittsburgh workers succeeded in assembling the right amino acids in the right sequence to duplicate the A chain. Confirmation of the A-chain synthesis came from G. H. Dixon of the University of Toronto, who combined a sample of the synthetic A chain with the B chain of natural insulin to obtain an insulin with full biological activity. More recently the Pittsburgh group produced a preparation containing synthetic B chain. Although the concentration of the B chain was low, a sample was sent to Dixon. Slight but definite hormone activity was found when the sample was reacted with either natural or synthetic A chain. Insulins with greater activity are anticipated when the B-chain preparation is purified.

The A and B chains synthesized by the Pittsburgh workers are believed to have the amino acid sequence of sheep insulin. (Amino acid sequences differ slightly in insulins from different species, but this has little effect on the activity of the hormone.) In addition to providing new support for the insulin amino acid sequence originally worked out by Frederick Sanger of the University of Cambridge, the synthesis is expected to advance the understanding of diabetes and hormone action. Because a majority of diabetics are now treated with oral drugs, the shortage of natural insulin once widely forecast as a result of the increase in the number of diabetics is no longer considered likely.

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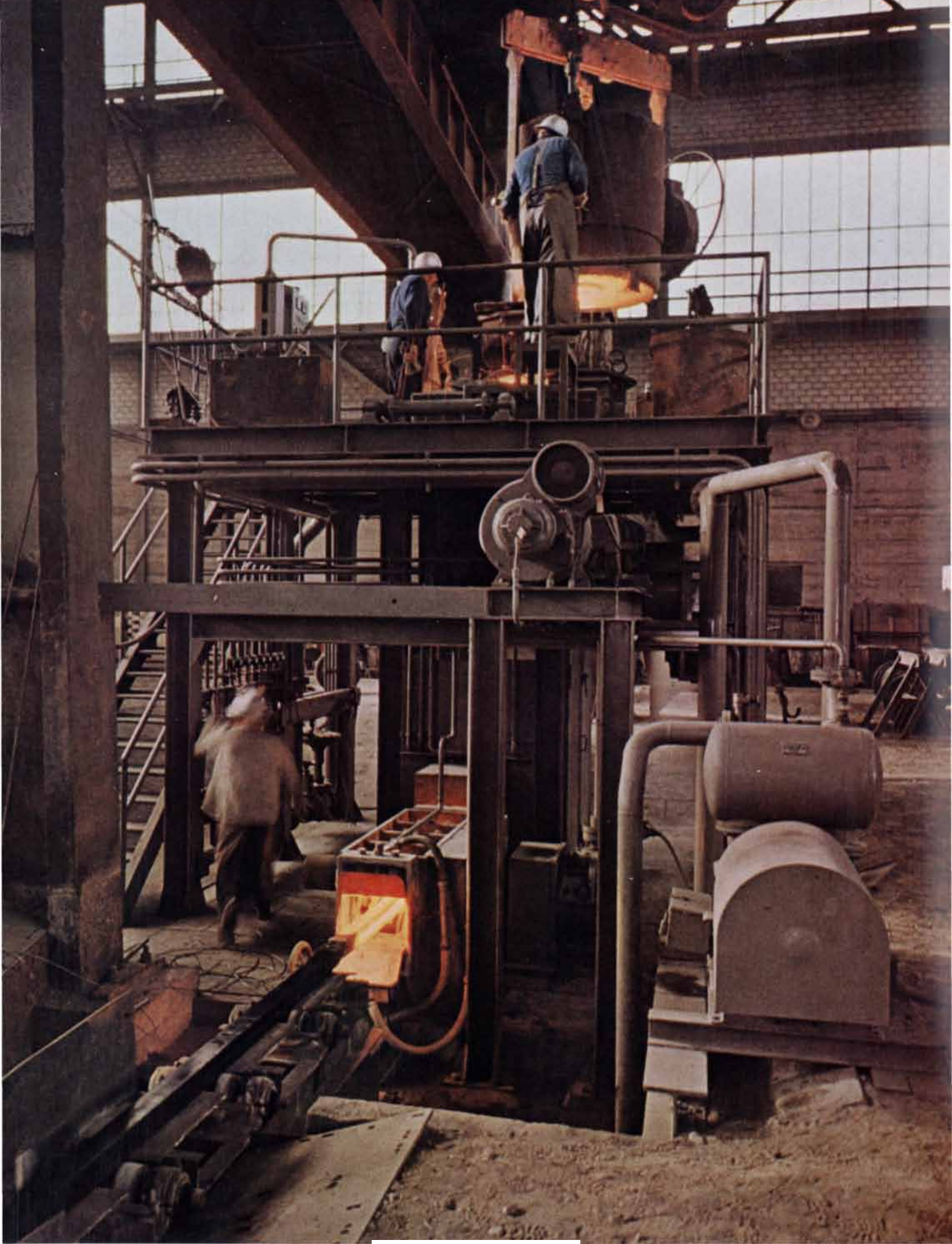


The Continuous Casting of Steel

This new method of steelmaking shapes and solidifies molten steel, readying it for the rolling mill in virtually one step. Developed in Europe, it is now being implemented in the U.S.

by Leonard V. Gallagher and Bruce S. Old

The evolution of an industrial process almost always involves the elimination of steps in the process. In recent years a number of steelmaking organizations in western Europe and the U.S.S.R. have succeeded in eliminating several costly steps in the manufacture of steel by advancing the technique known as continuous casting. U.S. steel firms, which account for about a third of the world output, were for the most part content to observe these developments. They were inhibited by a paradox of industrial supremacy: the huge sums invested in established methods made experimentation with the new technique seem impractical. The smaller producers, whose competitive position might have been enhanced by continuous casting, could least afford to build the pilot plants. At long last, however, several U.S. manufacturers have joined organizations abroad in purchase agreements that will undoubtedly give continuous casting a place in the technology and economics of the U.S. steel industry.

Both conventional and continuous steelmaking begin with the melting of pig iron and scrap steel, together with fluxing, alloying and purifying agents, in a furnace. At intervals dependent on the speed with which the furnace operates, the ingredient materials are weighed and charged into it in "heats," or batches. Each heat is brought to the requisite temperature and held there until the steel in the furnace has attained the desired chemical composition. The furnace is then tapped and the molten steel is transferred to one or two ladles that will hold up to 300 tons of liquid metal at temperatures of 2,500 to 3,100 degrees Fahrenheit.

CONTINUOUS BILLET of steel is emerging red-hot from the casting machine shown in photograph on opposite page. Molten steel is pouring vertically from the ladle (*top*) into a casting "strand." The mold is curved to shift the flow of steel to the horizontal plane and thus reduce the over-all height of a plant designed to house a continuous-casting system. The photograph was made in a pilot plant in Lucerne, Switzerland, designed by the firm of Concast A.G.

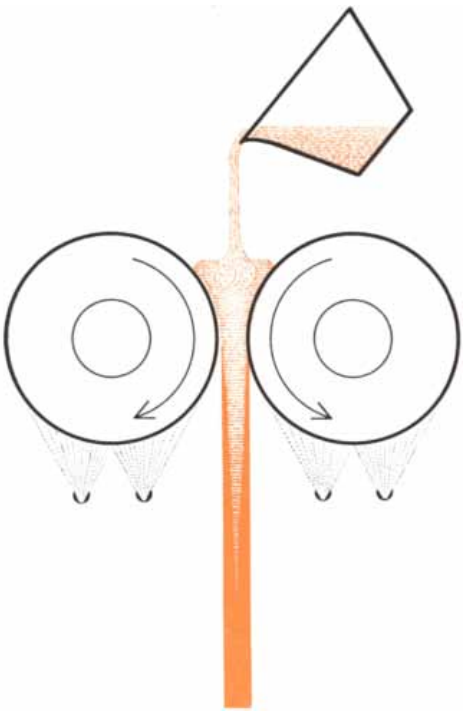
The Bypassed Steps

It is in the next stage of production, the shaping and solidifying of the molten metal, that continuous casting offers its great economies in plant investment and in operation and energy costs. In the conventional procedure the full ladle is moved to a casting pit, where, supported by an overhead crane, it is tapped into a series of individual ingot molds standing upright on rail cars. A manufacturer of products with a small cross section, such as rods to reinforce concrete, may want to cast fairly small ingots to minimize their subsequent reduction in the rolling mill. Most producers, however, prefer to cast the largest ingot their rolling mill can handle (usually an ingot weighing between five and 15 tons). When the surface of the ingots has solidified so that they can stand alone, the molds are stripped off. The ingots are then transferred to another furnace, the soaking pit, where they are heated to uniform temperature for the rolling to follow.

The hot ingots are first sent through the primary, or breakdown, mill: a series of massive rollers that squeeze the ingots down to the cross section appropriate to the type of product that is being made in that particular plant. As the ingot cools it contracts in such a way that a "pipe," or cavity, forms at its upper end. Often the metal around the pipe is of erratic chemical composition. During the hot-rolling operation the deepest part of the pipe may be welded shut, but most of the pipe must be cut off and remelted as scrap at additional cost. The products of the primary mill are classified according to size and shape as slabs, blooms and billets. (Slabs have an oblong cross section; if they are destined to be rolled into plate or sheet, this cross section is usually larger than three by 12 inches. Blooms have a square cross section greater than five inches; billets are blooms that have been reduced to a smaller cross section.) The investment in a primary mill is heavy because the mill must have a large rated capacity in order to pay. In today's steel industry the primary mill should have a capacity of more than a million tons a year.

Continuous-casting methods are not all the same, but they are enough alike to fit a generalized description [*see illustration on page 80*]. The ladle of molten steel is transported by a vehicle or crane to a platform above the casting machine, where it is teemed, or discharged, into a rectangular trough called a tundish. From this vessel the steel flows into a casting "strand" (or strands), the heart of which is a bottomless vertical mold that receives and confines the molten metal, partially shaping it into the desired cross section as it passes through. Just below the upper surface of the metal a thin skin forms on the surfaces adjacent to the inner walls of the mold; this skin thickens as the metal is pulled through the mold.

The steel continues to solidify as the billet is withdrawn, and to hasten cooling it is usually passed through a secondary cooling chamber where it is sprayed with water from an array of nozzles. The solid billet, still at red heat, is pulled by rollers that are synchronized with the level of liquid metal in the mold in order to ensure that the billet is formed in a steady manner. Beyond the withdrawal



BESSEMER PATENT granted in 1865 called for pouring metal between two water-cooled rollers to form a solidified plate.

COUNTRY	MACHINES
ARGENTINA	1
AUSTRALIA	1
AUSTRIA	4
CANADA	2
CHINA	1
CZECHOSLOVAKIA	1
FRANCE	4
GERMANY (EAST)	1
GERMANY (WEST)	5
HUNGARY	1
INDIA	1
ITALY	2
JAPAN	3
MEXICO	1
NORWAY	1
PERU	2
SPAIN	1
SWEDEN	1
SWITZERLAND	2
UNITED KINGDOM	11
U.S.	1
U.S.S.R.	12

PLANTS IN OPERATION with continuous-casting units were concentrated in Europe as of October, 1963. Plants under construction will bring total (now 59) to more than 90.

mechanism the continuous billet is cut into convenient lengths for subsequent reduction. In short, continuous casting eliminates the pouring, molding, transporting and reheating of ingots.

Developers and Sponsors

The concept of continuous casting seems so logical that one might ask why it was not suggested and implemented long ago. Actually the suggestion was made almost a century ago by Sir Henry Bessemer. Patent records for 1865 show that Bessemer had considered pouring steel directly onto two water-cooled rollers and then withdrawing solidified plates [*see illustration at left*]. Numerous technical problems intervened, and Bessemer never did obtain his solidified plate, but a version of his scheme has been applied in the production of alloys of aluminum and copper that solidify at lower temperatures than steel.

The pattern of research in continuous casting resembles a river with tributaries and a delta. Inventors allied themselves with organizations, and organizations allied themselves with one another. Successful modifications of one process were introduced into others; the exchange of ideas (voluntary and otherwise) and the eventual expiration of original patents brought the many streams into a common conceptual channel. Near the common goal of an economically feasible operation the organizations took different routes; some sought a process compatible with large-tonnage operations, others emphasized high casting speed and a few designed processes for a special purpose in a particular plant.

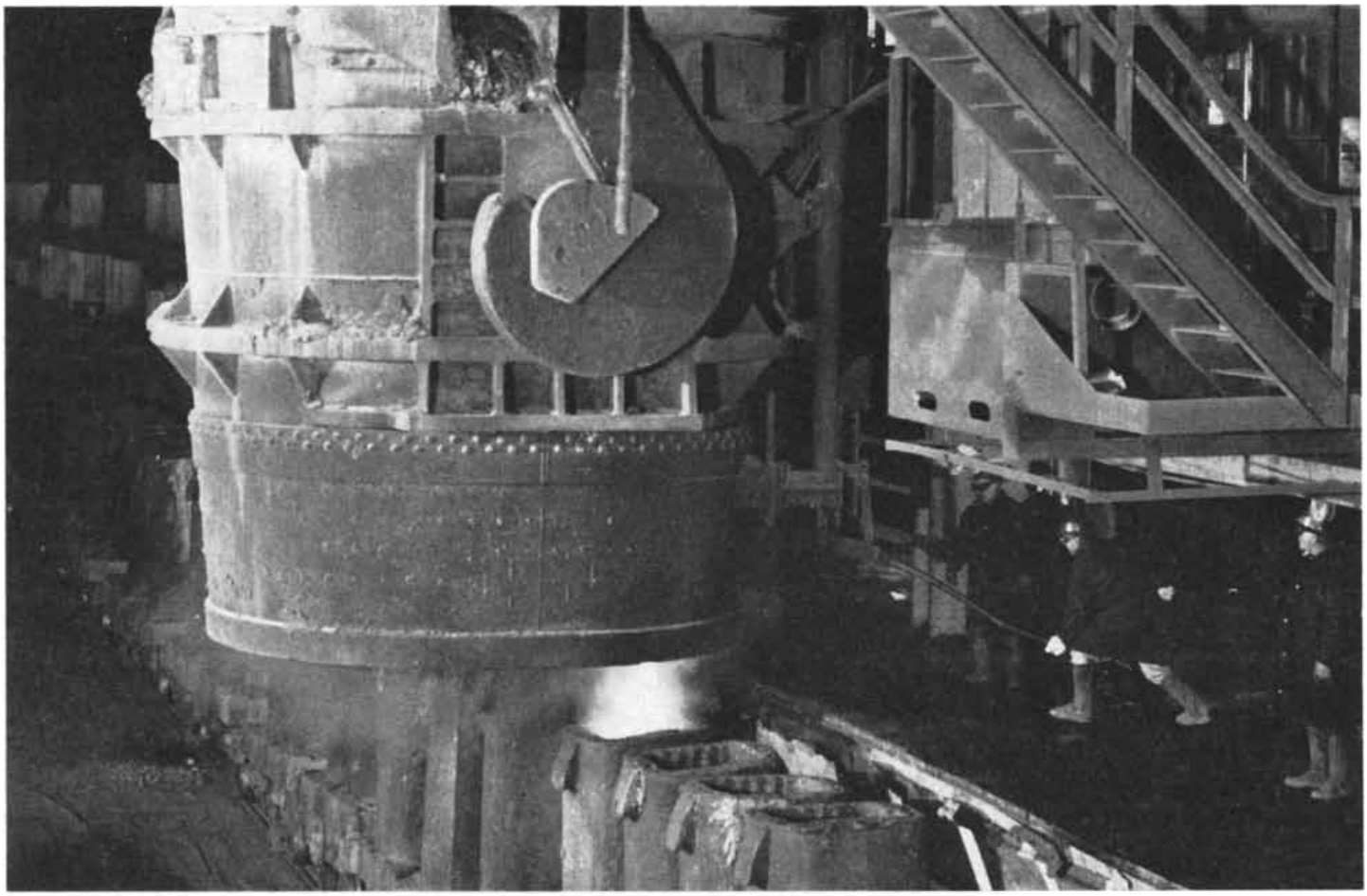
In one of the most fruitful associations Siegfried Junghans, a German engineer who had designed a continuous-casting system in the 1930's, entered into an arrangement with Irving Rossi, a businessman from Brooklyn who later founded a firm of consultants and process licensers: Concast A.G. of New York and Zurich. The Rossi-Junghans process was tried out on a pilot-plant scale in the U.S. by the Allegheny Ludlum Steel Corporation shortly after World War II, but the research was not sustained. Since 1951 the exclusive U.S. licensee of the Concast system has been the Koppers Company, Inc. Koppers built a continuous-casting plant for Atlas Steels, Ltd., at Welland, Ont., and participated directly in solving the initial operating problems at that plant. Now its agreement with Concast has terminated, and Koppers, which has assisted in the building of two other plants, has declared itself an independent source of continuous-casting technology. Concast has recently pooled its resources with Mannesmann-Hüttenwerke A.G. of West Germany and Gebr. Böhler A.G. of Austria, themselves partners of an earlier merger and the roundabout inheritors of Junghans' original research.

The advent of continuous casting in the U.S. is being hastened from other directions. Erik Olson, a Swedish engineer responsible for several significant innovations, has associated himself with the Loftus Engineering Corporation of Pittsburgh. From the U.S.S.R., where continuous-casting research was interrupted by the war, have come reports of a dozen plants annually producing more than a million tons of steel by the new method. U.S. manufacturers regard the Soviet technique as being near enough to commercial status to warrant licensing negotiations. The British Iron and Steel Research Association (BISRA) also placed considerable emphasis on continuous casting after the war. Its theoretical investigations of the physical phenomena involved in the process have now led to the marketing of designs. Recently the United Engineering and Foundry Company has obtained a license to market the BISRA concepts in the U.S. and Canada. There is evidence that the United States Steel Corporation, which reportedly began investigating continuous casting in 1932, is close to production. Continuously cast steel is being produced by the new technique at the Roanoke Electric Steel Company plant in Virginia. This apparently successful operation represents a joint research effort undertaken by the Babcock & Wilcox Company and the Republic Steel Corporation.

Bessemer's prevision of continuous casting sounds a leitmotiv that runs through the history of the process: the proposal of an idea before it is technologically feasible. The efforts of Soviet investigators first produced a horizontal conveyer mold, operating on essentially the same principle by which gypsum wallboard and plate glass are made today. Liquid material is simply poured onto the moving flat surface of the conveyer, and the liquid solidifies as it is carried along. Although a plant based on this principle is still operating in the U.S.S.R., the method has not proved practical for general use. Soviet engineers are concentrating their development effort on the vertical-mold technique.

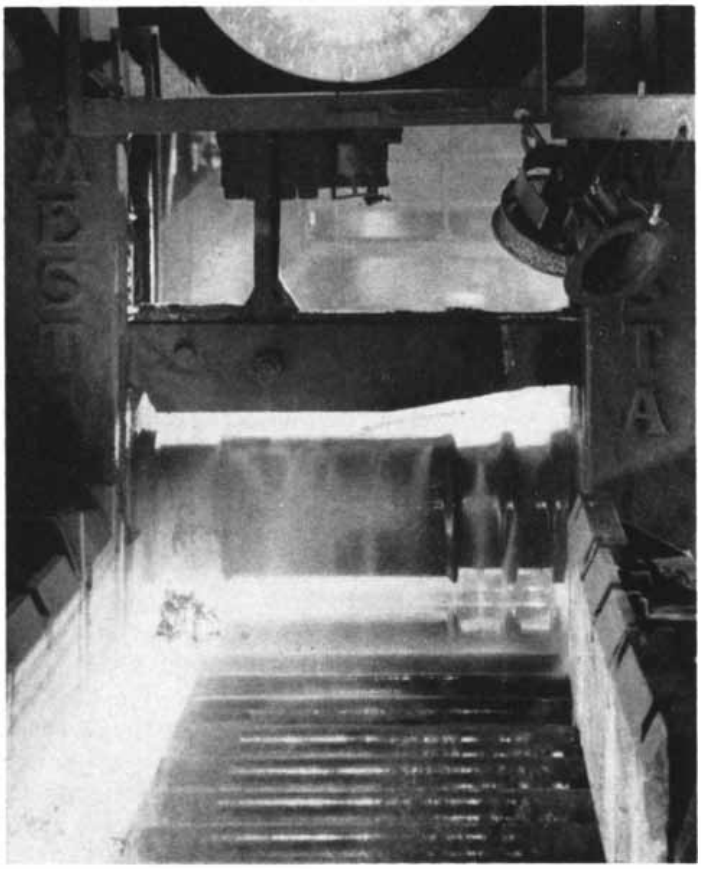
The Design of the Mold

The mold is the critical component of any continuous-casting system. The

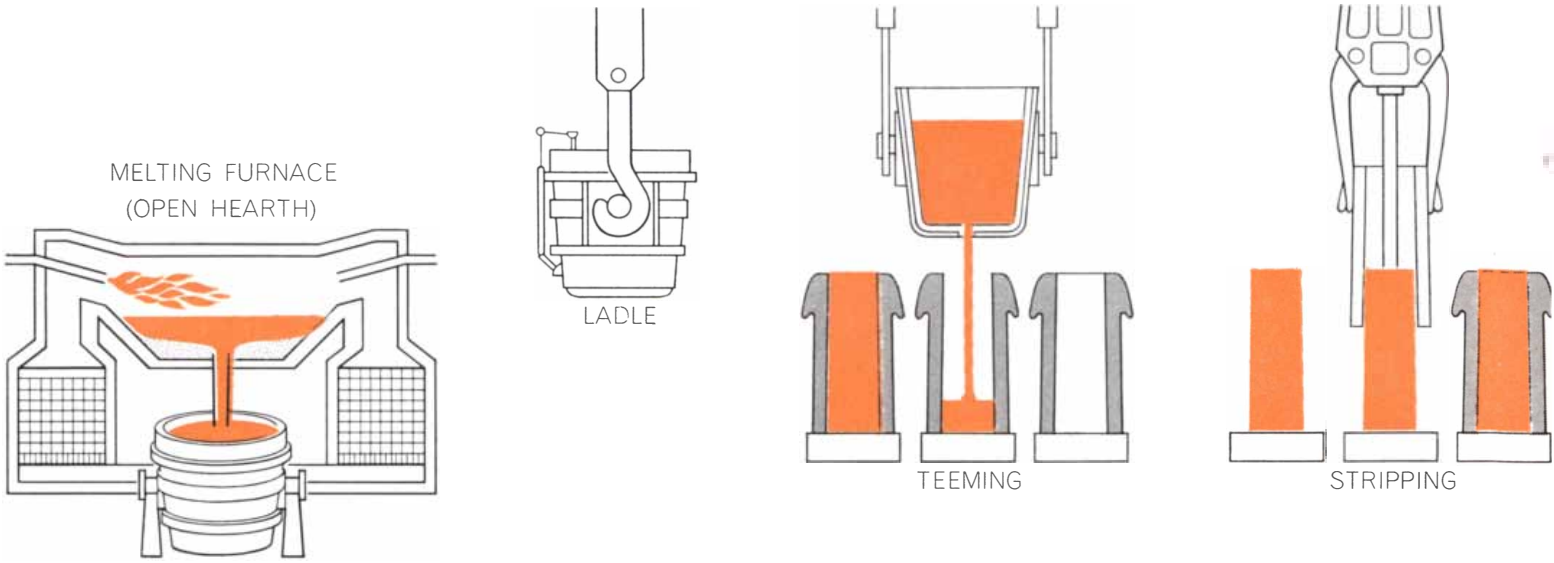


TEEMING, or pouring, molten steel from ladle to ingot molds, a major step of the conventional process, was photographed at the Bethlehem Steel Company's Lackawanna plant near Buffalo, N.Y. Ingot molds are standing on rail cars used for transporting them.

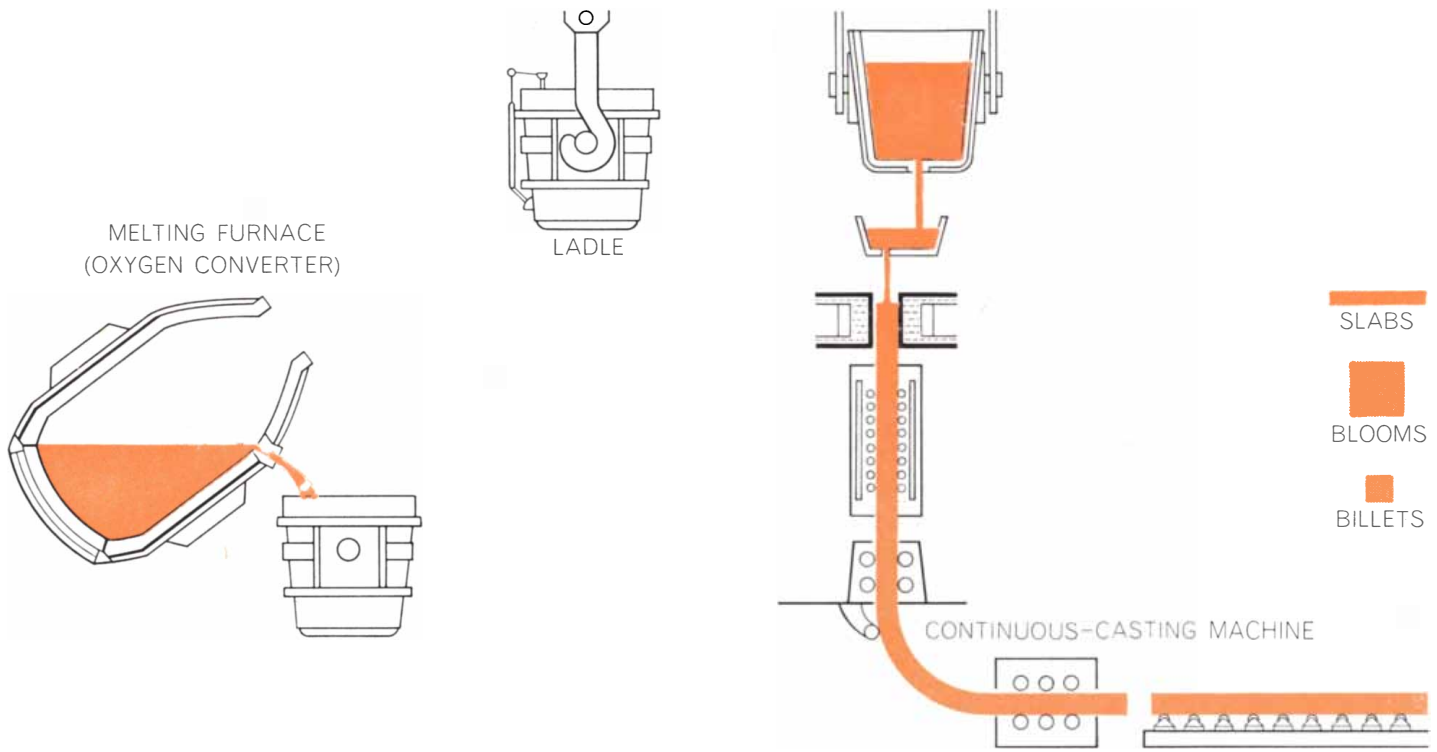
SOAKING PIT at the Bethlehem plant in Johnstown, Pa., receives an ingot from an overhead crane. Before rolling, the ingot is reheated in the gas-fired furnace to a uniform 2,200 degrees Fahrenheit.



PRIMARY MILL at the plant in Bethlehem, Pa., shapes "blooms" like the one emerging at left by the squeezing pressure of rollers. Later shaping in finishing mill is determined by desired product.



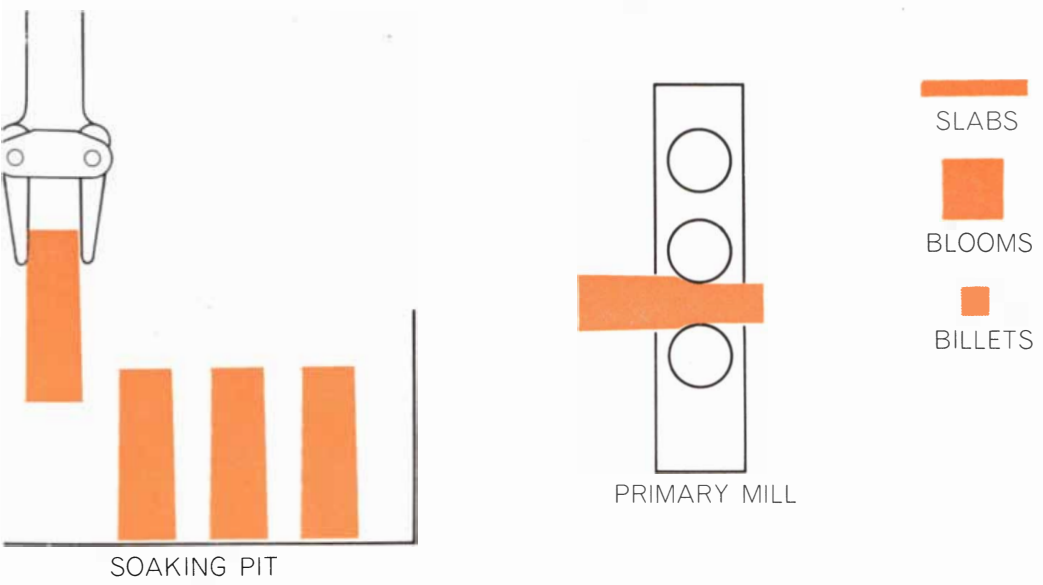
CONVENTIONAL STEELMAKING begins with the melting of pig iron and scrap steel in an open-hearth furnace. The molten steel is teemed from ladle into individual ingot molds. In cooling, the ingots contract to form a "pipe," or top cavity. The molds are



CONTINUOUS STEELMAKING is facilitated by the steady cycle of an oxygen-converter furnace. The molten steel is teemed into a tundish and then more steadily into a casting machine that shapes, cools and cuts the billet for rolling in a finishing mill.

tundish, the secondary cooling equipment and the withdrawal rollers have all been significantly modified during the past 30 years, but the design of these components is generally determined by the mold itself. Although controlled removal of heat from solidifying metal—the most important aspect of the process—is best effected slowly, the efficiency of continuous-casting equipment increases with the withdrawal speed attained. In the vertically mounted mold the maximum rate of descent of the solidifying steel is determined by the geometry of the mold and the cooling characteristics of the steel sliding through it. Since freezing proceeds from the perimeter of the mold to the center of the billet, at most withdrawal speeds the white-hot liquid core of the steel extends well below the mold [*see illustration on page 81*]. Indeed, in nearly all the present processes the thickness of the solid, red-hot skin at the point where the billet leaves the mold is less than an inch; for some small-cross-section billets produced on high-speed machines it is closer to a quarter of an inch.

There is a critical rate of descent for a billet of any given cross section; exceeding this rate results in a solidification crater so deep that the skin may be warped and broken by the tensile and hydrostatic stresses exerted as the metal emerges from the mold. The rate of descent, or withdrawal speed, is further limited by the tendency of solidifying steel to stick to the mold. Sticking generally occurs just below the level where the skin first begins to form, often rupturing the skin at that point. A slow rate of descent provides time for the



stripped off the solidified ingots, which must be reheated in a soaking pit before they are squeezed by the rollers in the primary mill into the shape of slabs, blooms and billets.

incipient crack to heal and prevents the molten steel from gushing out of the mold through the rupture [*see illustrations on page 82*].

In the earliest work in the U.S. and the U.S.S.R. the mold was fixed in position and copiously lubricated and relubricated with palm oil or rapeseed oil; the withdrawal rate was simply held low enough to ensure that sticking and the subsequent cracking of the skin would not occur. At the Böhler steelworks in Austria the fixed mold has been refined to its highest state and is still used for the production of continuous slabs as large as six inches thick and 40 inches wide. The steady casting rate, however, is still low.

Because high speed offers the best return on investment in equipment, radical modifications of the fixed-mold technique were attempted. Babcock & Wilcox, which since the 1930's had followed continuous-casting research in this country by Edward R. Williams, built a pilot plant in Beaver Falls, Pa., based on his designs. They hoped to avoid sticking by a system in which the speed of billet withdrawal varied cyclically so that the level of the liquid in the fixed mold alternately rose and fell in simple harmonic motion. As a result the position of the critical sticking point in relation to the mold face was never the same, and the probability of sticking was reduced. The cycling imposed inordinate power loads on the withdrawal-roller drives, however, and still required excessive lubrication of the mold surfaces. At its new plant in Roanoke, Babcock & Wilcox has abandoned the technique; it appears that the fixed mold is being discarded by natural selection.

One alternative to the fixed mold is the spring-mounted mold, investigated in some detail by BISRA and the early Soviet developers. To prevent the cracks caused by sticking, the entire mold was designed to "give," or move down, with the flowing metal whenever sticking occurred. Under normal casting conditions the compressive force in the mounting springs is slight as the metal skin slides down the mold face. When sticking occurs, the mold is pulled downward until the increasing force of the springs effects the upward release of the mold. This provision works to a disadvantage, however, because too violent a release can actually cause a crack in the skin and a breakout of metal beneath the mold. BISRA soon found it better to effect the release, when necessary, in a downward direction, so that the violent mold movement tends to compress the billet skin rather than tear it. In the BISRA "compression release" mold, if the first increment of increased compression in the mounting springs cannot overcome the sticking, the downward travel of the mold activates a limit switch, imposing an abrupt downward motion on the mold and releasing it from the billet skin with little chance of skin rupture. This technique allows some increase in casting speed and improves the surface quality of the billets. It is a corrective measure rather than a preventive one; if sticking occurs frequently, as is likely at high withdrawal speeds, the release mechanism does not have time to complete a smooth release cycle for each incident.

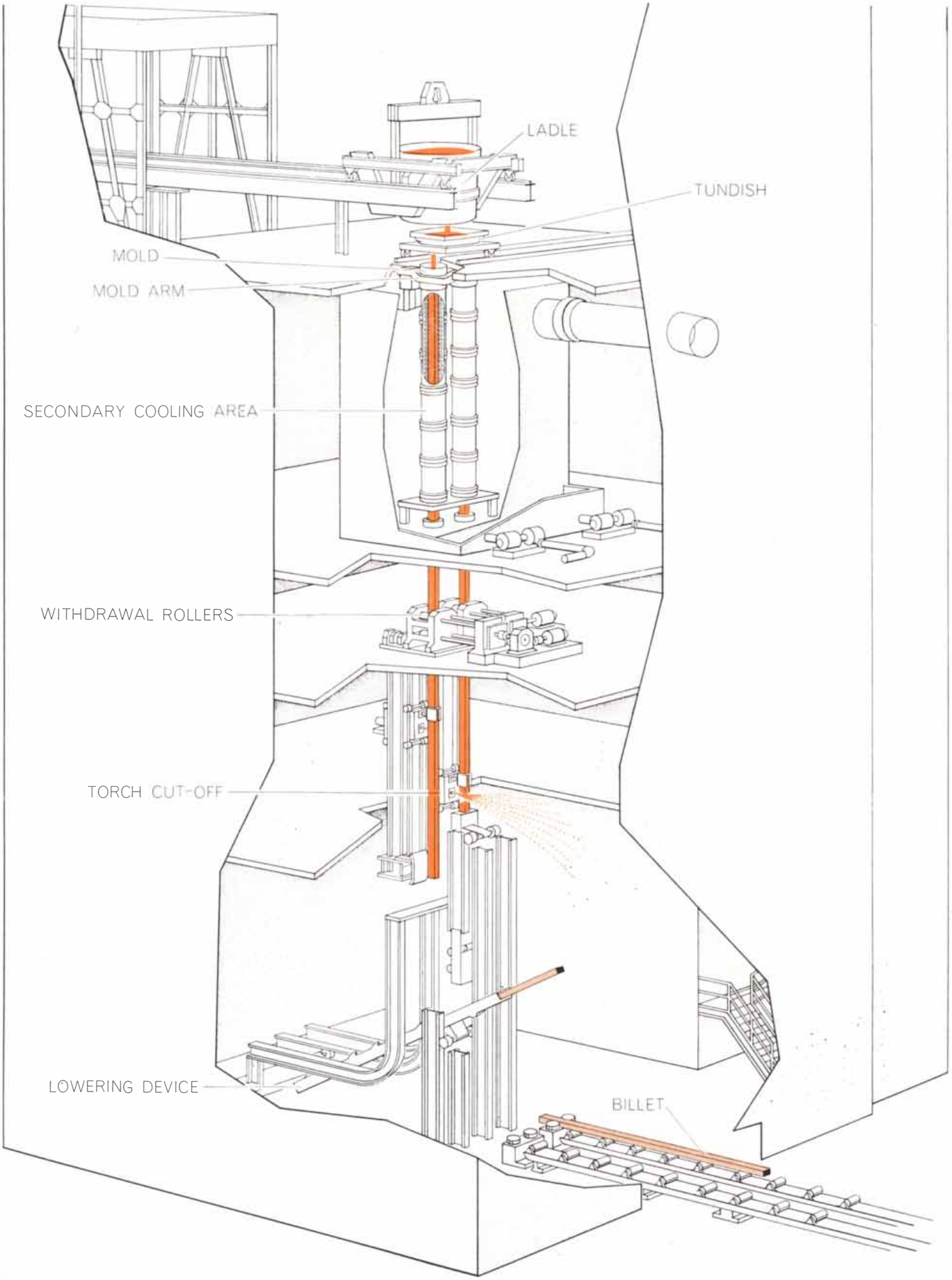
The method for which Babcock & Wilcox abandoned the fixed mold at the Roanoke plant is the reciprocating mold, used successfully at BISRA's first production plant for the Steel Company of Wales and now also preferred in the U.S.S.R. The principle of the reciprocating mold was patented as far back as 1933 by Junghans; he made numerous tests and initiated pilot-plant work at Mannesmann and Allegheny Ludlum, but it was some time before his mold was installed in an operating steel plant. Here again the more efficient concept had to wait for technological vindication as the development of practical fixed molds took precedence over the reciprocating mold. Today it is generally agreed that the eventual implementation of Junghans' idea has been the most significant achievement in continuous casting. It provides a means of attaining a combination of high casting speeds and good surface quality that would never have been realized with the fixed-mold arrangements. Almost all the new designs make use of the principle.

At those plants that first used the Junghans technique the mold is installed to move downward a short distance—less than an inch—at the same speed as the descending billet and then upward at a higher speed. The thin, newly formed skin is thus spared constant friction with the face of the mold, and during the downstroke the skin has more of a chance to form undisturbed. The rapid upstroke strips it from the mold surface more effectively than the sliding and dragging action of the fixed mold.

The Process of Modification

At the end of the war a wholesale resurgence of interest in continuous casting took place. In 1944 the Russians began work in earnest at the Tsniichermet Laboratory in Moscow. In 1946 Babcock & Wilcox opened its Beaver Falls pilot plant. In 1947 pilot-plant operations were started by Böhler in Austria (fixed mold), BISRA in London (spring-mounted mold) and Allegheny Ludlum at Watervliet, N.Y. (reciprocating mold). In 1950 Mannesmann in West Germany joined the development effort with a plant based on the Junghans patents, and in 1951 the Red October steelworks, the continuous-casting pilot plant of the U.S.S.R., was commissioned. A minute list could be compiled of the thousands of inventions and process modifications developed at these plants, but here it seems more useful to describe the evolutionary pattern of continuous casting.

The burgeoning plants all produced steel billets easily enough to prove the technical feasibility of the process. This, however, was only the first step toward

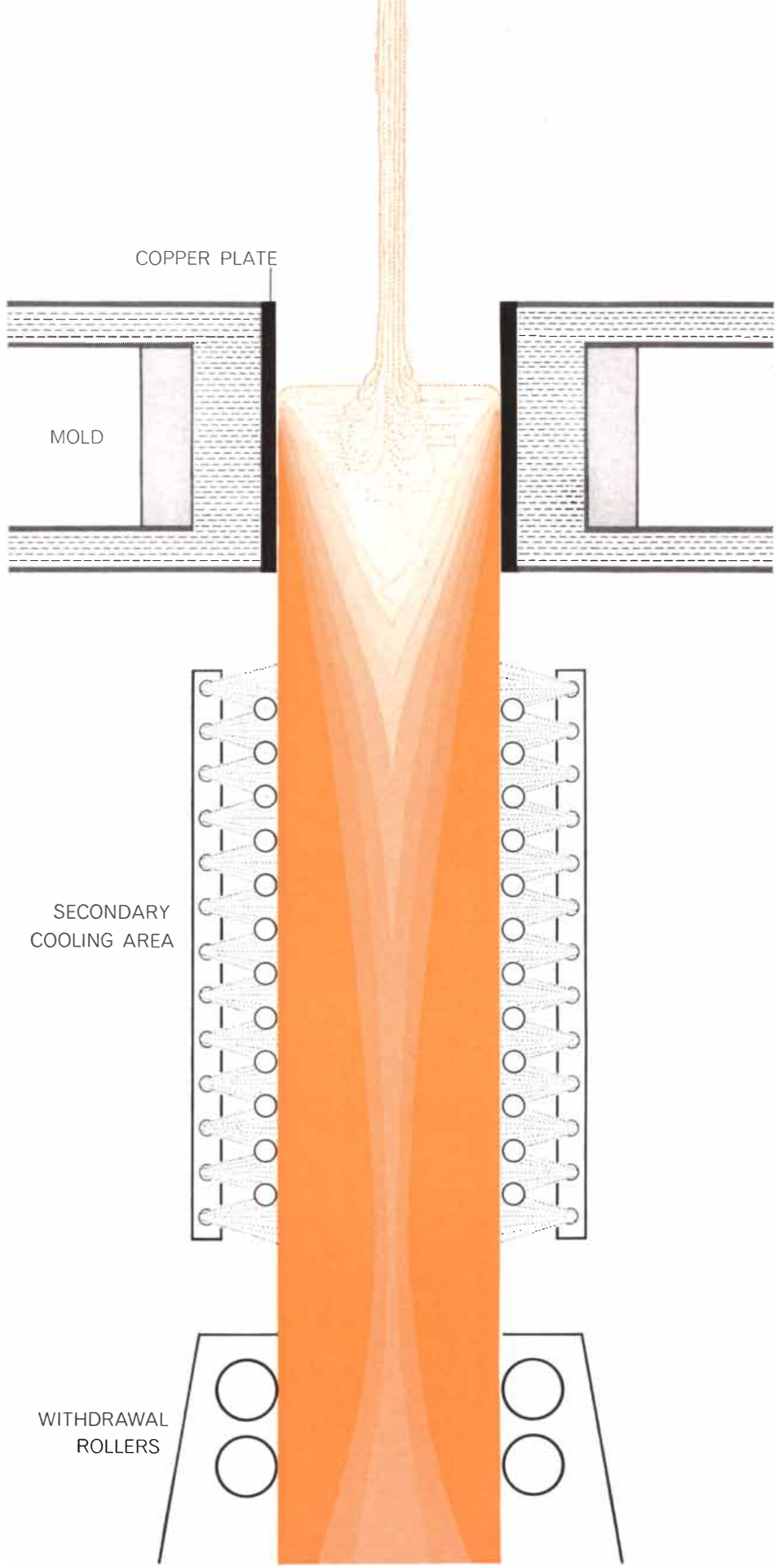


CONTINUOUS-CASTING PLANT can be synthesized from those in operation to illustrate common aspects of the process. Molten steel from melting furnace is poured from ladle (*top*) to tundish and funneled into the mold, a set of copper plates shown in cross section circled by cooling gear. As it leaves the mold the shaped, solidifying billet is still a white-hot liquid toward its center and cannot be grasped by withdrawal rollers until it passes through a secondary cooling area where it is sprayed by an array of water nozzles. Emerging from the withdrawal rollers, continuous billet is flame-cut to lengths suitable for rolling in the finishing mill.

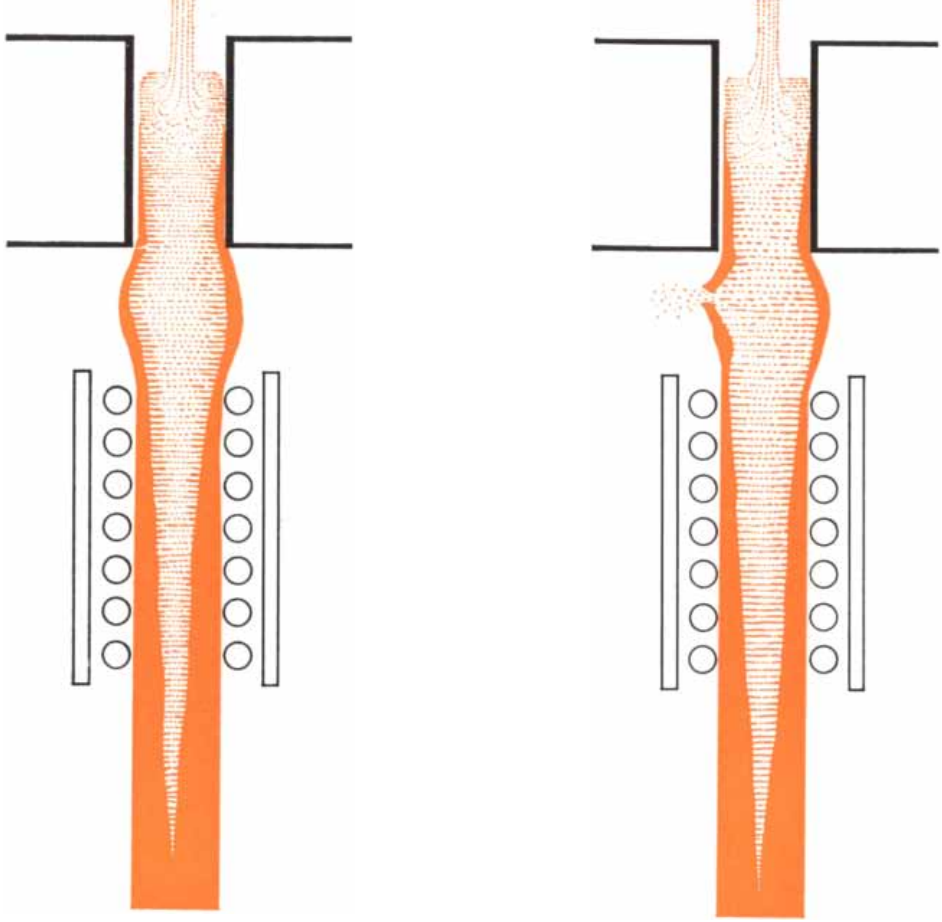
manufacturing steel of a quality competitive with the ingot-molded product and at competitive production rates as well.

The success of Junghans' designs induced the Barrow Steel Works of the United Steel Companies in England to ask Rossi to provide it with a single-mold machine capable of producing two-inch-square billets of carbon steel from a 7½-ton ladle already in use. These conditions presented an interesting problem to Rossi's Concast firm. When a heat of steel is held for more than 60 to 80 minutes in the ladle under normal atmospheric conditions, manganese begins to migrate out of the steel and other changes in chemical composition occur. Facilities for handling the output of a single-melting furnace, then, must at least be able to make use of its output in little more than an hour's time. In conventional steelmaking this simply calls for an adequate supply of ingot molds, but in continuous casting the ladle size effectively determines the design of the casting machine. The 7½-ton heat at the Barrow works could yield about 1,200 feet of two-inch-square billet. To achieve this result in 80 minutes meant that the speed of casting would have to be 15 feet per minute, a speed considerably higher than any of the earlier pilot plants had attained. The operators found that if the reciprocating-mold technique was used, it was impossible to cast at this speed without producing defective billets. The solution developed at Barrow, and applied in most of Rossi's later plants, was a modified pattern of mold oscillation. Ian Halliday of the Barrow works determined that if the mold moved downward faster than the hot metal, the skin being formed would be subjected to a slight compressive stress. Compression would help an incipient crack in the solidifying skin to heal itself before it left the mold. Moreover, the technique greatly reduced the chance that sticking, and consequently cracking, would occur, because the mold at no time traveled at the same speed and direction as the billet. Halliday's technique, called "negative strip," allowed steady casting speeds of up to 37 feet per minute for the two-inch billets.

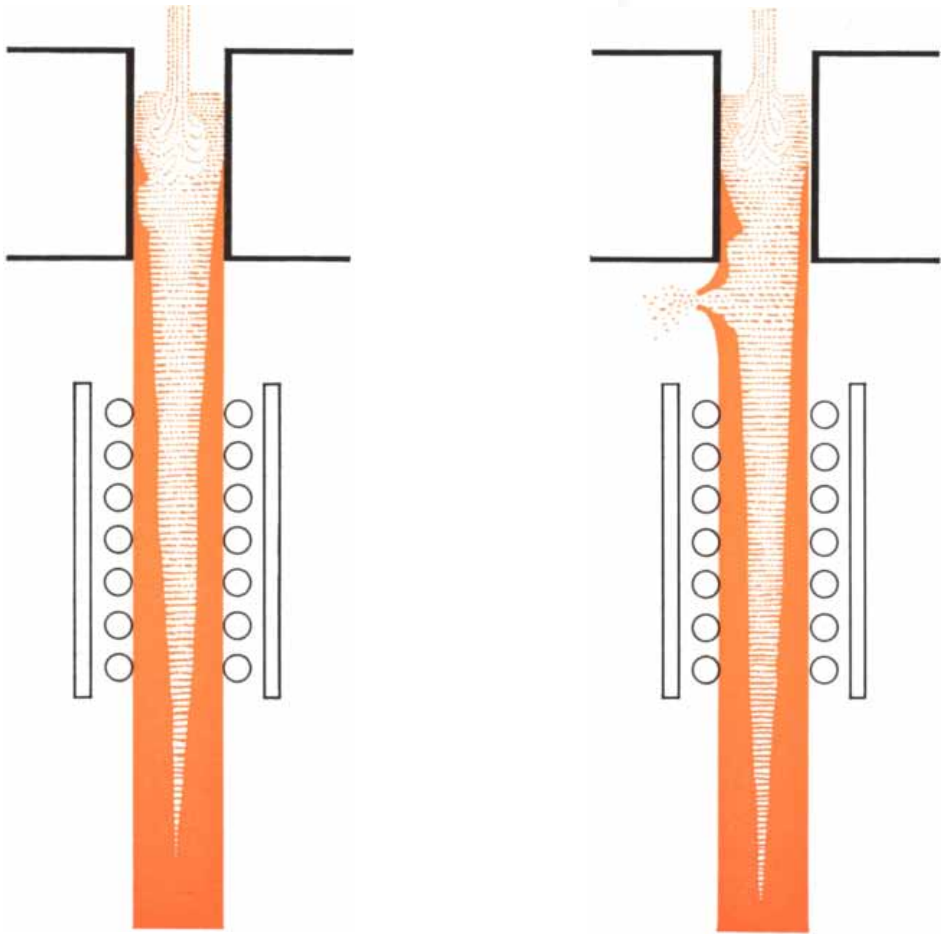
Soon after the innovation at Barrow, Concast began to install what is now an impressive array of pilot and commercial plants. Notable among these is the plant at the Dillinger Hüttenwerke in the Saar, which produces carbon steel in a continuous slab eight inches thick and 60 inches wide. The molds at this plant are composed of four water-cooled copper plates, backed with steel and so assem-



SOLIDIFYING begins as stream of steel (*top*) is poured into a water-cooled copper mold and forms its hard skin (*darker color*). Descending billet is gripped by rollers and sprayed by water nozzles so that its liquid core (*lighter color*) narrows. The core widens as billet reheats below the cooling area, but steel is solid enough for handling in withdrawal rollers.



EXCESSIVE SPEED of casting causes a long liquid crater and skin thin enough to break, as shown at right, when tensile and hydrostatic stresses are exerted on it below the mold.



STICKING of metal to the mold often occurs just below point where skin starts to form. It can lead to the formation of a thin wall, shown at left, and breakout depicted at right.

bled that slabs of different widths can be produced with the same mold by a simple adjustment of the end pieces, and slabs of different thicknesses can be made by replacing the end pieces. This type of composite-plate mold is now almost commonly employed in the larger plants in which the production of several product sizes is required.

BISRA has proposed an alternate means of casting a large amount of steel into small billets in a short time. With a nod to the makers of "popsicles," it has patented a unique mold design enabling it to cast three square billets joined along their diagonals from a single mold [*see top illustration on page 87*]. The triple billet, after emerging from the cooling zone and being cut into lengths for rolling, is divided along the thin webs of steel that join the square sections. This modification enables a single-mold machine to equal the output of a three-mold machine with no added investment or inordinately high casting speeds.

Toward the Horizontal

The most dramatic changes in plant design have been inspired by recent improvements in the discharge arrangement. As we have seen, the billet emerging from a water-cooled mold has only partly solidified and for some distance below the mold its center remains a white-hot liquid. The problem this creates for plant designers is that of minimizing the distance through which the solidifying billet must travel before it can be grasped by the withdrawal rollers. The disadvantage of the prevalent vertical withdrawal and cutoff arrangement, in which the desired lengths are flame-cut from the emerging billet and conveyed singly to the rolling mill, lies in the capital investment required for a plant tall enough to accommodate the descending strand. In the U.S.S.R., for example, several plants have been built with only the pouring platform and withdrawal rollers above ground level, so that the large ladles (with a capacity of up to 140 tons) need not be raised to a considerable height for pouring but can be moved into position over the casting tundish on the existing meltshop craneways. The finished billet or slab descends into a pit that may be 35 feet deep, and the cut lengths are hoisted back to the ground floor for transfer to the rolling mill. Where underground seepage is a problem, as at Roanoke Steel, the entire plant must be constructed aboveground.

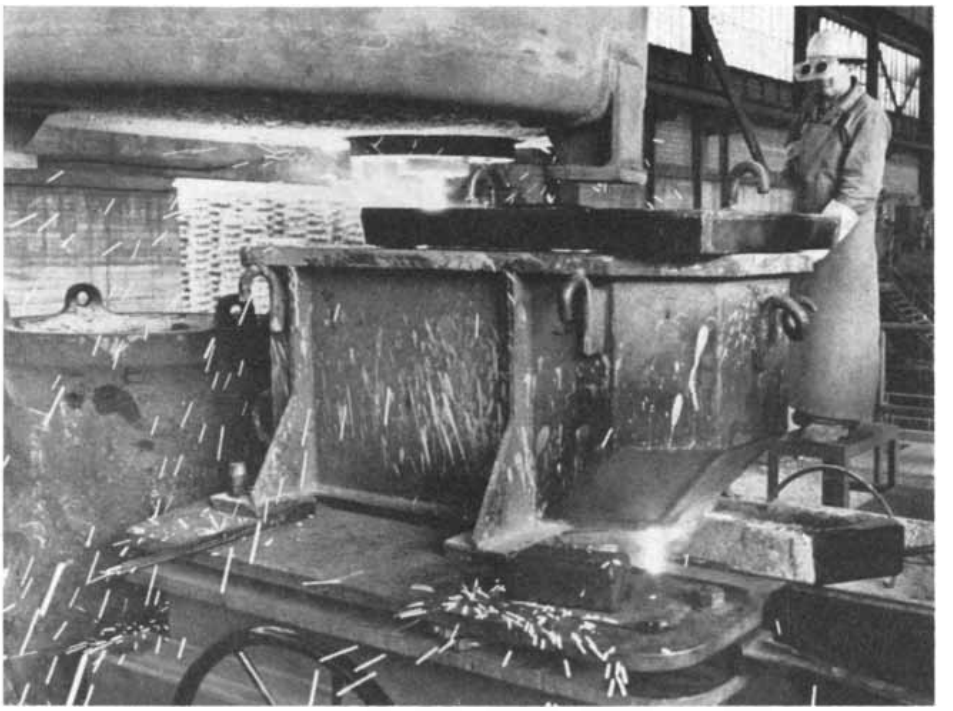
In designing better discharge arrangements the central objective is rapid, uni-

form cooling. The speed at which solidification is effected determines not only the distance through which the billet must travel before it can be handled by the withdrawal rollers but also the speed at which the entire casting machine will operate. The cooling technique will also exert a profound effect on the quality of the billets and slabs produced. At early pilot and semicommercial plants a completely uniform cooling pattern on all faces of the piece being cast was rarely attained; it was almost never achieved with wide slabs. At most plants now in operation the series of water-spray nozzles arranged uniformly around the descending billet has proved costly in terms of space. Even at the newer plants the problem will reassert itself because the requisite cooling rate varies with the type of steel cast, the size of the cross section and the casting rate, so that no one design can be universally applicable.

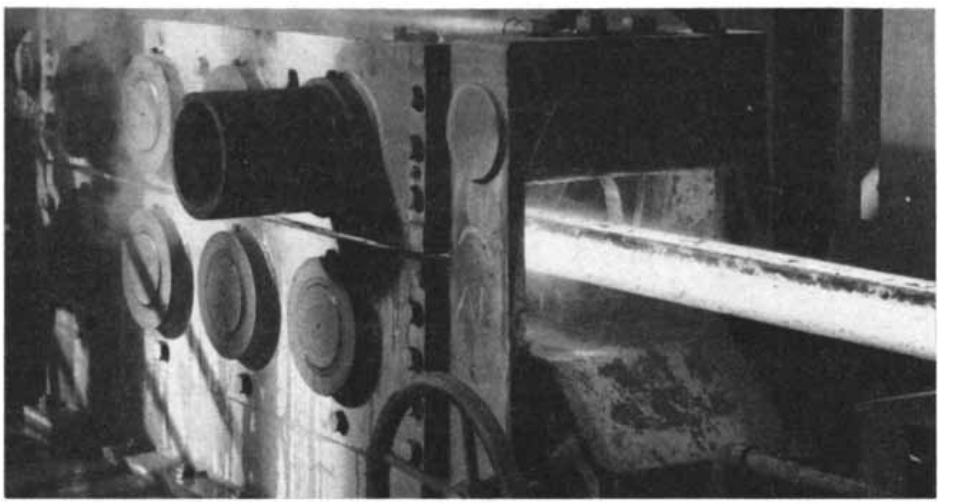
At the Barrow works Concast introduced a curved-discharge technique that has since been widely adopted. The same arrangement has been implemented at the Dillinger plant in the Saar, where the largest continuously cast slabs in the world are produced. Here the hot slab emerging vertically from the withdrawal rollers is bent and deflected to the horizontal plane by a heavy-duty hydraulically operated roller. The bent slab continues along its own radius of curvature through an angle of 90 degrees; then it is straightened in another set of rollers. The finished slab proceeds horizontally to a cutting station, where it is sliced into rolling-mill lengths.

Recent work by Olson has introduced a rather interesting departure from these techniques. Dispensing entirely with water-spray cooling, his method involves cradling the hot, solidifying billet in a framework of heavy guide rollers as it emerges from the mold. These rollers deflect the soft billet around a 90-degree curve into a combination withdrawal-and-straightening-roller stand. The arrangement uses air convection to cool the casting, and therefore no headroom is required for a water-cooling chamber. The saving of space is significant, but so far the arrangement seems suitable only for small-section billets or low casting speeds.

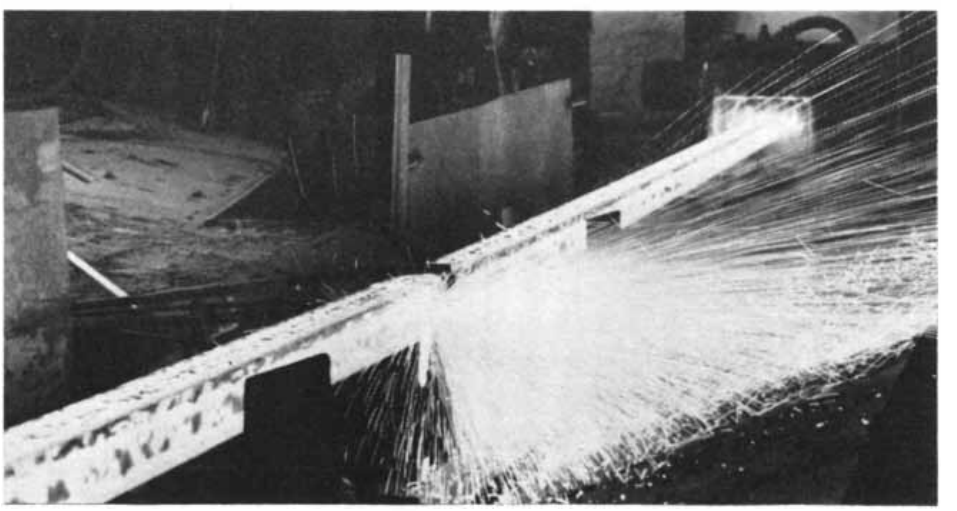
Another way to lower the over-all height of a continuous-casting plant was announced in May of this year by Concast; it suggests the direction in which mold technology is heading. The pilot plant designed by Concast in Lucerne features a curved mold. The shift of the advancing billet from the vertical to the horizontal plane is initiated not by de-



TUNDISH at the Concast plant in Lucerne receives a stream of molten steel from the ladle (*top left*) and funnels a thinner, steadier stream into the top of the mold (*bottom right*).

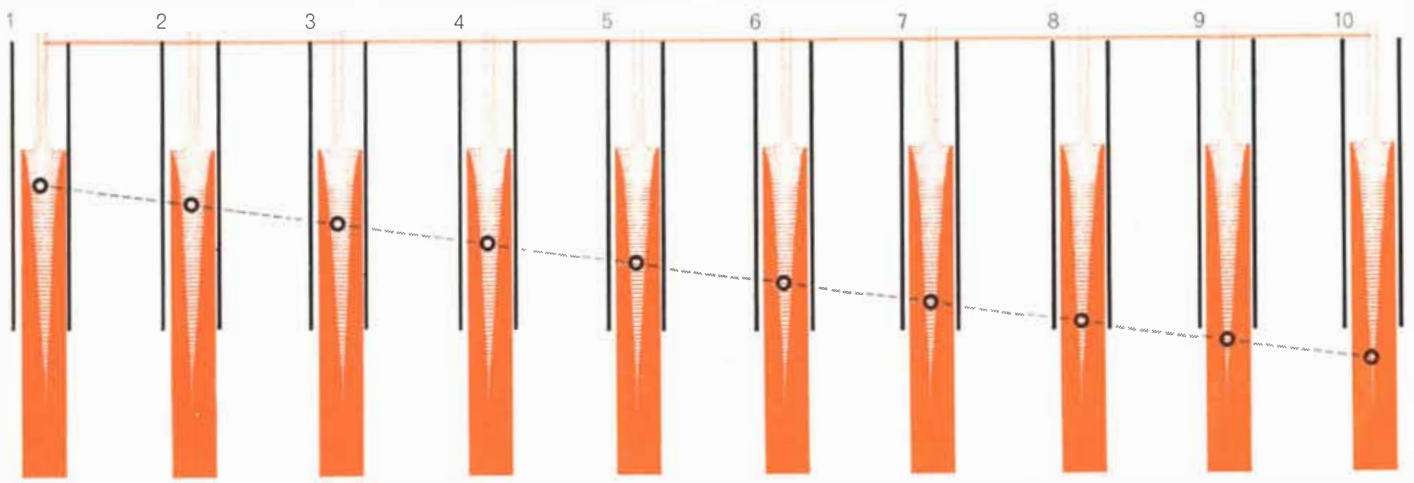


PINCH ROLLERS used at the Concast plant are synchronized to withdraw billet at rate corresponding to the flow of molten steel into the mold. The steel is discharged horizontally.

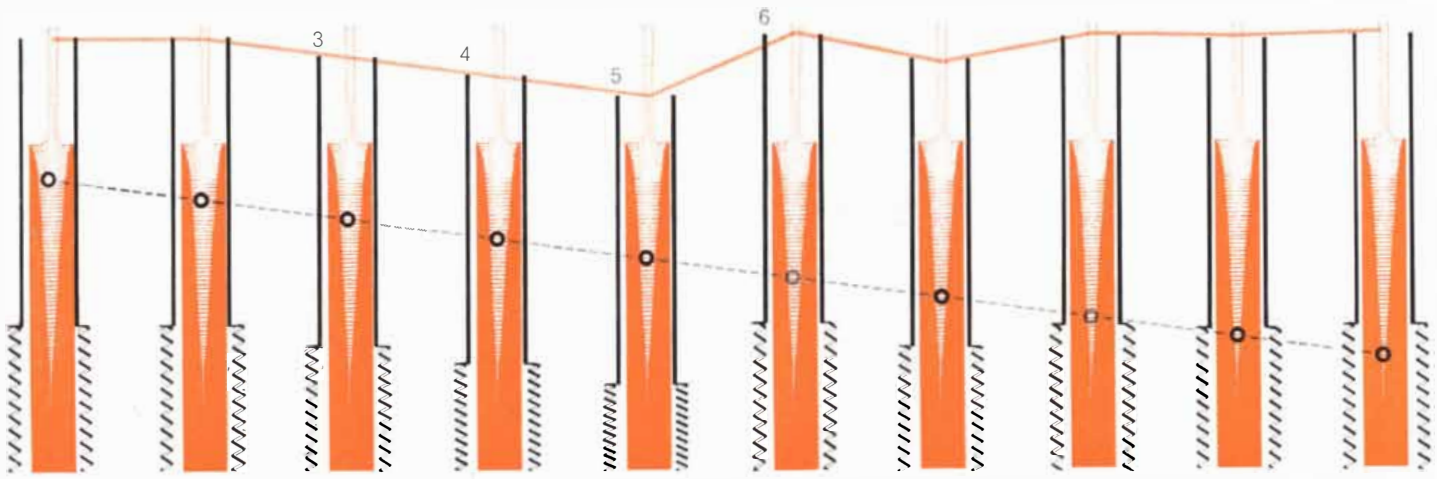


CUTOFF is effected by oxyacetylene torches beyond the withdrawal rollers. The torches can be moved to cut the billet prior to withdrawal, a process known as vertical cutting.

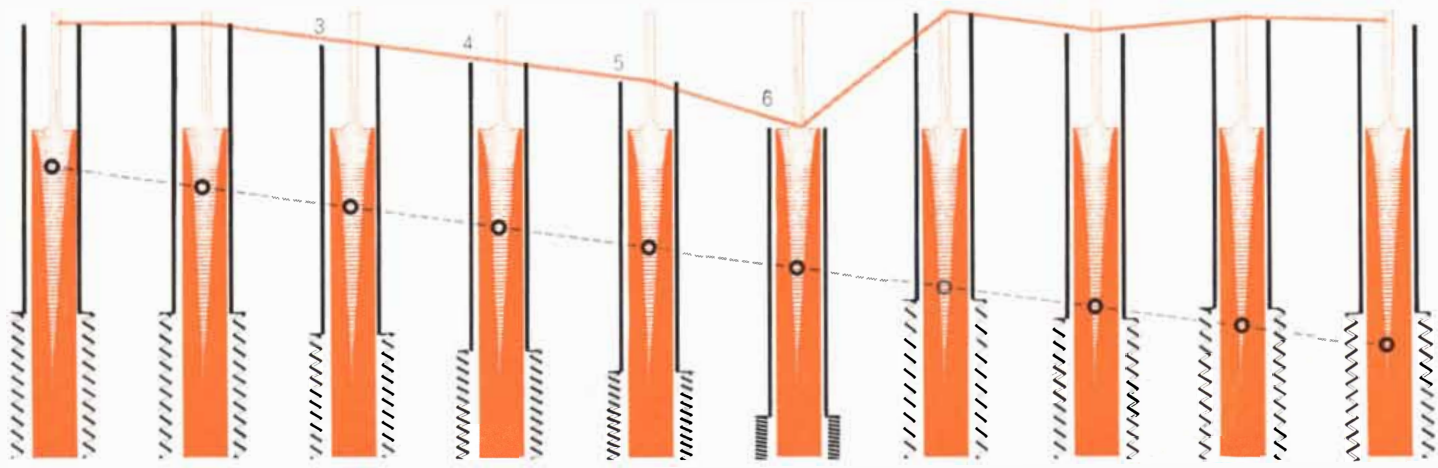
flection at the point of discharge but within the mold itself. The curvature of the mold itself eliminates the need for a bending mechanism. Emerging from the mold, the curved billet follows its own extended arc until it is horizontal. The curvature is designed to reduce the occurrence of sticking, and the entire mold is situated at the end of a long arm that imparts a reciprocating arc to it. Although this type of mold has not been used in the production of a wide range of billet and slab sizes, it has been successfully demonstrated in Lucerne. Considering the over-all shape of the mold-and-discharge arrangement as it has evolved in the past decade, it appears that the eventual development of a truly horizontal casting system may not be far off. This would complete the circle in mold technology begun when the Rus-



FIXED MOLD and steady withdrawal rate, the simplest continuous-casting pattern, is illustrated by comparing the locus of a point on the mold (*colored line*) with the locus of an arbitrary point on the billet (*broken line*) as it descends in the course of casting.



SPRING-MOUNTED MOLD moves down with billet when sticking occurs (*panels 3 through 5*). It is then released (*panel 6*) so that billet can slide free without cracking. Colored line shows pattern of mold displacement; broken line traces descent of the billet.



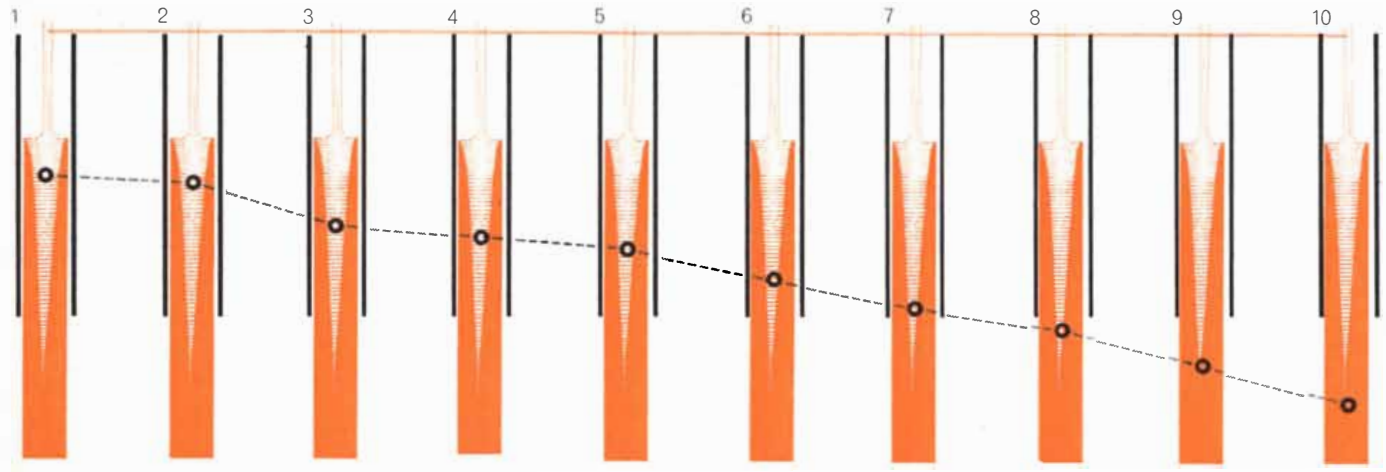
COMPRESSION-RELEASE MOLD starts moving down when sticking occurs (*panel 3*), is later released by a violent downward motion (*panel 6*) tending to compress the billet. Locus of mold movement (*colored line*) is highly schematized for purposes of illustration.

sians attempted horizontal casting with little success in the 1940's.

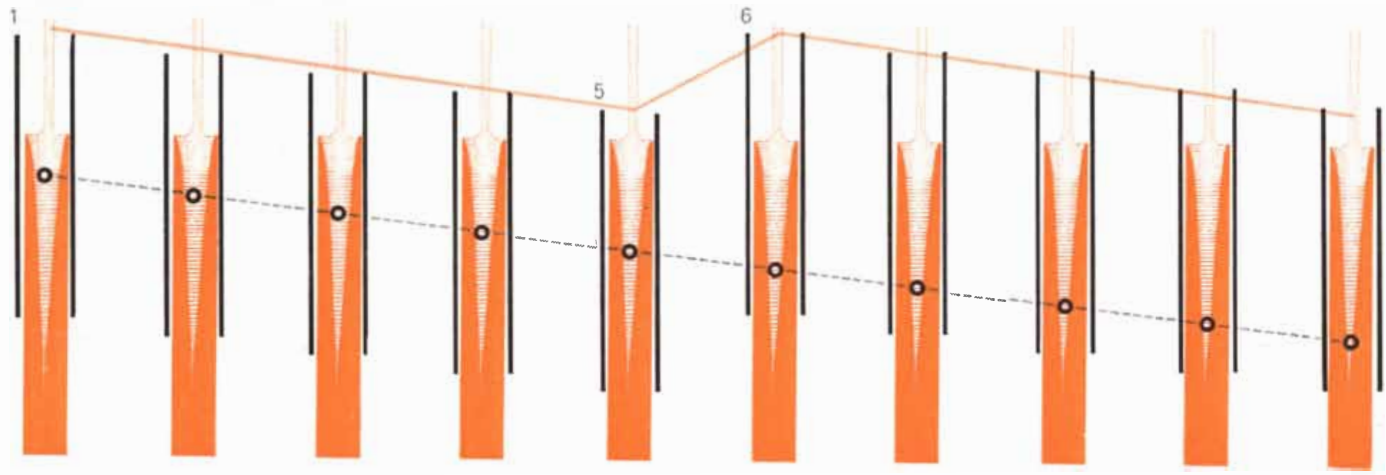
Continuous Casting in the U.S.

Reluctance on the part of steel manufacturers in the U.S. to accept continuous casting stems from two misgivings: technologically the process has not yet been applied in the production of all types of steel, and economically most manufacturers are committed to operations into which continuous-casting methods are not easily assimilated.

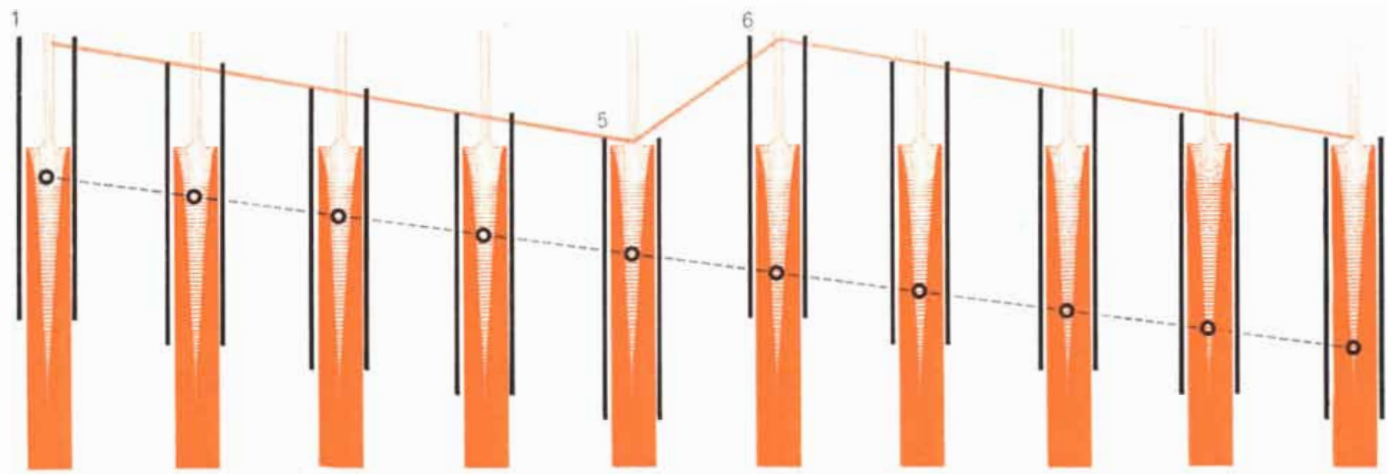
In partial answer to the technological misgiving it can be said that many types of steel, common and special, have been successfully cast at high rates of production. The earliest pilot plants concentrated on ordinary carbon steel, but soon common stainless varieties were being



VARIABLE WITHDRAWAL SPEED, an attempt to avoid sticking, is indicated by the broken line. The mold is fixed, as the colored line shows. Thus the level of the molten steel rises and falls in simple harmonic motion to prevent repetition of sticking point.



RECIPROCATING MOLD "gives" with the descending billet to prevent friction between the newly formed skin and the mold face. Thus the colored and broken lines run parallel until an upstroke (*panel 6*) strips billet from mold and the cycle must begin anew.



"NEGATIVE STRIP" technique prevents sticking because mold (*colored line*) and billet (*broken line*) never travel at the same speed and direction. During downstroke (*panels 1 through 5*) mold descends faster, exerting a compressive stress on solidifying metal.

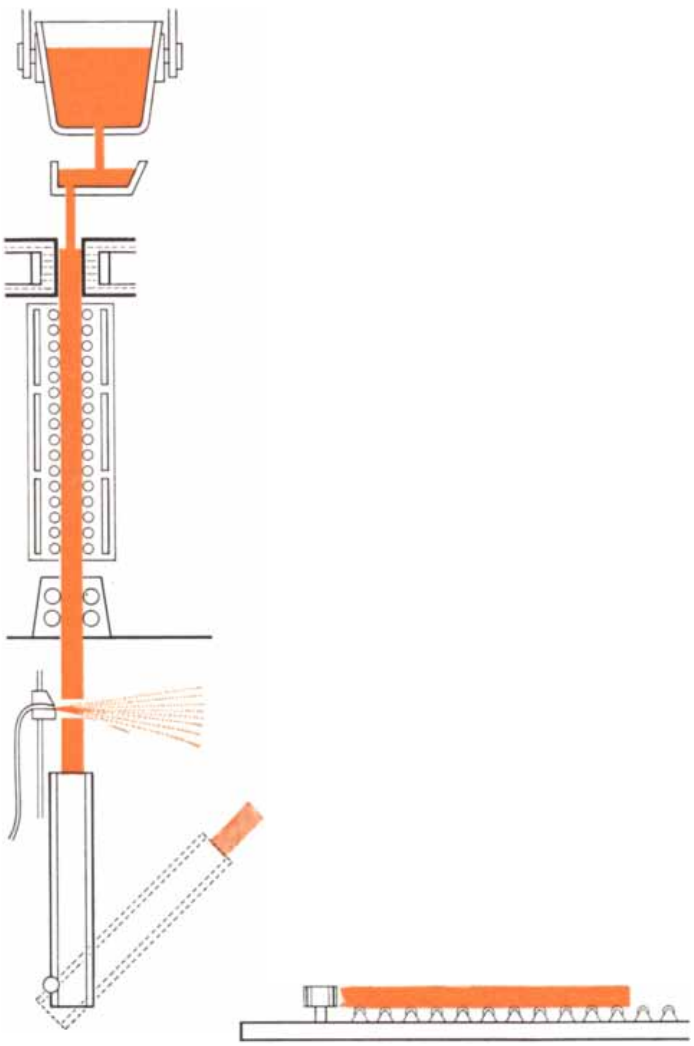
cast at the Red October works. The Atlas Steel plant in Ontario has concentrated on the production of stainless steel slabs, and its diligent study of such subjects as the cooling characteristics of stainless steel has evidently borne fruit: one of Concast's latest plants, built for the Yawata Iron and Steel Company, Inc., of Japan, presents excellent yield figures for the production of stainless steel slabs five inches thick and 48 inches wide.

No continuous-casting plant, however, has successfully produced the low-carbon rimming steel that forms such an important part of U.S. steel production. Rimming steel, so named because of a difference in density and composition between the interior of a solidified ingot and its outer rim, is rolled into thin sheets for automobile bodies, tin plate and galvanized sheeting. A continuously formed slab, quenched and rapidly solidified under conditions quite different from those in the ingot mold, is not likely to duplicate the combination of physical and chemical properties that characterize the "deep-drawing" rimming steels. It is unlikely that the complete acceptance of continuous casting in the U.S. will come about before the technique is able to produce this vital family of steels.

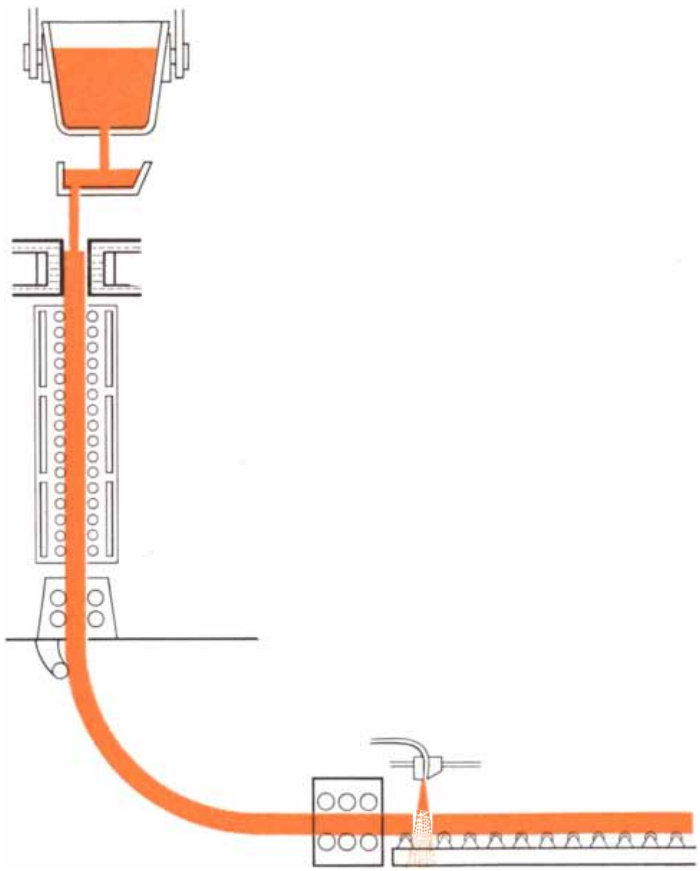
That day, however, may not be far off. The plant designed by BISRA for the Steel Company of Wales is specifically for the production of deep-drawing steel for tin plate, and it is reported that two plants now being built in the U.S. by the National Steel Corporation and the McLouth Steel Corporation will be used almost exclusively for manufacturing steel plate of rimming quality. The National Steel plant will subject the liquid steel to a vacuum-degassing operation before it is poured into the ladle. This will remove dissolved and occluded gases from the steel and improve the structure of the whole cross section of the resulting slab. If these two U.S. plants succeed in producing deep-drawing steels of acceptable quality, the last real obstacle to technical feasibility will have been overcome. Nonetheless, U.S. manufacturers will still have to question the economic applicability of the process in terms of their own operations.

The ideal time for a producer to consider the use of a continuous-casting machine is when he is building an entirely new steel mill, from melting furnace on through to milled products. In such a situation the mill can be designed around the known limitations of the continuous-casting process, and there will be no costly overlap between conventional and continuous equipment. Unfortunately U.S. firms are not planning to build many new steel mills. Therefore many U.S. producers are "not ready" for continuous casting, whereas small producers in India, Venezuela and Peru, for example, have already obtained plant designs. The producers in these countries will avoid the large cost of a primary mill. If there is any solace in underdevelopment, it is this "advantage."

In the U.S. the problem is one of fitting the new process into existing facilities. Because the context in which each manufacturer confronts continuous casting is different, the incentives for implementing it will vary. For instance, Roanoke Steel only manufactures products with small cross section; its operations previously involved teeming electric-furnace heats of 22 tons each into



VERTICAL-CUTOFF arrangement requires a multistory plant to accommodate it. Billet moving straight down is at no point bent.

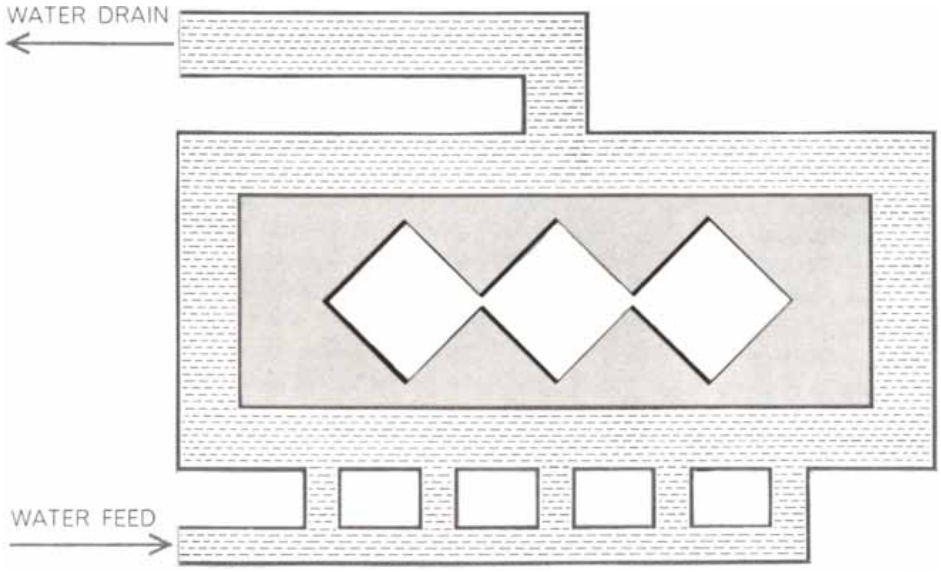


CURVED-DISCHARGE arrangement uses heavy-duty, hydraulically operated roller to deflect emerging billet to horizontal plane.

five-inch-square ingot molds. These ingots were reduced to the finished products in a light-duty rolling mill. Since the teeming operation involved filling more than 100 small molds per heat, it was a logical step for Roanoke to replace the tortuous routine with continuous casting. Furthermore, the cropping and remelting of the cratered tops of these small ingots was both costly and wasteful; the continuous-casting operation at Roanoke produces two billets rather than 100 ingots per heat, and the substantial saving in yield losses alone is plain.

In different circumstances Roblin-Seaway Industries, Inc., chose to integrate two previously independent operations with a Koppers continuous-casting machine. Earlier one division of the company had processed scrap steel for sale and another had obtained steel billets for rolling into rod and bar products. The new plant will allow internal production of billets from processed scrap.

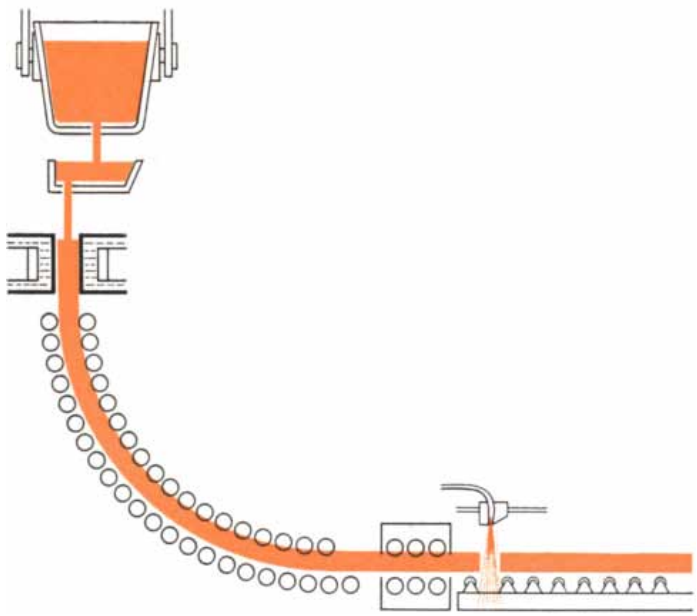
These two instances illustrate the way in which continuous casting may benefit a small producer of specialty steel products. But where can the process fill a need or offer advantages for the larger producer? Most obviously where the producer has an existing primary rolling mill taxed to capacity. As we have noted, the investment in ingot-rolling machinery is such that a profit-making primary mill must have a rated capacity of at least a million tons of steel per year. A continuous-casting plant, however, may have a much smaller capacity, so that the desired plant expansion can be accomplished in smaller increments than conventional equipment would efficiently allow.



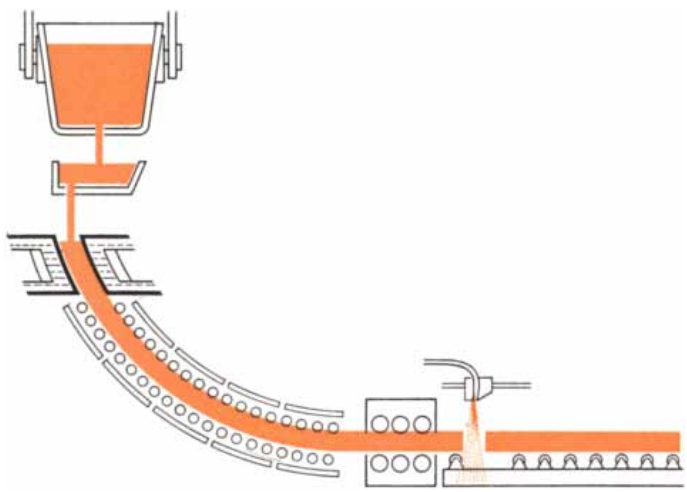
MULTIPLE-BILLET MOLD, depicted in cross section, casts a three-billet "popsicle" that can later be cut along the thin webs of steel shown joining three squares of the mold cavity.

Another economic advantage would lie in the large potential reduction of handling costs. In most big mills the casting pit, ingot-mold stripping station, soaking pits and blooming mills are separated by considerable distances and the labor involved in moving the ingots from point to point by cranes and rail cars accounts for a considerable part of slab-production cost. The compact, single-machine operation of a continuous-casting plant lends itself more readily to automatic control than does the materials-handling of the conventional steel-plant routine.

Perhaps the chief obstacle presented by existing facilities is the production schedule dictated by the open-hearth furnace. The open hearth melts a large quantity of steel at long and sometimes irregular intervals. This pattern is not well suited to an operation in which efficient use of the equipment and realization of the inherently lower operating costs depend on having a supply of liquid metal ready on demand. When a continuous-casting process is installed to operate according to the cycle of an open-hearth furnace, it is the casting equipment that must be ready on demand, and inefficient utilization is likely to result. Solving the problem by holding liquid steel for prolonged periods is inadvisable because of the difficulty in maintaining composition. It is equally inefficient to have more than enough



CURVED COOLING replaces the water-cooling chamber. Emerging billet is cradled by rollers and cooled only by air convection.

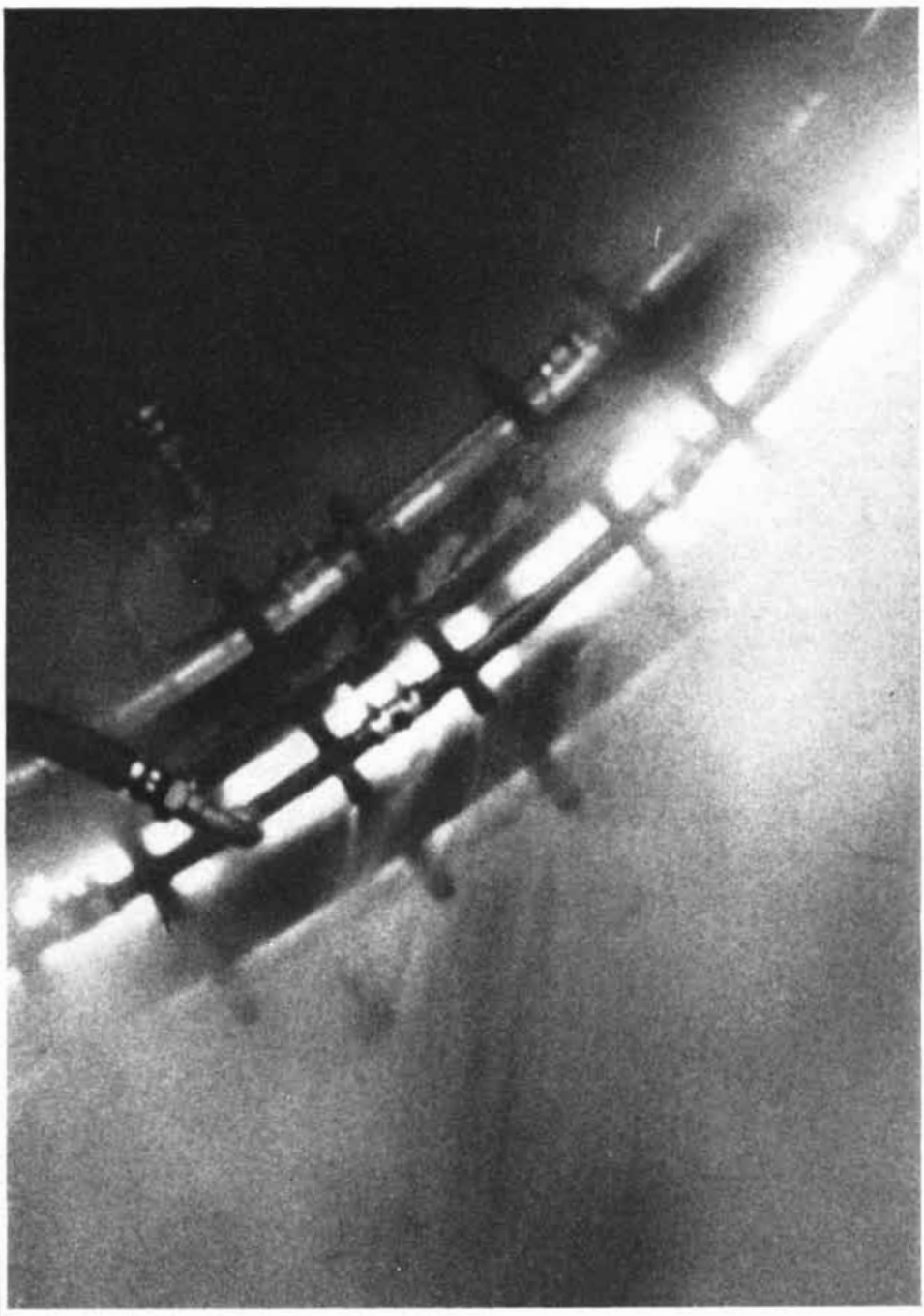


CURVATURE OF THE MOLD can shift the descending billet to the horizontal plane and thereby lower the necessary plant height.

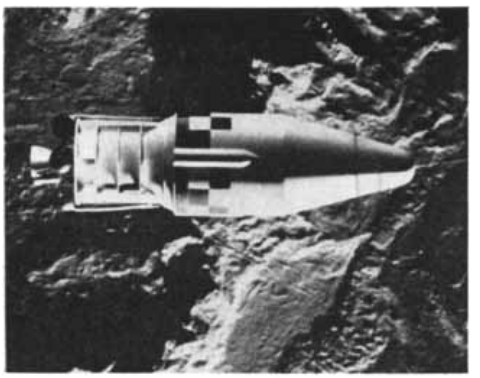
continuous-casting capacity merely to ensure the availability of a casting strand whenever a furnace is tapped.

Ideally the melting furnace should be designed around the continuous-casting machine. The basic oxygen converter, which runs on a shorter cycle than the open hearth does, is best adapted to the needs of a continuous-casting machine because it can more steadily supply the molten steel. It seems likely, then, that the continuous casting of steel on a large scale in the U.S. will be a function of the slow but progressive assimilation of the basic oxygen furnace into the nation's steel industry.

We have seen that some of the valuable pioneering of continuous-casting methods was undertaken by U.S. companies, notably Babcock & Wilcox and Allegheny Ludlum. In 1955, however, Allegheny Ludlum shut down its pilot plant at Watervliet and has not since resumed development work on the process. Rightly or wrongly, in the eyes of many U.S. steel producers this constituted a rejection of the process *in toto*. Except for intermittent efforts by Babcock & Wilcox and the private investigations of U.S. Steel, the history of continuous casting has been made on foreign soil. In this instance the U.S. is following rather than leading an industrial development.



CURVED MOLD in operation at the Concast plant in Lucerne is shown in this photograph shifting the plane of the descending billet from the vertical to the horizontal. The slope minimizes sticking, and the entire mold is on an arm that imparts a reciprocating motion.



Here, at Lockheed Missiles & Space Company's Space Communications Laboratory, scientists are re-investigating the possibility of using the moon to facilitate earth communications. Possibilities for the use of the moon as a relay station for earth-to-earth communications have been largely neglected because the moon's shape and rugged surface greatly distorted a return signal. But Lockheed research into the extension of communications on difficult communication channels, using techniques applicable to dispersive time variant channels, is making significant inroads into this problem.

Another area receiving intense study at Lockheed is satellite tracking of deep space probes. Since tracking accuracy depends greatly on stations being as far from each other as possible, while retaining line-of-sight communications, Lockheed is studying the use of two earth-orbiting satellite tracking stations, 8000 miles apart. Not only would great accuracy be gained by the separation, but it would be further enhanced by the positioning of the stations above the earth's atmosphere, thus eliminating atmospheric distortion.

Examples of other research projects being pursued by Lockheed in the communications area include: Random multiplexing, satellite readout techniques, scatter communications, radar mapping, submarine tracking, modulation of optical energy, communications over multipath channels, and learning systems.

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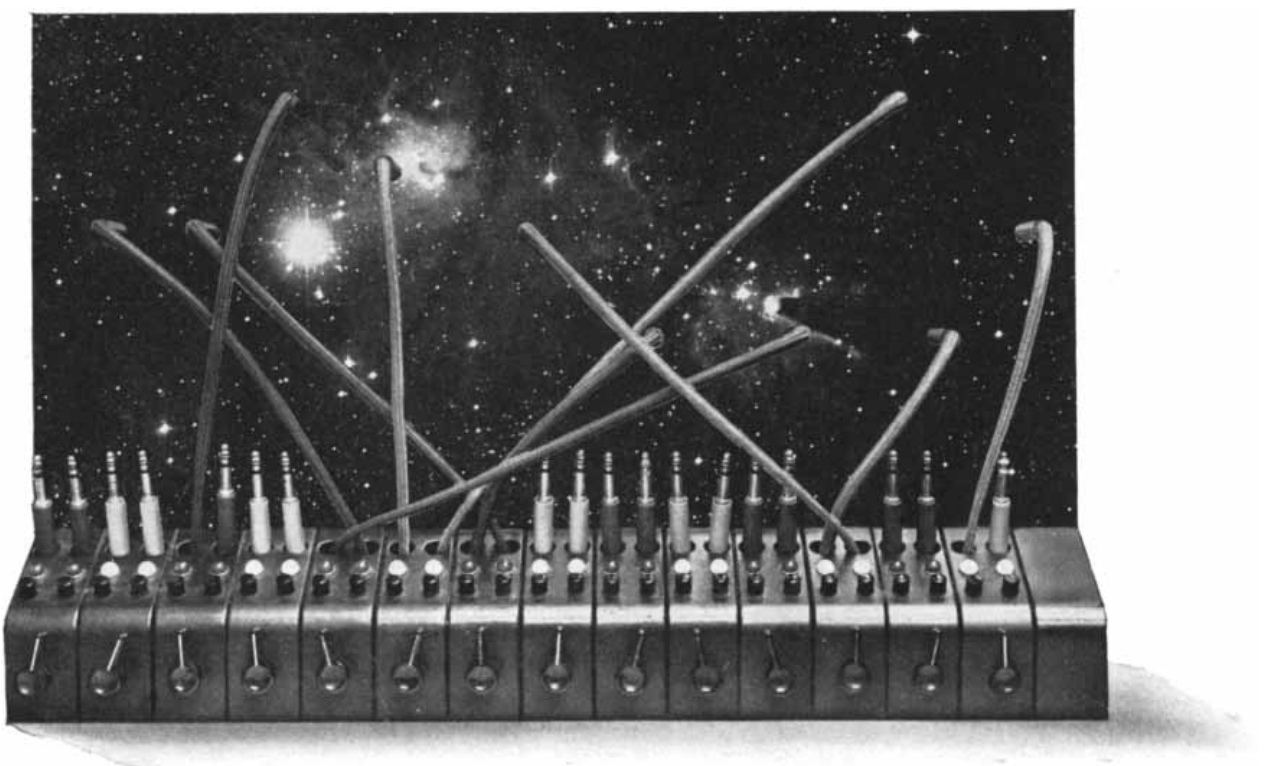
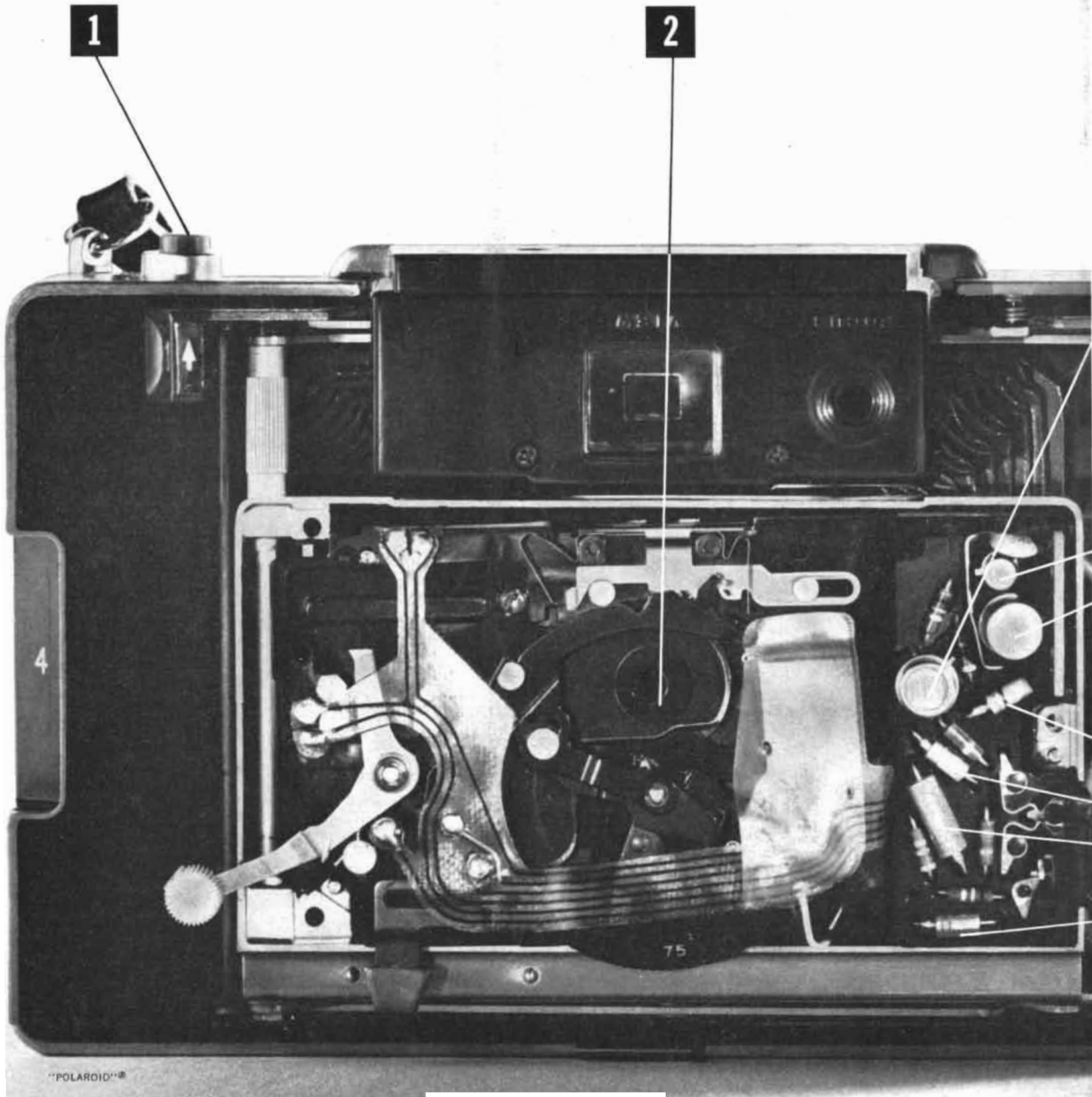
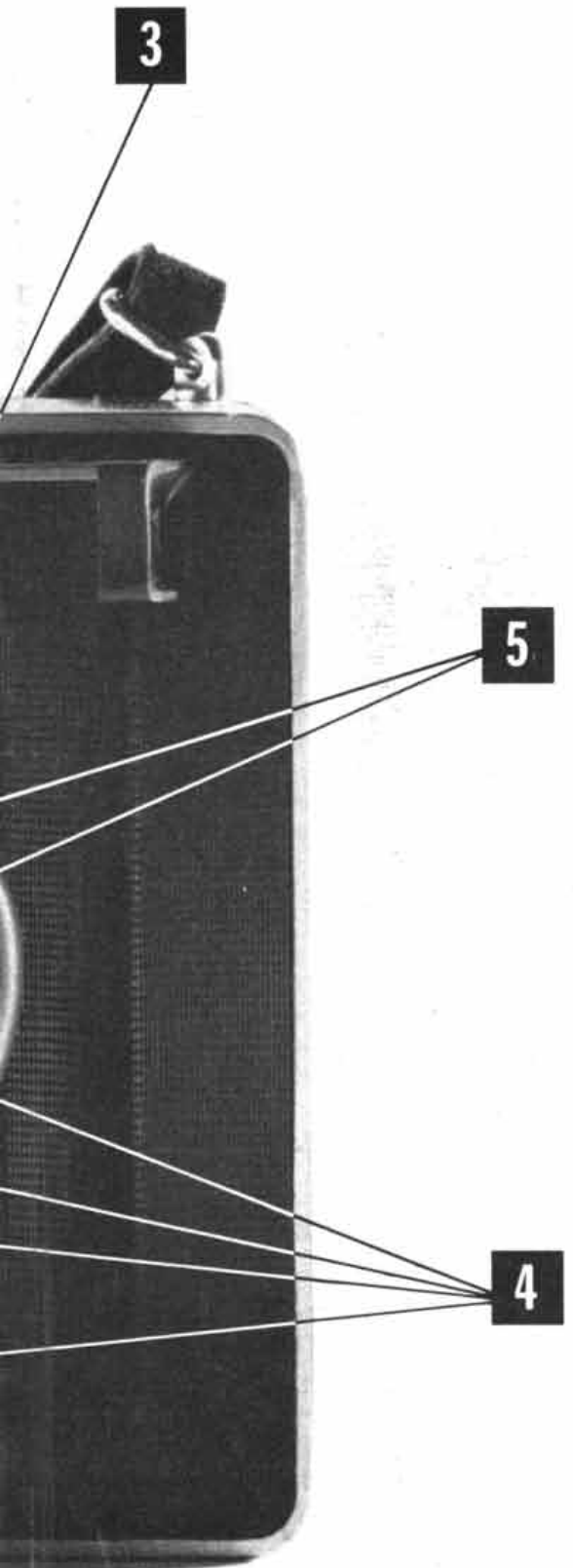


The front of the camera is now



as remarkable as the back.



This is the new Polaroid Color Pack Camera.

We've removed the front face plate to show you a truly significant advance in precision photography—*a shutter system activated by a transistorized electronic circuit.*

Until now, the major interest in Polaroid Land cameras has been in the back, where finished pictures are printed and delivered in seconds. This development broadened the horizons of amateur and professional photography and created many new industrial applications.

Now, the back of the camera must share interest with the front.

For the new Polaroid Color Pack Camera, with its transistorized shutter, does things no camera could do before.

It measures the split-second burst of a flash and automatically sets the right exposure for your indoor color shots *during the flash.* At the other end of the light scale, it can measure the glow of a candle and automatically make the proper time exposure of up to several seconds for black and white pictures. (Other electric eye cameras need manual settings for low light or color flash shots.)

This, of course, means greater accuracy in exposure, greater simplicity in operation.

Behind the simplicity, however, is an achievement of considerable technical extent. Here is how this new shutter system works:

When you press the shutter release button (**1**) to take the picture, several things happen. The electronic circuit is activated by a switch and current flows from the battery beneath the camera body. It energizes an electromagnet which holds back one of the two shutter blades (the closing blade) between the lenses. A second blade (the opening blade) is released allowing light to strike the film through the lens aperture (**2**). Instantaneously another switch sends current through the electric eye (**3**) to charge the capacitors (**4**).

This complex chain of events has occurred in less than a microsecond. The image is now being recorded on the film.

When the capacitors are charged to a voltage level corresponding to the optimum amount of light to expose the picture, the transistorized switching circuit (**5**) is instantly activated cutting off power to the electromagnet. This releases the first blade and closes the shutter.

The time lapse between opening and closing can be as short as 1/1200 of a second or as long as several seconds depending, of course, on the light level of the scene.

Notice—there is no delicate galvanometer, no intricate mechanical timing device, with dozens of moving parts, to be affected by friction and temperature.

Instead, electronic components register the light; electronic circuits do the timing. The shutter itself has only five major moving parts.

This transistorized shutter isn't all that's new about the Polaroid Color Pack Camera.

In addition, it uses a new film pack—with 8 exposures, color or black and white—that loads in seconds. The pictures develop *outside* the camera, so sequence shots can be taken.

Interestingly enough, it is Polaroid's lightest, most compact camera—weighing less than many 35mm cameras.

Here now, in the logical development of Polaroid Land photography, is a precision camera combining the convenience and pleasure of finished pictures in seconds, with perfect exposure settings achieved automatically at all light levels.

We think you'll be impressed with your dealer's demonstration. **Polaroid Corporation**

The Master Switch of Life

Studies of diving have led to the identification of the vertebrate animal's ultimate defense against asphyxia: a gross redistribution of the circulation that concentrates oxygen in the brain and heart

by P. F. Scholander

In the higher animals breathing and the beating of the heart seem synonymous with life. They implement the central process of animal metabolism: the respiratory gas exchange that brings oxygen to the tissues and removes carbon dioxide. Few events are more dangerous to life than an interruption of breathing or circulation that interferes with this exchange. It is not that all the tissues of an animal need to be continuously supplied with fresh oxygen; most parts of the human body display a considerable tolerance for asphyxia. The tissues of an arm or a leg can be isolated by a tight tourniquet for more than an hour without damage; the kidney can survive without circulation for a similar period and a corneal transplant for many hours. The heart and the brain, however, are exquisitely sensitive to asphyxia. Suffocation or heart failure kills a human being within a few minutes, and the brain suffers irreversible damage if its circulation ceases for more than five minutes.

One might expect that the body would respond with heroic measures to the threat of asphyxia. It does indeed. The defense is a striking circulatory adaptation: a gross redistribution of the blood supply to concentrate the available oxygen in the tissues that need it most. The identification of this defense mechanism has resulted from studies, extending over a number of years, of animals that are specialized to go for an unusual length of time without breathing: the diving mammals and diving birds. Only recently has it become clear that this "master switch" of life is the generalized response of vertebrate animals to the threat of asphyxia from any one of a number of quite different circumstances.

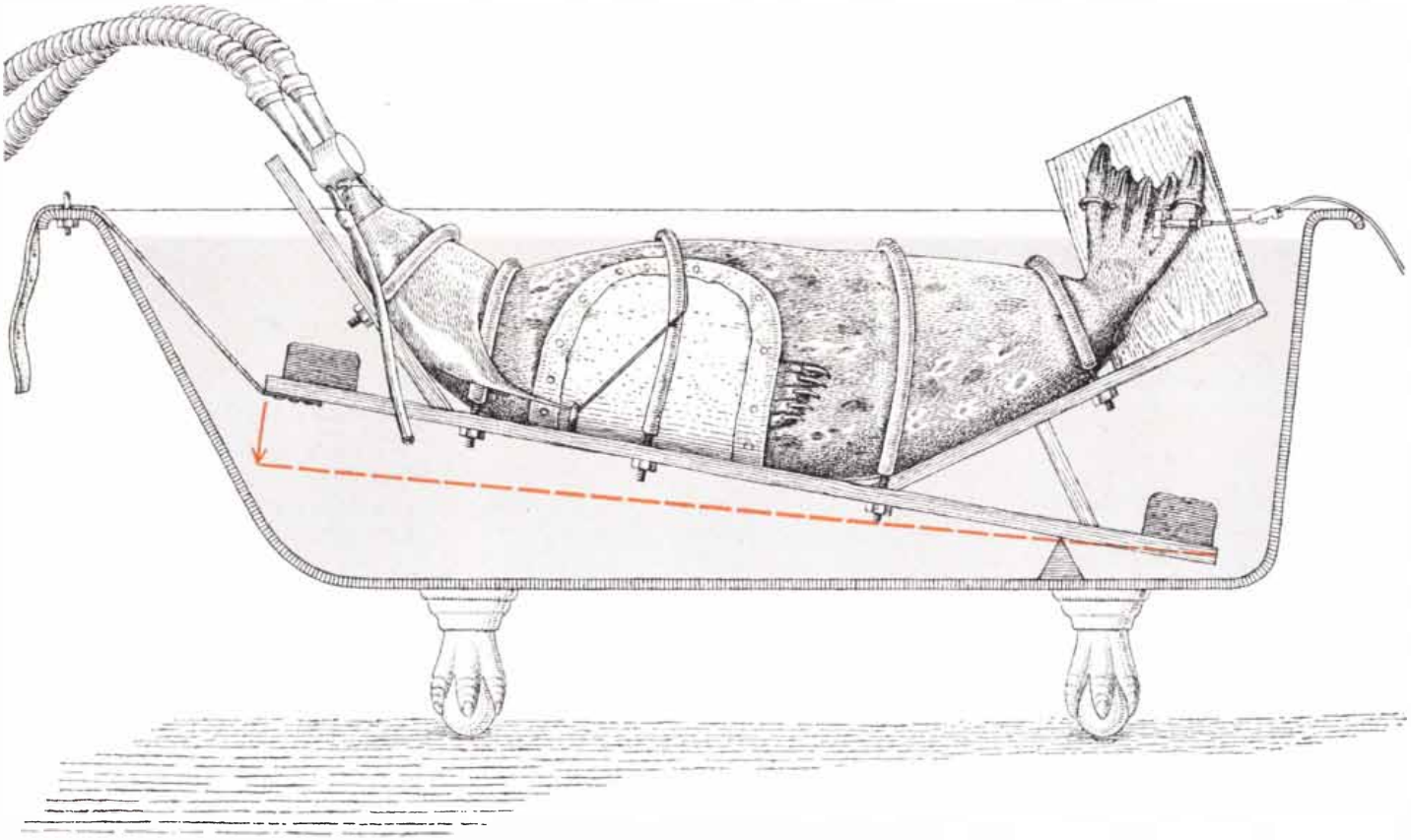
A cat or a dog or a rabbit—or a human being—dies by drowning in a few minutes. A duck, however, can endure submersion for 10 to 20 minutes, a seal for 20 minutes or more and some species of whales for an hour or even two hours. How do they do it? The simplest explanation would be that diving animals have a capacity for oxygen storage that is sufficient for them to remain on normal aerobic, or oxygen-consuming, metabolism throughout their dives. As long ago as the turn of the century the physiologists Charles R. Richet and Christian Bohr realized that this could not be the full story. Many diving species do have a large blood volume and a good supply of oxygen-binding pigments: hemoglobin in the blood and myoglobin in the muscles. Their lungs, however, are not unusually large. Their total store of oxygen is seldom even twice that of comparable nondiving animals and could not, it was clear, account for their much greater ability to remain submerged.

At the University of Oslo during the 1930's I undertook a series of experiments to find out just what goes on when an animal dives. For this purpose it was necessary to bring diving animals into the laboratory, where they could be connected to the proper instruments for recording in detail the physiological events that take place before, during and after submergence. Over the years my colleagues—Laurence Irving in particular—and I have worked with many mammals and birds. We have found seals to be ideal experimental animals: they tame easily and submit readily to a number of diving exercises. At first we confined them to a board that could be lowered and raised in a bathtub full of water. Lately my colleague Robert W. Elsner at the Scripps Institution of Oceanography has trained seals to "dive" voluntarily, keeping their noses under water for as long as seven minutes.

Our first experiments at Oslo confirmed the earlier discovery, by Richet and others, of diving bradycardia, or slowing of the heart action. When the nose of a seal submerges, the animal's heartbeat usually falls to a tenth or so of the normal rate. This happens quickly, indicating that it occurs by reflex action before it can be triggered by any metabolic change. The initiation of bradycardia is affected by psychological factors. It can be induced by many stimuli other than diving, such as a sharp handclap or a threatening movement on the part of the investigator when the seal is completely out of the water. Conversely, bradycardia sometimes fails to develop in a submerged seal if the animal knows it is free to raise its head and breathe whenever it likes. In long dives, however, the slowing down is always pronounced. It is significant that the impulse is so strong it ordinarily continues for the duration of the dive, even when the animal works hard—a situation that would normally cause a rise in the heart rate.

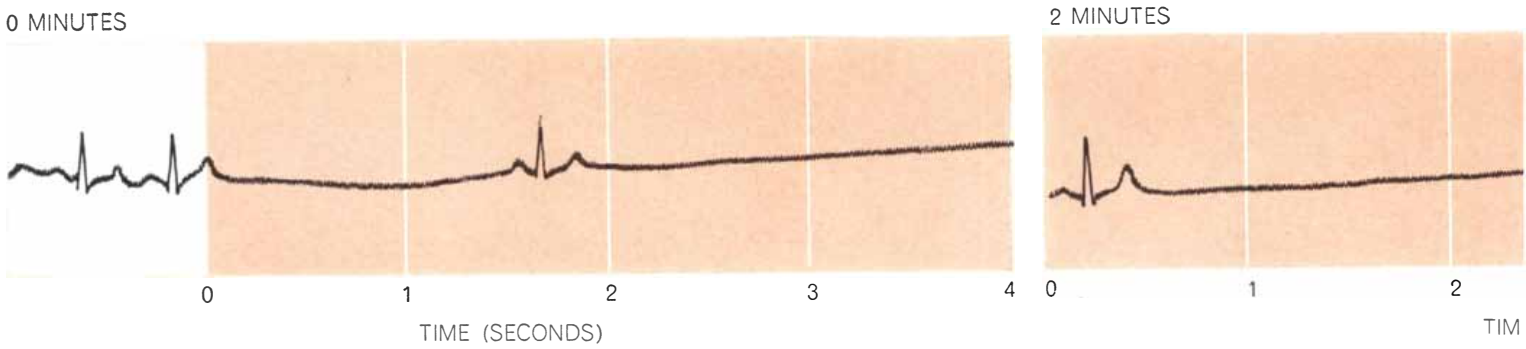
Bradycardia occurs in every diving animal that has been studied. It has been reported in such diverse species as the seal, porpoise, hippopotamus, dugong, beaver, duck, penguin, auk, crocodile and turtle. The same thing happens in fishes when they are taken out of the water. And when such nondivers as cats, dogs and men submerge, bradycardia develops too, although it is often less pronounced than in the specialized divers.

When the heart of a seal beats only five or six times a minute, what happens to the blood pressure? We found that the central blood pressure—in the main artery of a hind flipper, for instance—stays at a normal level. The shape of the pressure trace, however, reveals that



SEAL DIVES IN LABORATORY by being ducked in a bathtub full of water. The animal is strapped loosely to a weighted board. Its head is covered by a mask connected to a device for recording respiration. When the board is tilted down (*broken line*), the mask fills with water and the seal's nose is submerged. An artery in a hind flipper is shown cannulated for removal of blood samples.

VOLUNTARY DIVING eliminates any possibility that restraint affects the seal's responses. This harbor seal (*Phoca vitulina*) is being trained to keep its nose under water until the experimenter lowers his warning finger and instead displays the reward, a fish.



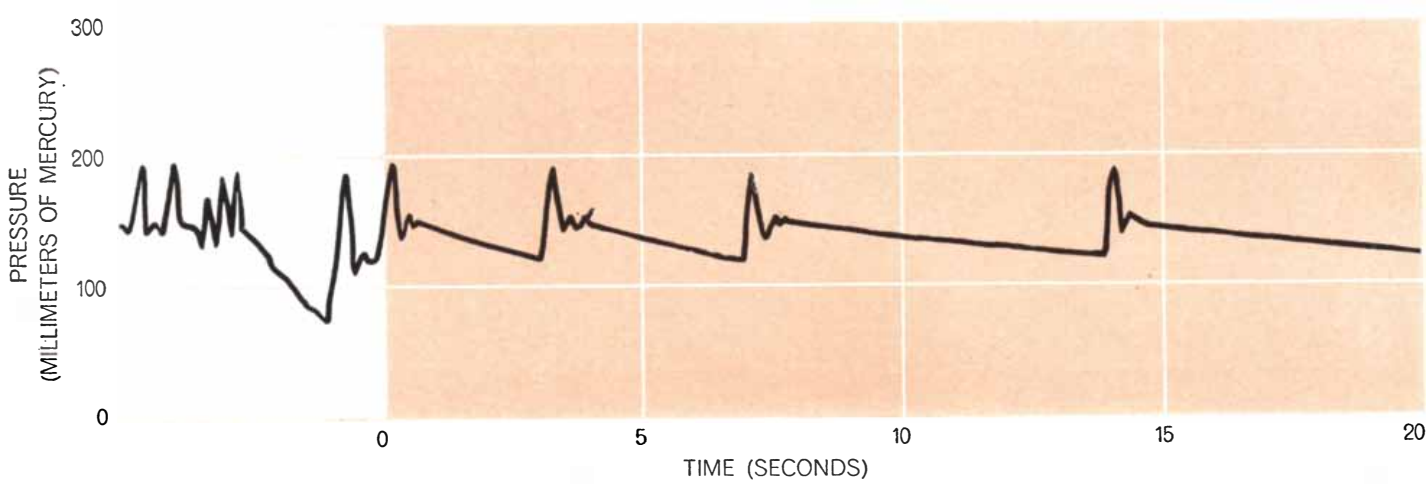
DIVING BRADYCARDIA, the slowing of the heart rate that occurs in vertebrates when they submerge, is quite apparent in this electrocardiogram of a diving seal. Three segments of the record are shown, made at the beginning of, during and at the end of an

whereas the pressure rise with each beat is normal, the subsequent drop in pressure is gradual and prolonged. This indicates that, although the systolic phase of the heartbeat is almost normal, the diastolic phase, during which the blood is forced through the aorta, encounters resistance: the peripheral blood vessels are constricted. Measurements in a small toe artery in the seal's flipper show that the pressure there drops when the dive begins, falling rapidly to the much lower level maintained in the veins. In other words, we found that the circulation in the flippers shuts down to practically nothing during a dive [*see bottom illustration on opposite page*].

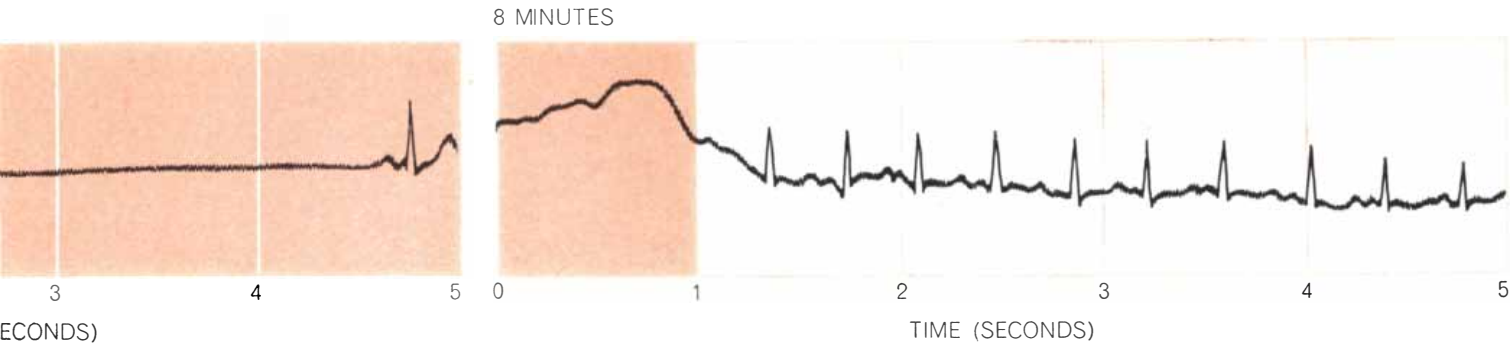
For another clue to circulation we measured the level of lactic acid in the muscles and blood of a diving seal. Lactic acid is the end product of the anaerobic metabolic process from which muscles derive energy in the absence of oxygen. The concentration of this metabolite in muscle tissue rises sharply during a dive but the concentration in the blood does not; then, when the seal begins to breathe again, lactic acid floods into the bloodstream. The same sequence of events has been found to occur in most other animals, showing that the muscle circulation remains closed down as long as the dive continues. Similarly, oxygen disappears from muscle tissue a few minutes after a seal submerges, whereas the arterial blood still contains plenty of oxygen—enough to keep the myoglobin saturated if the muscles are being supplied with blood [*see illustrations on page 96*]. Other experiments revealed that in the seal both the mesenteric and the renal arteries, supplying the intestines and kidneys respectively, close down during diving. All these findings made it apparent that a major portion of the peripheral circulation shuts off promptly on submergence. This was evidently the reason the heart slows down.

At this point our results tied in nicely with some conclusions reached by Irving, who was then at Swarthmore College. His efforts had been stimulated by pioneering studies of circulatory control conducted in the 1920's by Detlev W. Bronk, then at Swarthmore, and the late Robert Gesell of the University of Michigan. Bronk and Gesell had discovered in 1927 that in a dog rendered asphyxic by an excess of carbon dioxide and a lack of oxygen the muscle circulation slowed down as the blood pressure remained normal and the brain circulation increased. Irving noted in 1934 that this phenomenon might explain a diving animal's resistance to asphyxia, and he proceeded to measure blood flow in a variety of animals by introducing heated wire probes into various tissues and recording the rate at which their heat was dissipated. His data indicated that during a dive the flow in muscle tissue is reduced but the brain blood flow remains constant or even increases. He decided that the essence of the defense against asphyxia in animals would prove to be some mechanism for the selective redistribution of the circulation, with preferential delivery of the decreasing oxygen store to those organs that can least endure anoxia: the brain and the heart.

When the blood flow closes down in most tissues during a dive, what happens to energy metabolism? This is best studied during a quiet dive, with a seal or



CENTRAL BLOOD PRESSURE stays at about a normal level during a seal's dive (*color*); the rate of increase in pressure during a contraction is also normal. The slow pressure drop between contractions, however, suggests constriction of peripheral blood vessels.



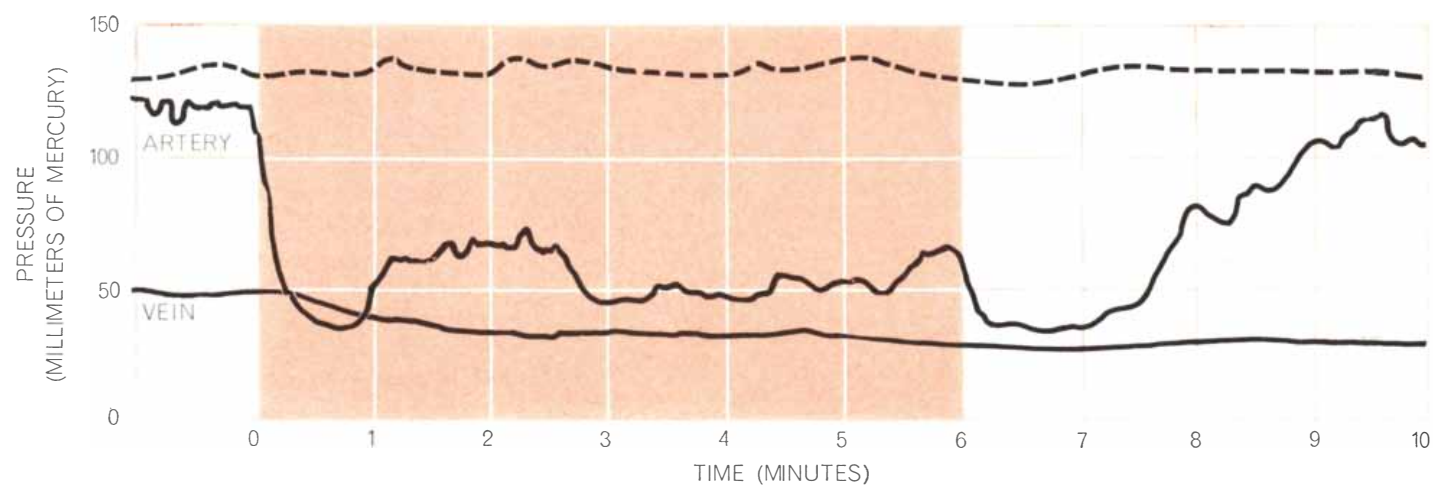
eight-minute dive, the duration of which is shown in color. The heart slows down at the start of the dive. The rate remains as low as seven or eight per minute during the dive and then returns to a normal 80 or so per minute as soon as the seal breathes again.

duck trained to remain inactive while under water. The oxygen stores are large enough to provide only a quarter of the energy expended in a predive resting period of the same length. The next question was: Do anaerobic processes, including lactic acid production, substitute fully for the lack of oxygen? Muscle on anaerobic metabolism incurs an "oxygen debt" that must be paid off when oxygen becomes available. The excess oxygen intake on recovery from a dive is a measure of that debt. If an animal consumed energy at the same rate during a dive as before it, this excess intake would be enough to equal a normal oxygen-consumption rate during the dive. We found that it was characteristic in quiet dives, however, for the seal or duck to exhibit an oxygen debt much smaller than this. In the case of the sloth, a tree-living animal that is curiously tolerant of submersion, there was no apparent oxygen debt at all [*see illustration on page 98*]. The implication was that metabolism must slow down.

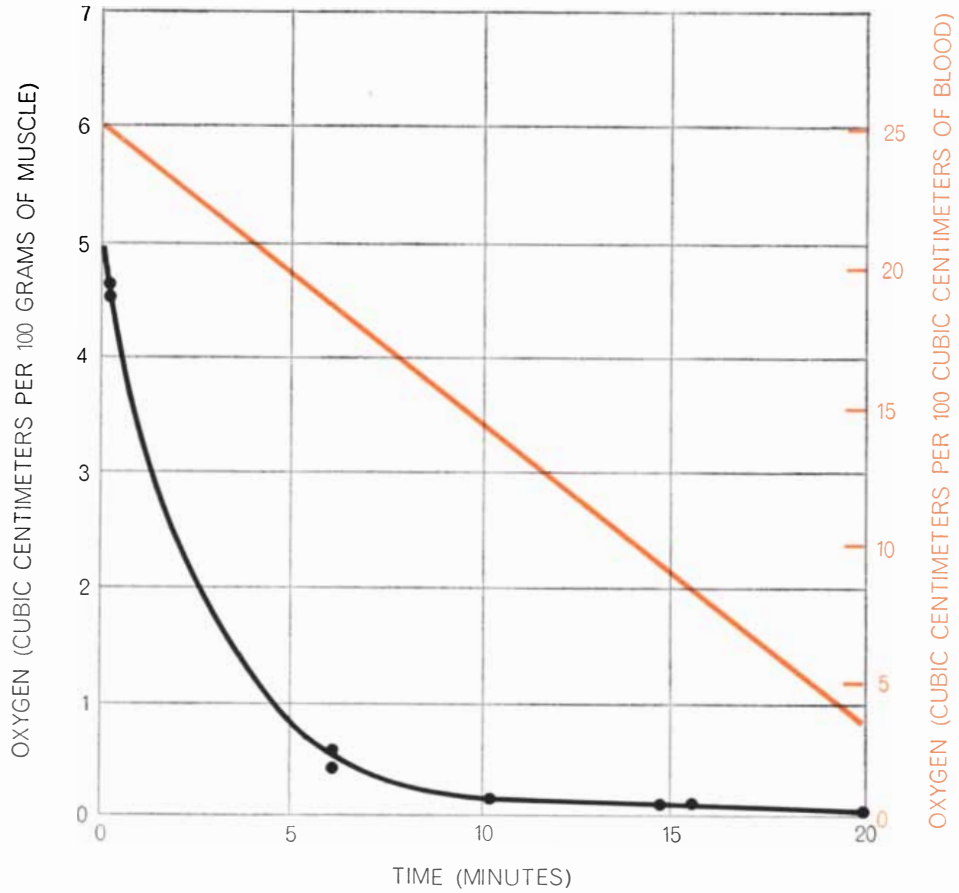
We could not settle this definitely by studying the oxygen debt alone; it was conceivable that the debt was being paid off so slowly it eluded us. Temperature measurements, however, confirmed the impression of decreased metabolism. We often noticed that after long dives (20 minutes or so) the seal would be shivering during the recovery period. We found that the animal lost body temperature at a rapid rate while submerged. Now, this could not be because of increased heat loss, since there was no substantial change in the thermal contact between the seal and the water; only the nostrils were submerged for the dive. Moreover, the reduction of circulation meant that heat conductivity was lessened, not increased. The loss in body temperature therefore meant an actual decrease in heat production—a slowing down of metabolism. Apparently the lack of blood in the tissues simply jams the normal metabolic processes by mass action; the flame of metabolism is damped and burns lower. It is quite logical that submergence should bring about a progressive reduction in energy metabolism, considering that the suspension of breathing ultimately terminates in death, or zero metabolic activity.

In most dives under natural conditions, of course, this general metabolic slowing down is masked. The animal is actively gathering food, and its muscles probably expend energy at several times the resting rate for the total animal. After a few minutes the muscles have used up the private store of oxygen in their myoglobin, and then they depend on anaerobic processes resulting in lactic acid formation. After such dives there is a substantial oxygen debt reflecting the amount of exercise; it is therefore impossible to detect the subtle lowering of metabolism that must still occur in the nonactive tissues deprived of circulation.

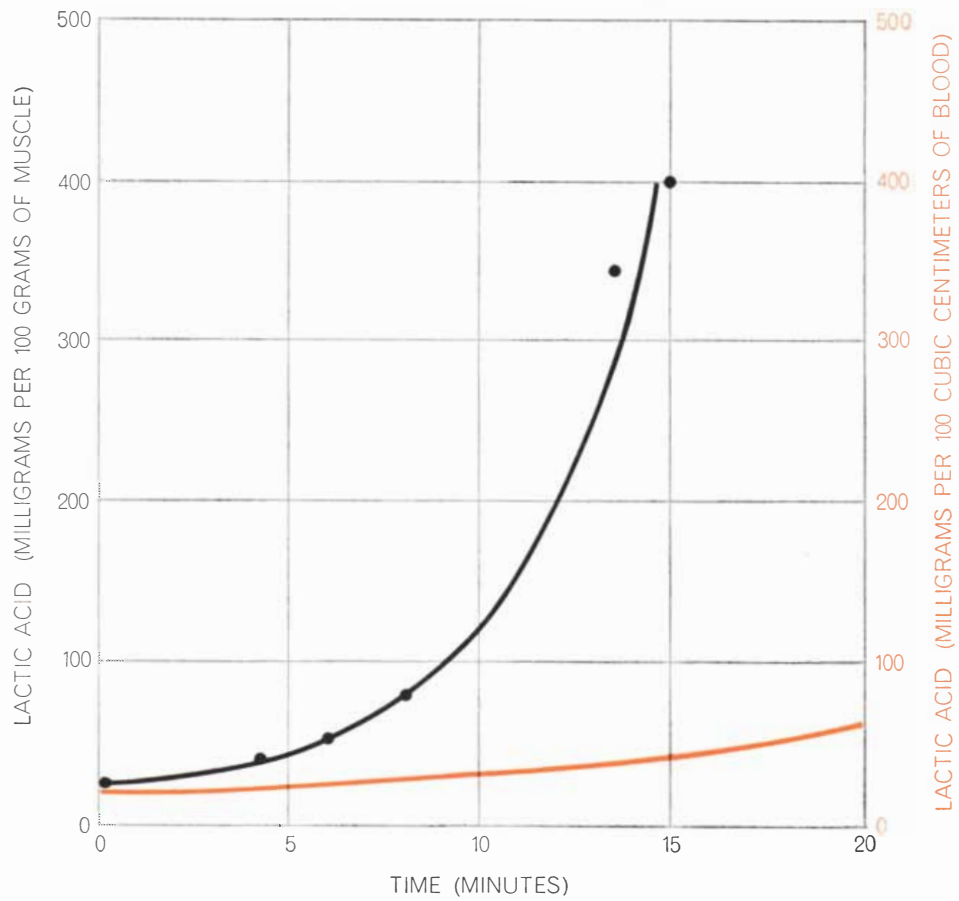
It has been fascinating, and of particular interest from the point of view of evolution, to discover the very same asphyxial defense in fishes taken out of the water—diving in reverse, as it were. The response is found in a variety of fishes, including many that would never leave the water under normal conditions. It is most striking in the aquatic versions of diving mammals and diving birds: the fishes that routinely make excursions out of the water, such as the fly-



PERIPHERAL PRESSURE, taken in a small toe artery, drops appreciably during a seal's dive (*colored area*). From near the central blood-pressure level (*broken line*) it falls almost to the venous level, which indicates a closing down of circulation in the flipper.



OXYGEN concentration is traced in the muscle (*black curve*) and arterial blood (*colored curve*) of a harbor seal during a dive. The sharp drop in muscle oxygen while the blood is still more than half-saturated suggests that there is no appreciable blood flow in muscle.



LACTIC ACID concentration confirms lack of blood flow in muscle. Lactic acid builds up in the muscle as the oxygen there is used up, but little enters the blood. The blood lactic acid level rises sharply only after the muscle circulation is restored when breathing resumes.

ing fish. It would be interesting to obtain an electrocardiogram of a flying fish taking off on a natural flight, but this would call for a rather tricky technique. When the leap is simulated, however, by lifting a flying fish out of the water, a profound bradycardia develops immediately.

Another fish that survives on land for some time is the grunion, an amazing little member of the herring family that frequents the coast of California. These fish spawn only on a few nights with maximum tides during the spring. They ride up the beach on a long wave at high tide. As the water recedes the female digs into the sand tail first and deposits her eggs; the male curves around her and fertilizes them. When they have finished, the fish ride out to sea again on another high wave. The spawning procedure can last five or 10 minutes or even longer and is accompanied by much thrashing about; in spite of this activity there is a profound bradycardia during the entire period. Walter F. Garey and Edda D. Bradstreet of the Scripps Institution have studied the lactic acid sequence in grunions caught on the beach and kept overnight in a laboratory tank. The fish are placed in a dish and prodded to keep them wriggling; blood and muscle are sampled during this period and after return to the water. Garey and Miss Bradstreet found that during the anaerobic period lactic acid increases rapidly in the muscles; practically none appears in the circulation until the fish is back in the water. Then, as the peripheral circulation opens up again, lactic acid is flushed out of the muscles and suddenly appears in the blood [*see upper illustration on page 102*].

Whereas fishes such as the grunion dive in reverse, the mudskipper (*Periophthalmus*) performs a double reverse. It spends most of its time out of the water in mangrove swamps at the edge of tropical seas, perching on a mangrove root and slithering, if it is frightened, into a burrow in the mud. These mudholes are frequently devoid of oxygen. By dint of heroic and slippery investigations in northern Australian mangrove swamps, Garey has determined that the heart of a mudskipper in its mudhole develops a pronounced bradycardia. It would seem, then, that the creature has turned evolution around: it is more at home as an air-breathing animal than as a proper fish!

In view of the strikingly similar responses to asphyxia in so many quite different vertebrate animals, it would be strange if human beings did not con-

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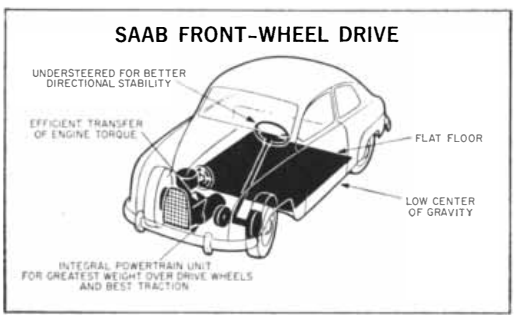

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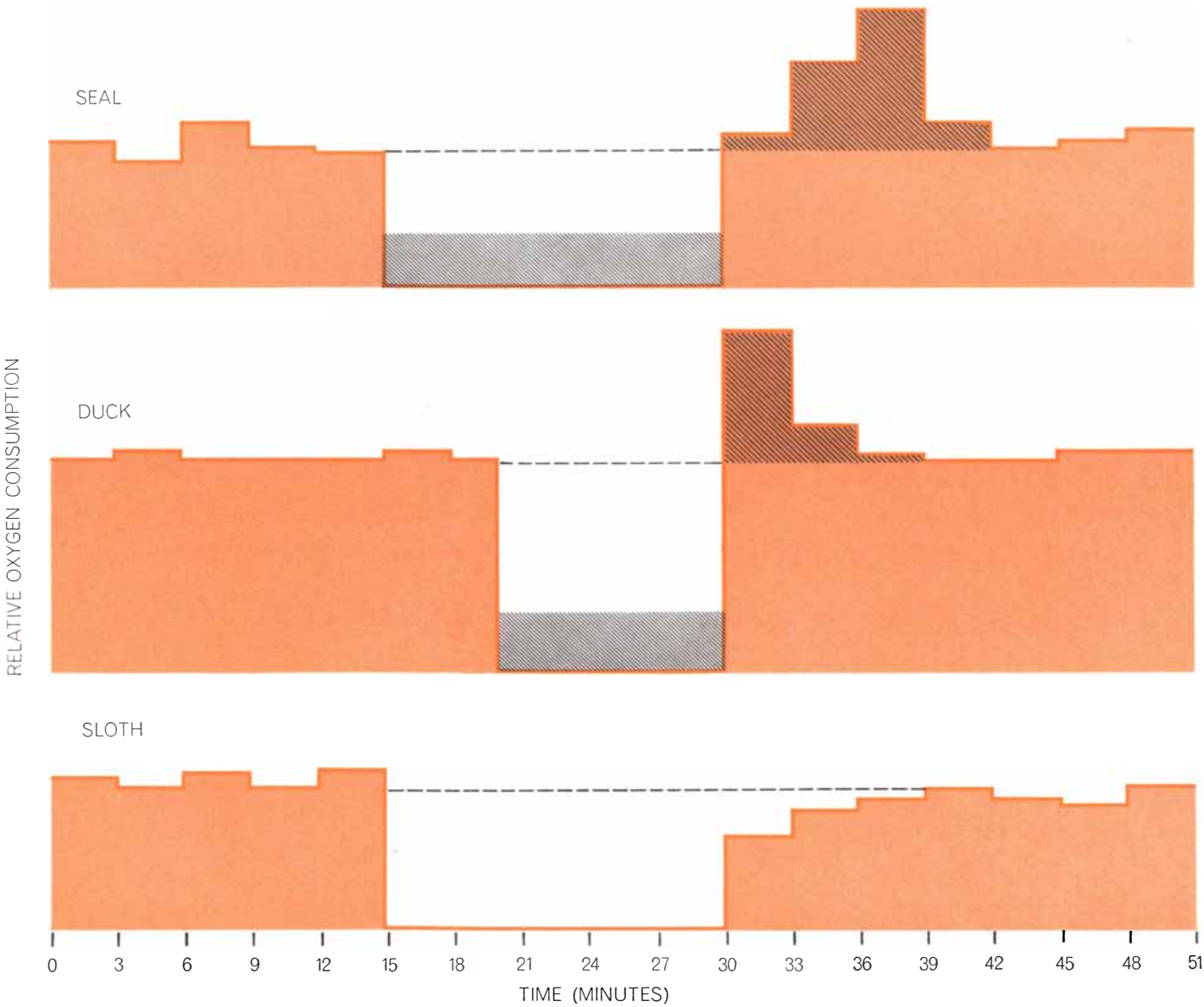
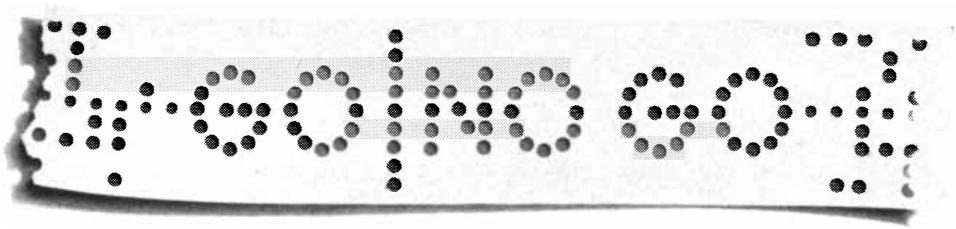
form to the common scheme. Indeed, a number of recent studies of human divers, of birth anoxia in babies and of several pathological conditions have turned up exactly the same pattern.

My associates and I obtained valuable information by examining the native pearl divers of northern Australia, who are trained from boyhood to make deep dives. (We found, incidentally, that these experts seldom stay down for longer than a minute; many individual divers can remain submerged for twice as long, but this is evidently too strenuous as a regular practice.) A diver develops bradycardia within 20 to 30 seconds whether he remains quiet or swims about. The arterial blood pressure is normal or even elevated; just as in the seal, the diastolic pressure drop is slowed down, apparently by constriction of the peripheral blood vessels. As we expected, there is little or no rise in the lactic acid level in the blood during the dive, but there is an acute rise in the recovery period. In all these respects human divers respond like other vertebrates. In one respect, however, human beings may be unique: Pathological arrhythmias, or irregularities of the heartbeat, are alarmingly common in man after only half a minute's dive and such arrhythmias have so far not been observed in animals.

In our laboratory at the Scripps Institution, Elsner has been able to demonstrate ischemia, or lack of blood flow, in the muscles of an extremity simply by having a volunteer submerge his face in a basin of water. An electrocardiograph measures the heart rate, and the flow of blood into the calf is measured by plethysmography. In this technique a cuff placed around the thigh is inflated just enough to occlude the return of blood through the veins while leaving the arteries open to supply blood to the lower part of the leg. As the calf fills with blood its circumference is measured and traced by a recording device. As soon as the subject immerses his face his heart slows down. At the same time there is a sharp decrease in the extent to which the calf expands when the venous return is obstructed; the constriction of the small arteries diminishes and may virtually stop blood flow into the calf. As soon as the subject lifts his face out of the water and breathes, the arterioles open up again and the calf expands [*see illustrations on page 104*]. If a subject is merely told to hold his breath without submerging his face, all these effects are less pronounced. As in the case of the seal that is free to breathe at will, psychological



METABOLIC SLOWING DOWN during a dive is demonstrated in three animals by the record of oxygen consumption in successive three-minute periods. In the seal and duck the amount of excess oxygen intake after the dive (*hatching on color*) represents the oxygen debt incurred by anaerobic metabolism during the dive. This debt (*hatching on white*) is clearly not enough to have sustained an energy expenditure at a normal rate (*broken lines*) during the dive. The sloth seems to incur no oxygen debt while diving.



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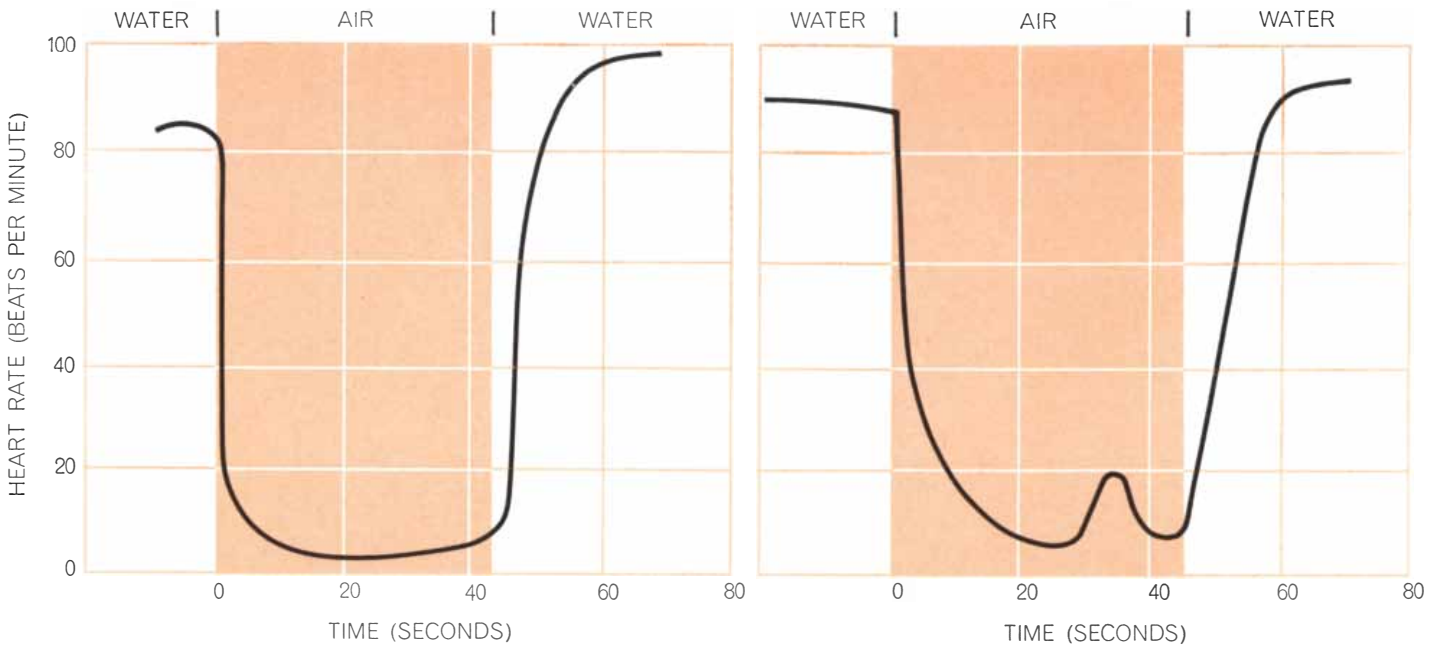


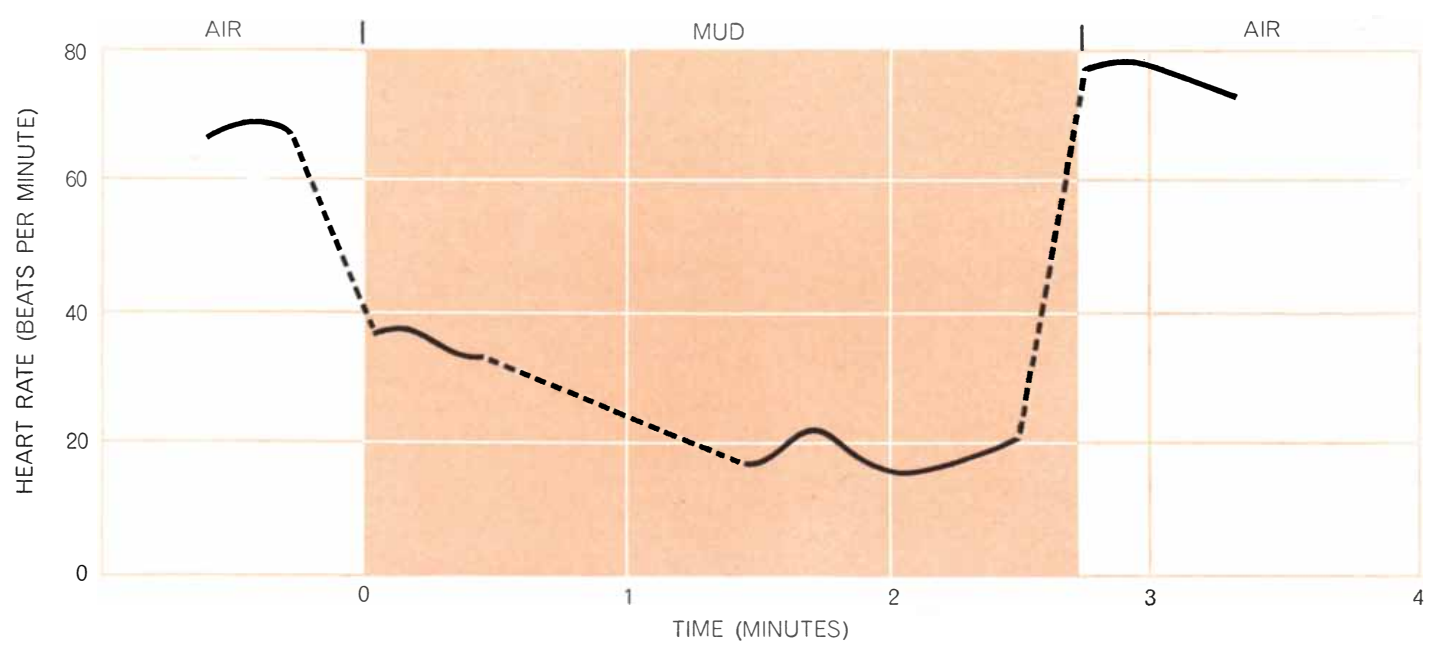
FISH OUT OF WATER develops bradycardia just as a diving animal does when it submerges. These two graphs show the sharp decrease in heart rate that occurs in the grunion (*left*) and the flying fish (*right*) when they are temporarily taken out of water.

factors seem to influence the physiological response to asphyxia.

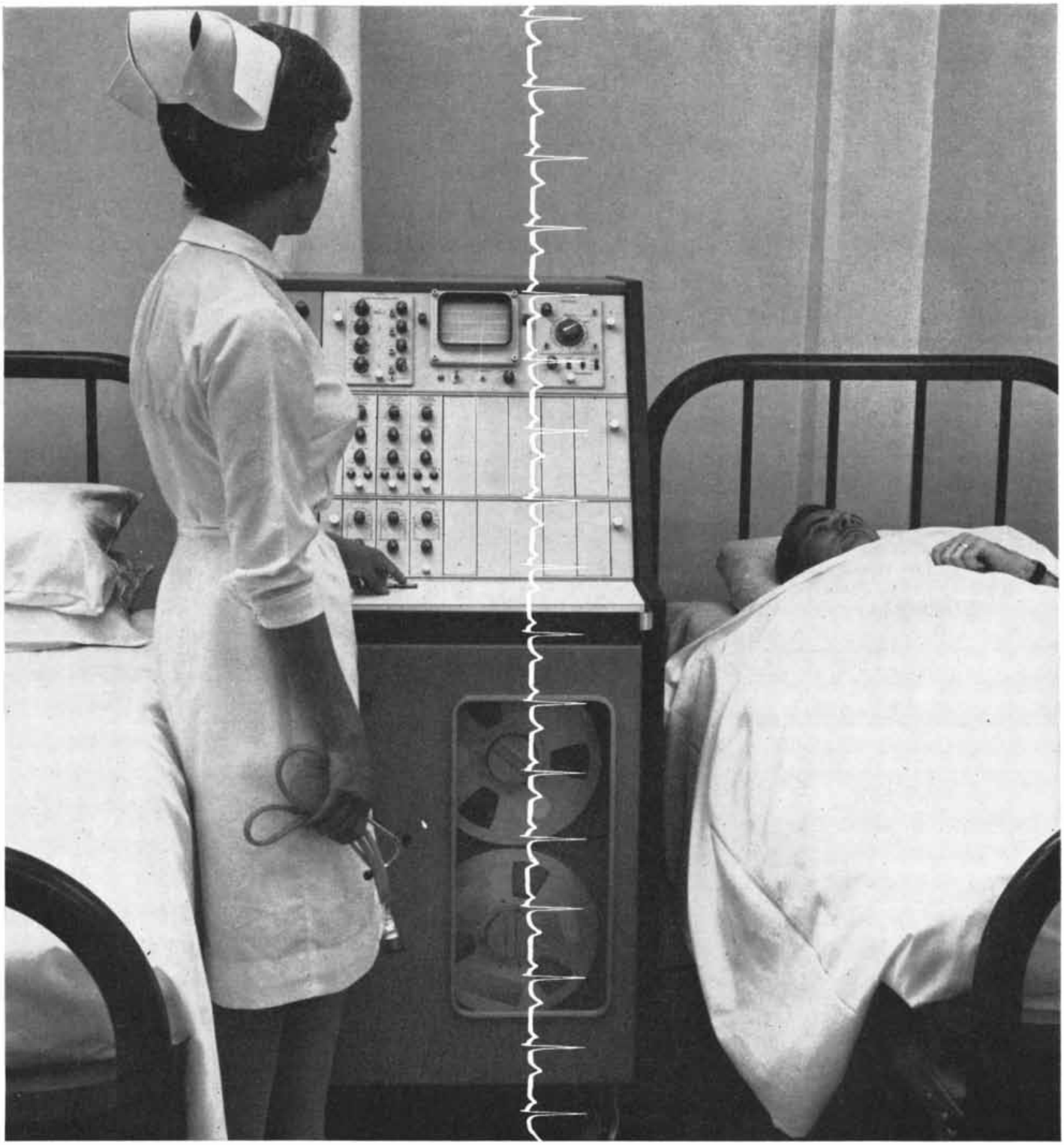
Physicians have been aware that bradycardia sometimes occurs in babies before, during and immediately after birth and that this can be a sign of asphyxia induced by obstruction or final interruption of the placental blood flow. This concept has been strengthened by lactic acid measurements in newborn infants by Stanley James of the Columbia University College of Physicians and Surgeons. Judging by his data, a normal birth is always followed by a sharp rise in the blood lactic acid. This rise is sharper and higher in babies that have survived a difficult delivery and show clinical symptoms of birth distress; in other words, the longer the period of anoxia, the greater the lactic acid build-up [*see lower illustration on page 102*]. Newborn animals in general have a short period of increased resistance to asphyxia. The sequence of events in babies suggests that selective ischemia is an important asphyxial defense even in newborn infants.

Various pathological conditions that decrease cardiac output, such as arrhythmias and coronary occlusions, are sometimes followed by such apparently unrelated complications as damage to the kidneys or even gangrenous sores in the intestine. Donald D. Van Slyke and his collaborators at the Rockefeller Institute for Medical Research found in 1944 that severe shock in dogs resulted in decreased kidney function and tissue damage—and that the same symptoms appeared if they simply clamped the renal artery of a healthy dog. Pointing out the analogy to the peripheral vasoconstriction we had reported in diving animals, Van Slyke concluded that under stress the blood supply to the brain is maintained, if necessary, at the cost of restriction of circulation to other areas: the organism, as he said recently, is reduced to "a heart-lung-brain preparation."

More recently Eliot Corday and his



MUDSKIPPER is a curious fish that has become acclimated to breathing air. While it is out of water, its heart rate is normal; when it enters its mud-filled burrow, it develops bradycardia. Broken lines join the various segments of this fragmentary record.



What new data acquisition system has refined bedside manners? AMPEX DAS-100

So refined, for example, that it can be pushed between two beds. That's the new Ampex DAS-100 Mobile Version — an analog data acquisition system complete from low-level physiological amplifiers to recorded tape with up to seven channels of data. Yet the Mobile Version is only 22 inches wide by 36 inches deep by 48 inches high: small enough to go anywhere in the hospital or research institution to the patient who needs it. And, too, it's simple to operate. A single integrated control panel handles calibration, level set, monitoring, voice annotation, recording and reproducing of data. The system is designed to work with existing transducers and electrodes, with graphic recorders and analog computers and spectrum analyzers and analog-to-digital converters. Today, the DAS-100 is used in government hospitals throughout the United States to record cardiovascular data. Here vectorcardiographic data is amplified, displayed and recorded on magnetic tape. This is sent to a centralized facility for computer aided diagnosis. Also available: a console version with up to 14 channels. Brochure? Write to Ampex Corp., Redwood City, California. Term financing and leasing available. Sales, service throughout the world.

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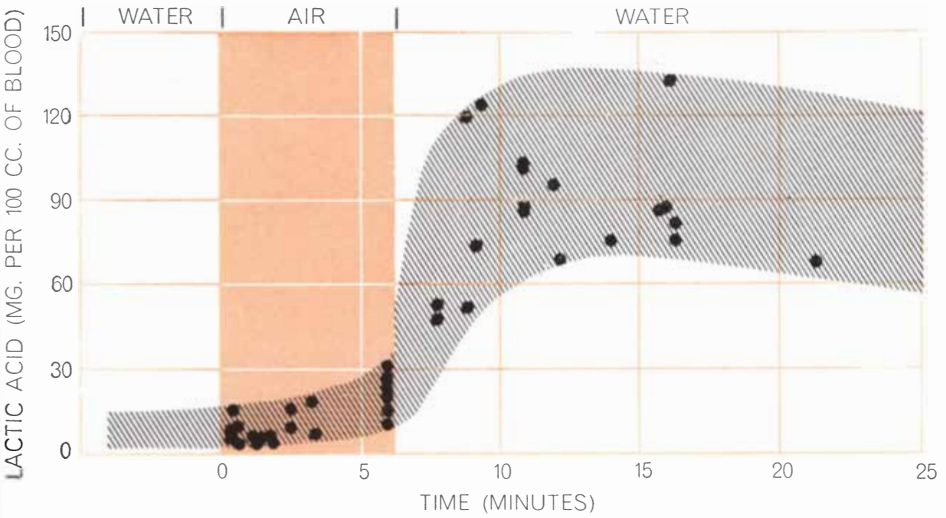
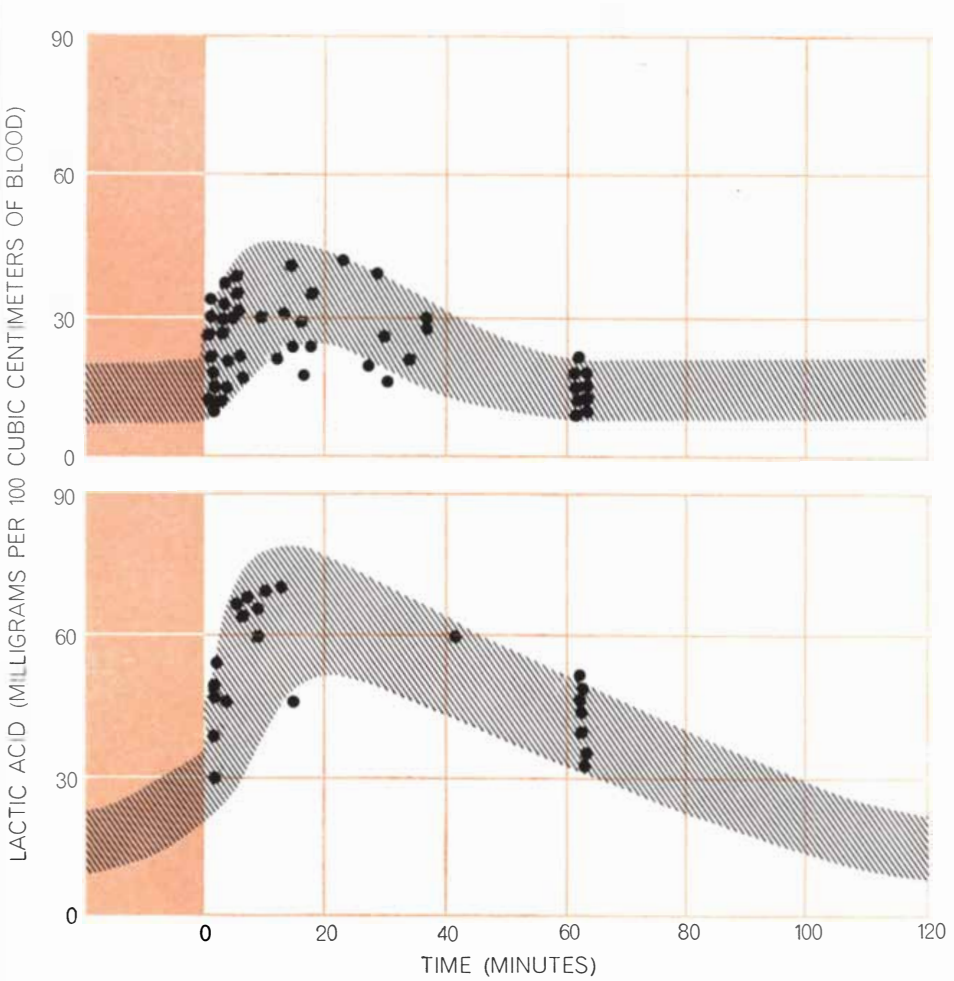
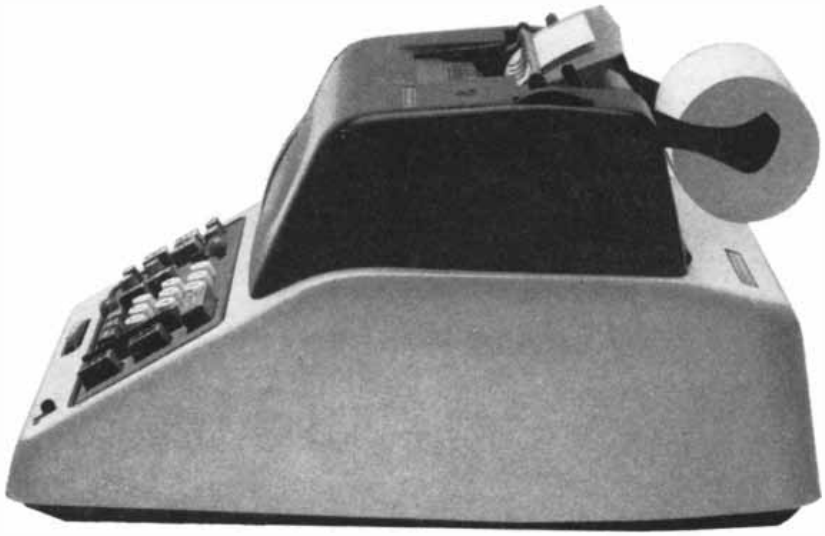
colleagues at the University of California at Los Angeles have found that the same events account for certain gangrenous lesions of the intestine. They impaired the circulation of dogs in various ways, inflicting cardiac arrhythmias by electrical stimulation or decreasing the blood pressure by bleeding the animals. With modern blood-flow-metering techniques and blood-pressure measurements they were able to demonstrate a widespread vasoconstriction that tends to sustain the blood pressure near a normal level but leaves the kidney, the gastrointestinal tract, the muscles and the skin with greatly reduced circulation. These workers again recognized the sequence as a mechanism for maintain-



MUSCLE ISCHEMIA, or lack of blood, in grunions results in a lactic acid build-up in muscle while the fish is out of the water. As seen here, the lactic acid does not rise much in the blood until the muscle circulation is restored when the fish re-enters the water.



SIMILAR ISCHEMIA apparently protects a baby during the delivery period (*color*). When breathing begins, the muscle circulation opens up and lactic acid floods the blood. The lactic acid build-up is smaller in a normal delivery (*top*) than in a long, difficult one (*bottom*).



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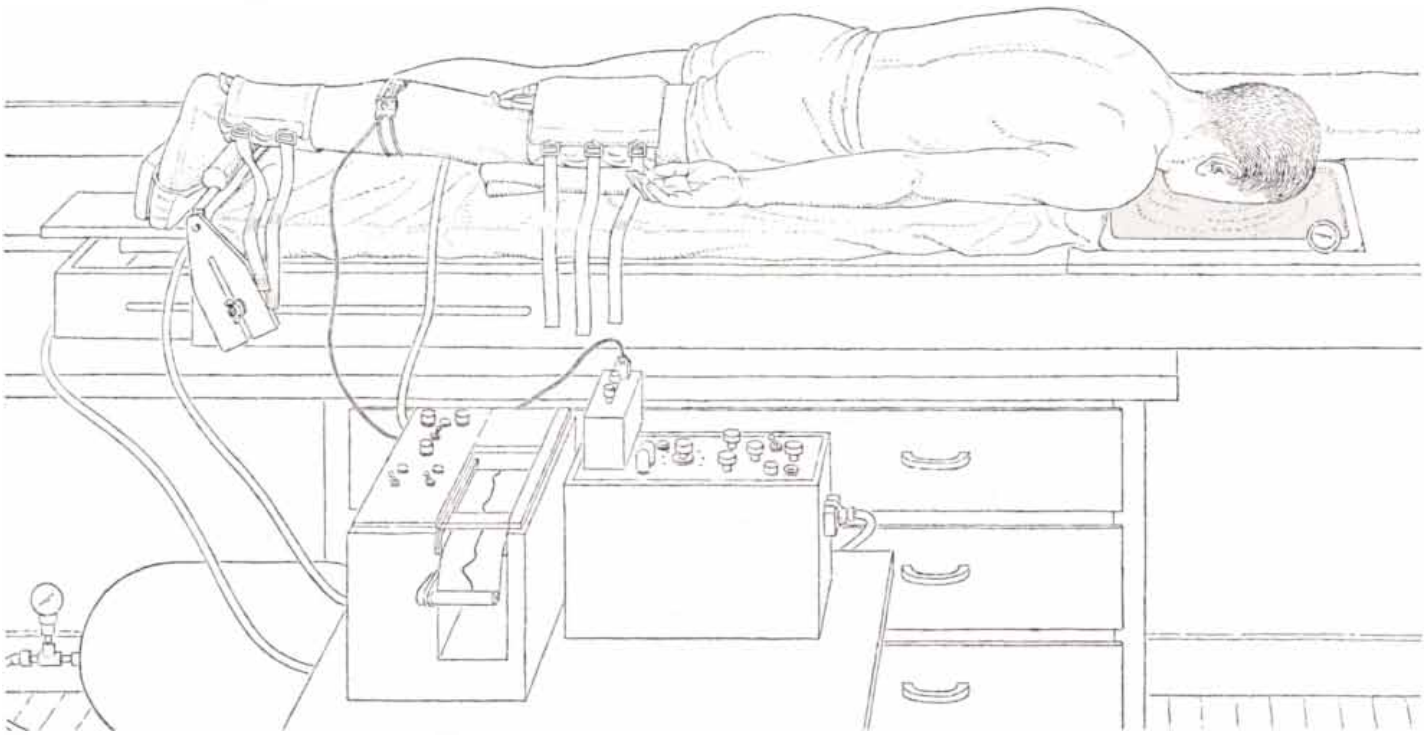
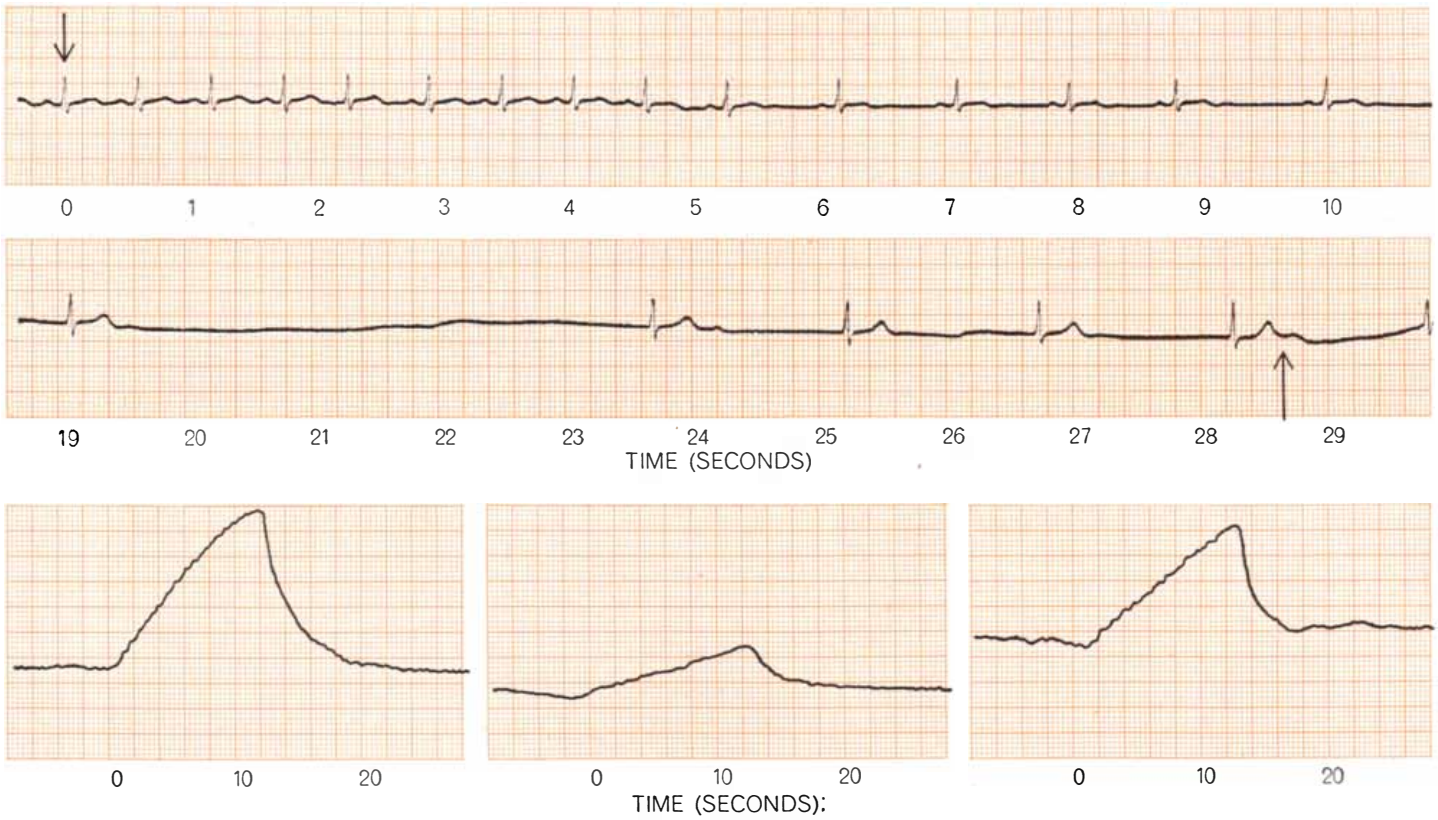
ing an adequate blood supply to the most sensitive organs.

A quite different physiological event that seems to depend on the same circulatory switch as the prime control is hibernation. In all the relatively few species of mammals and birds that hibernate the body temperature is lowered in the presence of an unfavorable thermal environment. In most animals hibernation is seasonal but in others the temperature drops in a daily cycle. The dormant state is characterized, in any case, by a body temperature only a degree or so warmer than the surroundings; along with this there is a correspondingly low metabolic rate, perhaps a tenth or less of the resting rate in the waking condition. The heart rate is very low—only a few beats per minute—but



HUMAN DIVING is investigated in the laboratory by having a volunteer immerse his face in a basin of water. In this case the circulation in the lower leg is being measured by plethysmography. The inflatable cuff on the thigh occludes the veins draining the calf but leaves the arteries open. By measuring the circumference of the calf one can determine the blood flow into the lower leg.



FACE IMMERSION results in bradycardia. The electrocardiogram (*two top strips*) records an extreme case (*arrows mark start and end of dive*). Plethysmographic records (*bottom*) show changes in calf circumference when venous return is occluded for some 12 seconds before (*left*), during (*center*) and after (*right*) face immersion. Blood flow into calf is clearly much reduced during dive.

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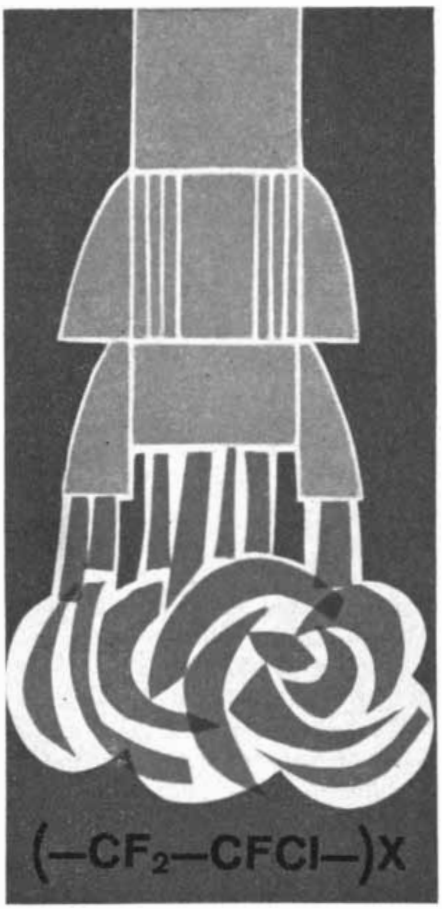

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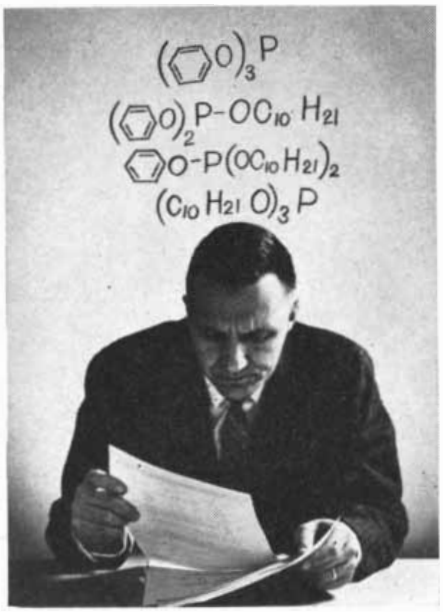

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the central blood pressure remains quite high in relation to this bradycardia. Again the pressure trace shows the slow diastolic emptying of the arteries that suggests a peripheral vasoconstriction. There is good evidence that hibernation is a controlled state; when a decrease in the ambient temperature brings a threat of freezing, the animal increases its heat production and usually emerges from hibernation.

The transition periods during which the animal enters or emerges from hibernation are of particular interest. When a ground squirrel or woodchuck goes into hibernation, the heart rate slows down before the body temperature starts to drop, indicating that the drop in metabolic rate is caused—as in asphyxial defense—by a primary vasoconstriction. Arousal from hibernation is easier to study because it can be precipitated at will by disturbing the animal. This triggers an immediate acceleration of the heartbeat to as much as 100 times the hibernating rate. There follows an intense shivering of the front part of the body, which warms up much more quickly than the rest of the body does as measured by the rectal temperature. Midway through arousal the blood flow in the forelegs of the squirrel is sometimes 10 times greater than in the hind legs. The uneven distribution of metabolic and circulatory activity is apparently accomplished by a dilation of the blood vessels that begins in the forward parts. When the vessels in the rest of the animal finally dilate, the over-all metabolic rate sometimes rises as high as when the animal exercises. The entire sequence is consistent with the idea that the onset and termination of hibernation are triggered in the first instance by vasomotor impulses controlling the size of the small blood vessels. The circulation then throttles metabolism in the tissues to a rate compatible with the blood flow. Going into hibernation seems to call for the same primary vasoconstriction that operates in asphyxial defense.

Any mechanism that operates in many kinds of animals across a wide range of circumstances must be of fundamental physiological significance. In our current work at the Scripps Institution we are trying to learn more about the details of blood flow in animals by implanting ultrasonic measuring devices on arteries and veins. We hope to discover just how the autonomic nervous system responds to environmental changes and the threat of anoxia and what sequence of events actually throws the circulatory switch.

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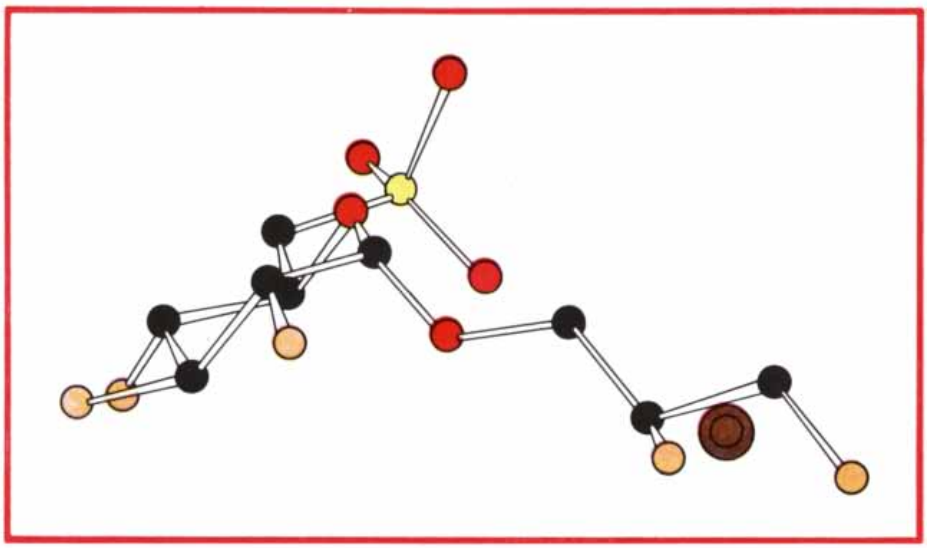
X-rays, from the device at the right in this picture, strike against a crystal sample held in the goniometer, left. A geiger counter measures intensity of refracted X-rays.



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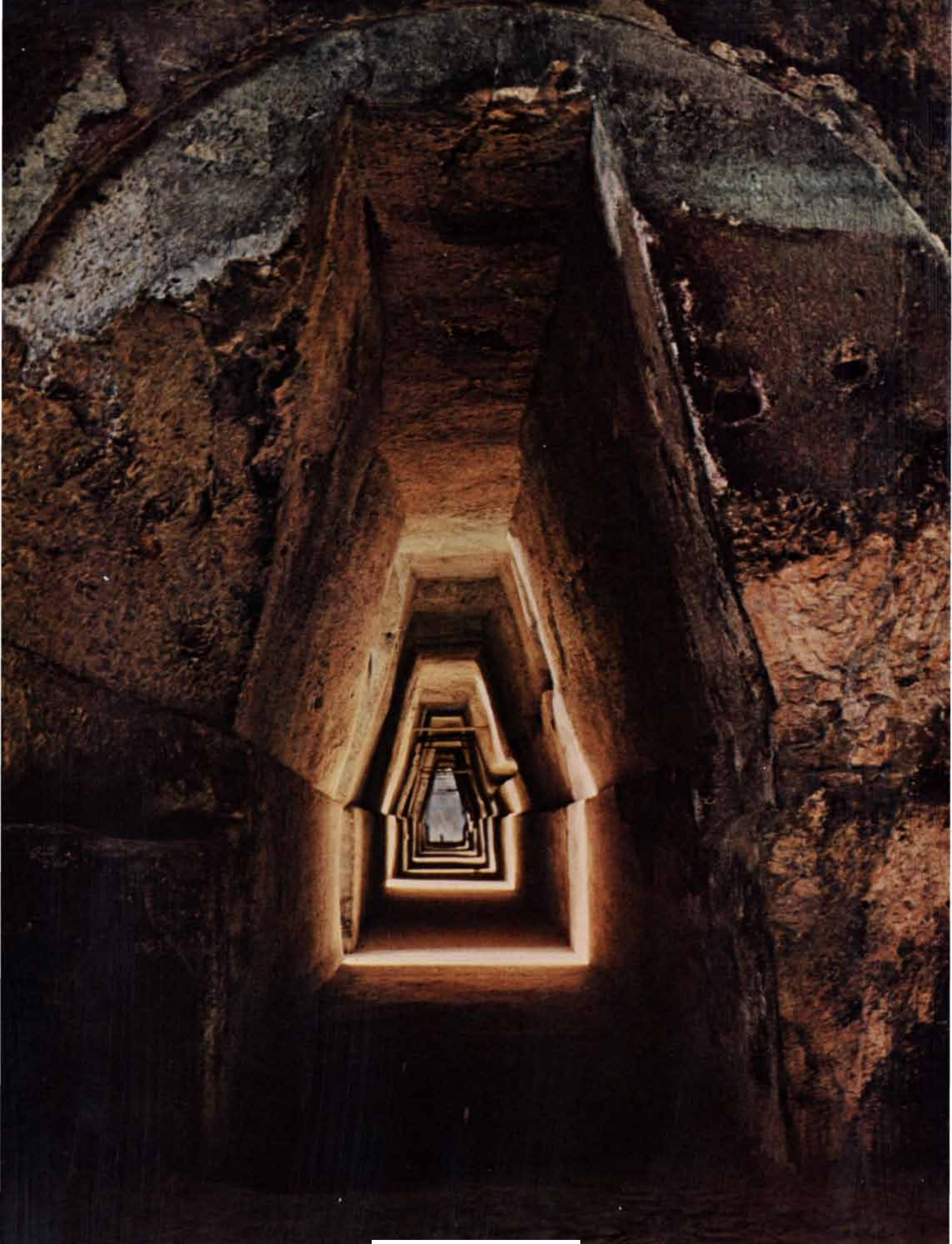


ANCIENT CUMAE

The first Greek colony in Italy was established here in the eighth century B.C. For the next 2,000 years Cumae played a unique role in the development of Western civilization

by Raymond V. Schoder, S.J.

The pivotal sixth book of Vergil's *Aeneid* is set at Cumae, an ancient site about 10 miles west of modern Naples. Here Aeneas and his men first set foot in Italy, ending their long sea journey from Troy and entering on a new phase in the struggle that led to the founding of Rome. Thereafter the action of the epic is confined to Italy, as the mythological ancestors of the Romans surmount the final obstacles in their path.

Vergil's choice of Cumae as the Trojans' landfall was not fortuitous. Something of a protosociologist as well as a great poet, he had a profound understanding of Cumae's unique importance in the history of Western civilization. Here, some 700 years before the *Aeneid* was written, the first Greek colony in Italy was founded. Here the Greek alphabet, religion and culture took root in Italy, eventually to shed its light throughout the West. Cumae's past, as revealed in the writings of classical historians and corroborated by archaeological remains, is a major chapter in the evolution of Western culture that deserves to be better known.

The area around Cumae has long been noted for its volcanic character. Numerous craters of extinct volcanoes give the landscape something of the appearance of the moon, except that all is covered with the lush vegetation flourishing in the deposits of phosphorus and potash from Vesuvius and nearer volcanoes. During the second millennium B.C. the area was still sufficiently active with volcanic rumblings, fire and smoke to terrify sailors from Minoan Crete and Mycenaean Greece, evidence of whose passing can be seen in distinctive pottery and tomb structures found in this region and in Sicily along the way. King Minos of Crete was said to be buried, in a temple-tomb like those at Knossos, at Minoa in Sicily, and it was at Cumae itself that Daedalus landed when he flew off from tyranny in Crete. Ancient legends told of Hercules' and Odysseus' strange adventures in this mysterious region, and it may well have been travelers' stories of its volcanic phenomena that lay behind many Mycenaen myths and Homeric tales.

Archaeological investigations indicate that the area around Cumae was inhabited at least from the 11th century B.C. by a Neolithic people called the Opici, or Oscans. At nearby Lake Avernus lived the fabled Kimmerians, said by Homer to dwell in perpetual darkness, meaning that they stayed in mines and underground tunnels from dawn to dusk. There were an oracle and a peculiar cult of the dead at Lake Avernus from earliest times; this was the reputed entrance into Hades. It was primarily the mines that attracted the Greeks to settle at Cumae: the arms of their hoplite soldiers had created a demand for metal.

The evidence for the presence of the Mycenaean Greeks at Cumae dates back even earlier than that for the Oscans. With the decline of Mycenaean power in the 12th century B.C. the record of Greek occupation is interrupted. The Greeks returned, however, after the "dark age" of the Dorian invasion.

With shrewd appraisal of the trading possibilities, a group of Greeks from Chalcis and Eretria on the island of Euboea north of Athens established an outpost at Pithecussae (modern Ischia), a large island opposite Cumae. Their arrival is dated about 770 B.C. by archaeological finds at the site, confirming the accounts by Strabo, Livy and other ancient sources. The earliest Greek vases found in Cumaean and Etruscan tombs are from Pithecussae. The island had fine soil and commanded the sea routes along the coast to the Etruscan markets northward. Dissension developed between the two founding groups, however, and late in the eighth century B.C. or early in the seventh century the Eretrians left Pithecussae. The Chalcidians left somewhat later, probably because of earthquakes and new opportunities at Cumae itself.

Before this civic discord had set in, Cumae had been founded. Colonists from Eretria and Chalcis, together with some from Pithecussae, joined in considerable force to establish a vigorous settlement on the splendidly situated hill of Cumae, on the mainland a few miles east of Ischia. Apparently some Aeolians from northern Boeotia and from the little city of Kyme on the northeast coast of Euboea also joined in the founding. Strabo says that one of the two official founders was from Chalcis and that the other was from Kyme, but he may have meant the original Kyme in Aeolis, southeast of Troy. In any event the new colony took Kyme for its name, which in Roman times was transliterated into Cumae. Strabo, who apparently considered Pithecussae only a trading post, also says that Kyme was "the first of all [Greek] colonies in Italy or Sicily."

This priority of Cumae over all other Greek colonies is supported by a wealth of archaeological finds. The proto-Corin-

SIBYL'S GROTTO at Cumae is viewed from inside the audience chamber in the photograph on the opposite page. The trapezoidal corridor leading into the grotto is cut through solid rock in a straight north-south line; it is 16 feet high and 427 feet long. Light enters through six lateral galleries cut in the same trapezoidal style along the west side of the corridor (*left*). The Sibyl's living quarters are at the right, out of view.

thian vases from the earliest Greek tombs at Cumae are of the oldest type, none of which appear in the remains of Greek colonies in Sicily and southern Italy. The vases indicate that Cumae was founded 20 years or so before the first colonies in Sicily: Naxos and Syracuse, dated by Thucydides from 735 and 734 B.C. respectively. Thus Cumae had a founding date between 755 and 750 B.C.

This first colony was also the most remote ever established by the Greeks in Italy. Why did they choose Cumae instead of the nearer eastern or southern coast of Italy? Evidently because the local people were less barbaric and more open to profitable trade, and particularly because of the access to metals. Copper was mined in the area and was also brought in from Elba; the Etruscans had ample gold and were eager buyers of vases made by the Greeks locally or imported from Corinth, Cyprus and the Cyclades Islands. The land is the most fertile in Italy. Furthermore, the steep hill of Cumae was easily defended, protected by a swampy lake to the north and mountains to the east. Below the hill lay a long, sandy beach, ideal for the small ships of the day. The colonization of Cumae was a commercial venture, not military imperialism.

The Greeks of Cumae were the first to come into extensive contact with the Italic peoples. The Latin name *Graeci* originated there; a group of the colonists were the *Graikoi* of eastern Boeotia, who worshiped the goddess Graia. Their name was applied by the local people to the whole group of colonists from Hellas, and it has carried over into all European languages. It was at Cumae that the Greek alphabet first became well known outside Greece. The Etruscan alphabet closely parallels the Euboean script and so must be primarily based on the Cumaean usage, although it may have been influenced by other Greek sources as well. The earliest Latin writing also imitates Euboean, as can be gathered from the inscription on an ancient gold brooch from Latium; the letters on the brooch are much like those on a tiny vase of the early seventh century B.C. found at Cumae. The words on the vase read: "I am Tatie's *lekythos;* if anyone steals me, may he become blind!"

In addition to writing, Cumae brought other cultural influences to Italy, such as the potter's wheel, the noble styles of Greek pottery, painting and architecture, and Hellenic concepts of a rational and humanistic approach to life and the universe. Greek religion also had profound and lasting impact, particularly the cult of Apollo. The Homeric epics, written down at just about this time, must have come to Cumae early; some of their brilliance, joy and vision surely affected the local people who came into close contact with the Cumaean Greeks.

So happily established, Cumae prospered. More colonists came to swell its ranks. Commerce and agriculture flourished and the surrounding peoples remained friendly. Cumae expanded its domain to include the fine protected harbors at Baiae and Misenum two or three miles to the southeast and also took over the institution of the oracle at Lake Avernus. It seems that at first the divinity honored at Cumae was Hera, but soon Apollo superseded her and the Cumaean Sibyl became the chief religious attraction of Italy. In the sixth century B.C. her prophecies were enshrined in Rome in Jupiter's temple on the Capitoline Hill, to be used as the ultimate authority in deciding matters of state. Vergil has Aeneas come to Cumae to seek the Sibyl's guidance before he undertakes the conquest of Latium and the founding of Rome, thereby emphasizing the ancient primacy of Cumae for religion in civilized Italy.

Spurred by its success and rich opportunities around it, Cumae soon began to establish colonies of its own. The earliest was Zancle, a trading station at the narrows between Sicily and Italy that controlled shipping along the entire southwestern coast of Italy. This outpost became a full-fledged colony sometime before 725 B.C.; in the early fifth century B.C. it was taken over by other Greeks and renamed Messana (the modern Messina).

An even more important offspring of Cumae was Naples. Ancient sources vary on the early history of Naples but make it clear that sometime in the seventh or sixth century B.C. settlers from Cumae absorbed an outpost called Parthenope that had been established by traders from the island of Rhodes and made the town important. Renamed New Town (in Latin Neapolis, whence the modern Napoli, or Naples), it overshadowed Cumae itself when around 450 B.C. more colonists came from Chalcis, Pithecussae and Athens. Cumae had also established a busy harbor facility in the beautiful bay of Baiae, and around 530 B.C. it allowed Greeks from the island of Samos to develop a colony there. Later called

ETRUSCAN HELMET was captured by Hiero of Syracuse during the Greek naval victory at Cumae in 474 B.C. and was dedicated to Zeus in thanksgiving. Greek inscription reads: "Hiero, son of Deinomenes, and the Syracusans, to Zeus, from Etruscans at Cumae."

MAP OF ITALY shows the location of several of the important ancient sites mentioned in the text. Cumae was the first Greek colony in Italy and was also the most remote. In the *Aeneid* Vergil has Aeneas go directly to Cumae from Carthage in North Africa.

Puteoli by the Romans, it became the chief commercial harbor for Rome. Today it is noisy Pozzuoli. These and other Greek cities of the area, including Pompeii and Herculaneum, were long allied for mutual defense under the leadership of Cumae.

All this activity, power and prosperity gave the Etruscans north of Cumae both concern and ambitions. They set up a colonial system of their own with its chief bastion at Capua, some 20 miles northeast of Cumae. In 524 B.C. a large Etruscan army attacked Cumae to remove its competition, but the Greeks maneuvered the invaders into the lowlands and swampy area, where they panicked and were destroyed. A daring and brilliant youth, Aristodemus, gained fame in the battle, and in 505 B.C. he led a Cumaean force that was largely responsible for the Etruscan defeat at Aricia, near Rome; this ended the Etruscan hope of regaining political control of Rome. With his fame and power Aristodemus established himself as tyrant of Cumae. He cleverly cultivated peaceful relations with the Etruscans, impounding Roman ships at Cumae to force the release of Etruscan treasures in Rome and granting asylum at Cumae to the deposed Tarquin the Proud, the last Etruscan king of Rome, after his final defeat at Lake Regillus in 495 B.C.

During Aristodemus' 20-year rule Cumae grew rapidly in wealth and luxury, but the Greeks of Cumae characteristically resented his dictatorial repressions. Led by the aristocrats he had exiled, rebellious forces slipped into the city during a festival, overpowered his guards and killed him and his children. Cumae stopped conciliating the Etruscans, who now determined to eradicate Greek competition by a massive naval attack. The Cumaeans appealed for help from the large Greek city of Syracuse, which sent a powerful fleet. In a fierce battle off Cumae in 474 B.C. the Etruscans were decisively beaten, and Cumae became the unchallenged ruler of commerce and the sea routes along the southwestern Italian coast. Cumae let Hiero of Syracuse take over Ischia, but his forces later withdrew and the island fell under the domination of Naples. A fascinating relic of the great victory of 474 is an Etruscan helmet now in the British Museum, which Hiero dedicated to Zeus at Olympia in thanksgiving [*see illustration on opposite page*]. With peace assured, Cumae turned to an ambitious building program. The old temples of its acropolis were completely rebuilt, the fortifications of its citadel were much improved and a remarkable shrine for the oracular Sibyl was constructed in the side of the hill.

Archaeology confirms many details of this brief historical account (based mostly on the *Roman Antiquities* of Dionysius of Halicarnassus). Tombs at Cumae contain an abundance of vases of seventh- and sixth-century styles from the Greek

lands overseas but very few of the late sixth-century types; this is doubtless because of the rise of Etruscan naval power. After the Etruscan defeat of 474 Greek vases from abroad reappeared for about 50 years and then are no longer in evidence. This reflects the fact that Greek Cumae had come under Oscan-Sabellian domination.

The improvement of the fortifications of Cumae in the middle of the fifth century B.C. shows that the Cumaean Greeks fully recognized the danger of invasion by their neighbors. The local Oscans had long been infiltrated by Sabellian Samnites; the Samnites had moved into Oscan territory and intermarried with Oscans, giving rise to a new people known as Campanians. The Etruscans of Capua had been weakened by the defeat of 474, and new incursions of warlike Samnites from the central mountain area encouraged the Campanians to attack. They captured Capua in 423 B.C. This further encouraged them to seize Cumae, which they did in 420 B.C. by siege after defeating the Greek army in

VOLCANIC CHARACTER of the area around Cumae is shown in this map. The ancient Roman roads are in black; modern roads and cities are in gray. Greek or Latin place names are used, except where the modern Italian version is given in parentheses. The

the plains. Some Cumaeans escaped to Naples; the others were killed or enslaved. Cumae suddenly ceased to be a Greek city at all; it became Campanian in government, language, customs and population, although many Greek women remained and most of the Greek buildings survived. A new Samnite temple was built at the foot of the acropolis. An Oscan inscription survives from the temple of Apollo above the Sibyl's cave, showing that the Greek cult was to some extent retained. By 400 B.C. Pompeii, Naples and Herculaneum had also fallen into Samnite hands. In less than a century, however, this small empire gave way to the emerging might of Rome. New invasions of Samnites from the mountains threatened the earlier waves, and the Campanians in their fear requested an alliance with Rome.

In the First Samnite War (343–341 B.C.) Rome secured Campania against its foes but also made it politically dependent. The Campanians tried to shake off Roman control when Rome became

island of Ischia is just off the map to the lower left; Mount Vesuvius is off the map to the lower right. During the second half of the first century B.C. much of this region was converted into a vast military complex with long tunnels connecting strategic points.

ACROPOLIS OF CUMAE is shown from the east in this photograph, with the Tyrrhenian Sea in the background. Ruins of the Roman forum area are in the right foreground; halfway up the hill at the left is the temple of Apollo; the upper temple is at the summit, where Daedalus was said to have landed. The entrance to the Sibyl's grotto is out of sight on the other side of the acropolis.

RUINS OF TEMPLE OF APOLLO on Cumae's acropolis reveal some of the differences between Greek and Roman construction methods. The large limestone blocks are from the Greek temple erected in the fifth century B.C. The diamond-shaped brickwork (called *opus reticulum* in Latin) is characteristically Augustan and dates from the first century B.C. The Arcus Felix is at top right.

embroiled in the Latin War (340–338 B.C.), but when Rome won that too, the Campanians lost even more of their independence. They were absorbed into the expanding Roman state as citizens without the right to vote. Cumae, like Capua and the rest of Campania, was henceforth essentially a Roman city, although like Herculaneum and Naples it kept a certain Greek flavor to the end. The new system of circuit judges (*praefecti Capuam Cumas*) brought Roman justice to these Campanian centers. The Romans had brilliantly grasped the importance of Campania: with possession of its fertile soil, its fine harbors with long-established trade contacts throughout the Mediterranean world and its rich supply of vigorous men, Rome now had the resources to become a world power.

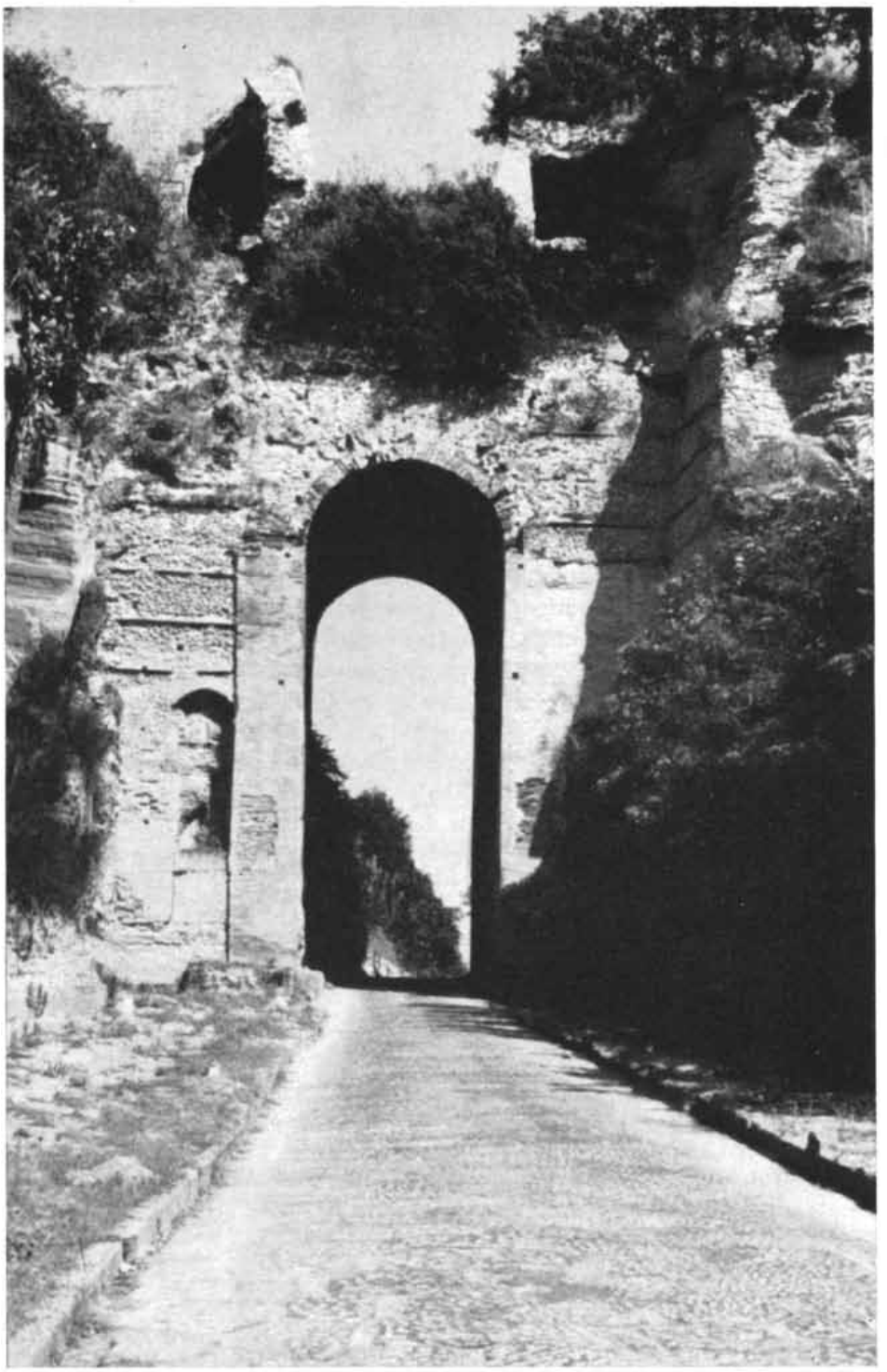
Carthage, on the northern coast of Africa, also sensed the value of Campania, and its leader Hannibal tried to conquer the area during the Second Punic War (218-201 B.C.). Capua, resenting Roman domination, went over to him after the Roman disaster at Cannae but could not persuade Cumae to do likewise. Instead Cumae called in the Roman consul Sempronius Gracchus. He humiliated the Carthaginians by capturing Hamae, then beat off Hannibal's attack on Cumae in 215 B.C. and again the next year, when Hannibal returned to the area to sacrifice at Lake Avernus. For its loyalty to Rome throughout the war Cumae was in 180 B.C. granted the right to substitute Latin for Oscan as its official language. Cumae became thoroughly Romanized, and by early in the first century B.C. its citizens had rights equal to those of Rome. Lovely Roman villas were built at Cumae, Baiae and Lucrinus. Scipio Africanus lived nearby in retirement, as did Sulla. Many of Cicero's letters are dated from his Cumaean villa near Lucrinus, where he also wrote his famed treatise *On the Republic* and recruited support for the Senate during the Civil War.

Great changes occurred at Cumae during the last half of the first century B.C. During the power struggle between Mark Antony, Octavian and Sextus Pompey the consul Agrippa set up a remarkable military complex near Cumae for Octavian's benefit. In 37 B.C. he built a port and a shipyard in Lake Avernus; here were made many of the ships with which Octavian later routed Antony and Cleopatra at Actium. Misenum was transformed into a naval staging station, and a huge underground water cistern was constructed there. The acropolis of

Cumae was refortified; the Sibyl's grotto was made into a garrison warehouse and a water reservoir. A great tunnel was driven through the hill and was connected by a road to an even larger tunnel that cut through Mount Grillus and came out on the shore of the Lake Avernus shipyards.

After Octavian's eventual triumph and his establishment as the sole ruler of Rome, the temples of Cumae, the Sibyl's grotto and her cult were restored. This was a way of making reparation for the desecration of the area for military purposes. It is likely that the reparation was urged on Octavian, now called Augustus, by his friend Vergil, whose special reverence for ancient Greek and Roman Cumae was rooted in a deep understanding of its historic and cultural significance and its value as a symbol.

Cumae's period of influence in world affairs, however, was over. It declined steadily as Puteoli and Naples grew in size and industrial activity. A new colony of settlers was sent to Cumae by Rome in the first century A.D., and a road was built by Domitian in A.D. 95 to facilitate travel to Rome, Misenum, Puteoli and Naples. A Roman amphitheater for about 15,000 spectators indicates that the town was moderately large, although the events drew from the whole area and not from Cumae alone. The cult of the Sibyl languished and Cumae became primarily a tourist center, a way station on the road to Baiae's spas—a quiet, sparsely inhabited shell of its former glory. The ghostly estate of the place is somehow emphasized by the suicide there in A.D. 66 of Petronius, who had just written his final contemptuous exposé of the corruption and hollow materialism of Roman society under Nero, which he knew so well.



ARCUS FELIX was built about A.D. 95 to provide a more direct route through Mount Grillus between Cumae and Naples. The road under the arch is paved with its original stone.

In later years Christianity took strong root at Cumae. Both of the temples on the acropolis were made into churches, and Christian tombs are found throughout the hill. When the barbarian invaders poured into Italy, only Cumae and Naples in all Campania were strongly enough situated and fortified to resist. The great Byzantine general Belisarius, sent to defend Italy, occupied Cumae in 536. The Ostrogoths under Totila finally stormed the citadel in 542, and for 10 years that fierce and gaudy chieftain used the cave and underground corridors of the Cumae acropolis as a storehouse for the vast loot he had taken in Italy. He died there in 552. The Byzantines renewed the siege, led now by Narses. The defense by the Ostrogoths was stubborn, and it took a year to capture the citadel by fire and undermining.

Cumae was the last city in Italy to fall into Byzantine hands. When the Longobards gained mastery of Campania, Cumae was the stronghold of Duke Romuald II; then Count Giovanni of Naples seized it in 717. In 915 a devastating attack by Saracen pirates totally wrecked the site. It never recovered. In its ruins and caves feudal lords made something of a castle, but pirates and robbers supplanted them, using Cumae as a base for plundering attacks on shipping and on Puteoli and Naples. Finally Naples could endure this no longer and in 1207 organized a force under Goffredo di Montefuscolo that burned and razed the citadel until it was useless to anyone. After nearly 2,000 years of a unique historic role Cumae had been done to death by its own daughter.

The abandoned site was soon overgrown by vegetation and covered with blown dirt and sand. The area around it reverted to fever-breeding swamp. In the 17th century farmers seeking to rehabilitate the land discov-

ered many statues and tombs. Systematic digging for antiquities was begun in 1852, and over the years much was found. In 1912 the excavation of the acropolis was undertaken, and in 1932 the archaeologist Amedeo Maiuri found at last the great grotto of the Sibyl. Although much work remains to be done, today Cumae is a major archaeological park.

These remains bring the long and eventful history of Cumae to life. The acropolis itself is part of a primitive volcano crater, of which only a partial arc remains; its mass is about a quarter of a mile long and rises to a maximum height of 247 feet above the sea adjacent to it on the west. Its cliffs are abrupt on the north, east and west, and on the south it slopes like a ramp to the plain. On its summit, where Daedalus was said to have landed from the sky, a great temple magnificently dominated the hill and was visible for miles along the coast.

Here must have stood the earliest shrine of Greek Cumae. In the middle of the fifth century B.C. a large Doric temple was constructed on the site; it was about 130 by 81 feet at its base and oriented east-west. Of this temple only some of the base remains. It had fallen into neglect, perhaps ruins, after the Samnite conquest of the Greek city. Augustus had it rebuilt around the beginning of the Christian era, and much of that structure is still recognizable. Toward the end of the fifth century A.D. the pagan temple was converted into a five-aisled Christian basilica.

There is no ancient evidence to show in whose honor the Greek and Roman temple was built. Today it is often called the temple of Zeus; Livy says one existed at Cumae. Vergil, however, speaks of "the two heights on which Apollo presides." This may mean that the temple honors Apollo, because the smaller temple below the summit is clearly associated with him by an Oscan inscription.

This lower temple was about 113 by 60 feet, with six columns along the front and back and 13 along the sides—the most approved Doric pattern. It too was built in the middle of the fifth century B.C., after the Etruscan threat was eliminated. The building was oriented north-south, a rare arrangement in Greek times, probably because of the lay of the land on the eastern brow of the hill. In the Augustan reconstruction the plan was radically changed to an east-west orientation, a porch was added on the east and the interior was divided into three halls. When the structure was rebuilt as a Christian basilica, the orientation was again made north-south and a baptistery

was added. Nearly 90 Christian graves were cut into the floor.

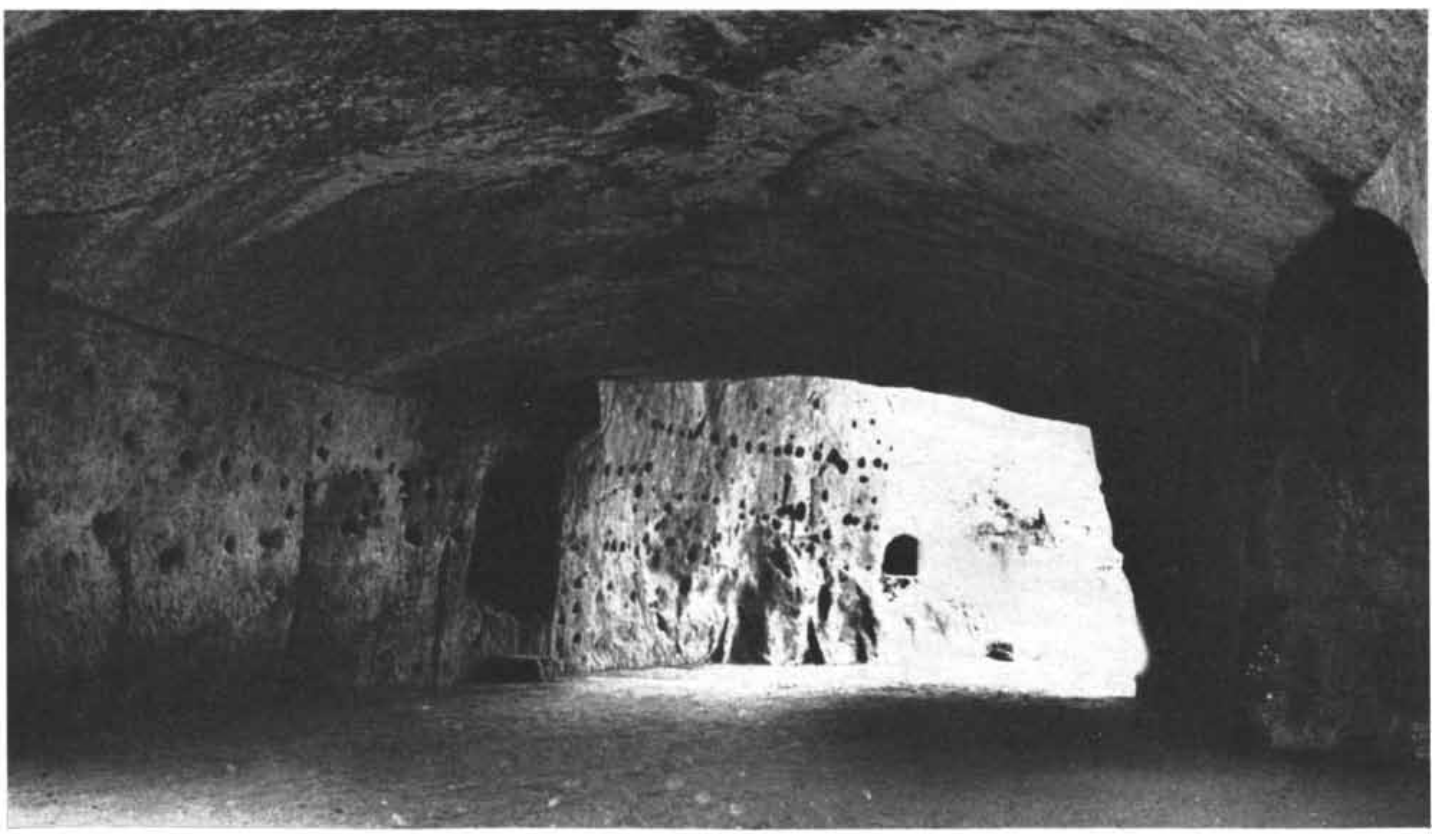
Leading from the city to the temples was a sacred way of large flat stones, considerable stretches of which are still in place. The rest of the acropolis was used for private buildings, particularly in Roman times. Part of the fortification wall survives; the various construction techniques and materials differentiate the Greek parts from later ones.

The most remarkable antiquities at Cumae are cut into the acropolis itself. High on the west edge of the cliff is the grotto of the Sibyl, one of the most impressive and mysterious monuments of the ancient world [*see illustration on page 108*]. The grotto is a long corridor cut through the rock in a straight north-south line for 427 feet. The floor is a little less than eight feet wide, the flat ceiling is four feet wide and the walls are 16 feet high. The trapezoidal shape was probably meant to imitate and recall the famous Mycenaean trapezoidal galleries under the east and south walls at Tiryns. At regular intervals down the long corridor are six lateral galleries, cut in the same trapezoidal measurements, that open at the top westward toward the sea. A seventh gallery that has no opening perhaps has mystic significance: counting the entrance and exit of the corridor, there are nine trapezoidal "doors," which is three times three, whereas two times three areas of light are cast on the corridor's floor and on the inner wall by the six openings toward the sea. Three was the symbolic number of Hecate, goddess of ghosts and of crossroads (often thought to be haunted), whose Roman counterpart Trivia also is symbolized by three. It is clear that the Sibyl at Cumae was prophetess of Apollo and priestess of Hecate combined—no doubt an indication of Greek assimilation of the earlier local cult at Lake Avernus, a combination of Olympian religion and the earlier worship of underworld powers.

This symbolic number is repeated elsewhere in the grotto. Halfway down its length a triple bath opens on the left, consisting of three separate rectangular pits below floor level. This fits the description in an account of Cumae by a visitor in the third or fourth century A.D.: "In the middle of the 'basilica' we were shown three cisterns excavated in the rock in which they said the Sibyl performed ablutions before donning her long robe and retiring to the innermost chamber cut out of the same rock, where she gave her oracles seated on a throne in the middle." Some time later these baths were converted into cisterns, perhaps during Agrippa's conversion of Cumae into a garrison. Eventually the whole grotto was made into a huge cistern and its floor level was lowered nearly four feet; this may have been when the Goths took over Cumae for a fortified treasure house.

At the end of the long corridor are three large rooms. The room into which the corridor opens is where the Sibyl gave her oracles; Vergil records that they were written on leaves and often confused. To the west is a large, high room, where presumably the consultant and attendants stood. Its opening at the top toward the sea may have originally been a window to let some light into the first room, but in its present large and ragged state it is clearly a door knocked through by postmedieval farmers, who used the room to store wine and hay. The third room, to the east of the first, is itself threefold, with side rooms flanking the central chamber. This must have been the living quarters of the Sibyl. Cuttings in the jamb show that it had a door on pivots. Other cuttings in the wall throughout the grotto indicate that there were wooden doors at many points, no doubt to add to the mystery of the place; they probably opened suddenly when the Sibyl cried out her prophecies. The weird play of light and shadow down the long corridor must have added to the atmosphere of awe engendered by the sacred ritual.

The neatly cut trapezoidal corridor is quite different in style and workmanship from the large Roman underground



WAREHOUSE cut into the rock of the acropolis at Cumae is an example of the extensive tunneling undertaken by the Romans during the first century B.C. This room seems to have been used to store food and armor for the Roman garrison and later for the Goths.

crypts at Cumae and elsewhere; they have rounder ceilings and roughly hewed vertical walls, and they are often patched or reinforced by bricks. The grotto must be Greek work of the late fifth century B.C., before the Samnite conquest in 420. It is one of the great engineering feats of the Greek world.

Just outside the grotto is a tunnel cut into the rock, with a large chamber deeper inside the hill. This seems to have been used by Agrippa's garrison as a warehouse for food and armor. From it a tunnel with a stepped floor leads upward in a curve to come out at the base of the acropolis fortification wall. This must be a military communication tunnel, perhaps as ancient as Greek times.

Next to the entrance to the tunnel is a large cave overlooking the sea. This was probably the primitive, perhaps pre-Greek, site for the religious cult at Cumae. It was greatly enlarged by Agrippa in 37 B.C., when he incorporated it into his huge tunnel through the acropolis. The tunnel is 585 feet long and in many places as high as 75 feet; it is a monumental example of Roman engineering ability and daring. Beyond an enormous vestibule the tunnel continues level for about 60 feet, with large storerooms cut into the rock on each side, then dips and curves into the heart of the hill. Farther along there opens on the right a gigantic cistern with a high curved ceiling and a heavy step-pyramid divider wall cutting the chamber into two separate reservoirs, to provide against pollution of the whole water supply in case seepage or other trouble should develop. On the ceiling outside the entrance to this cistern can be seen relief carvings of a palm, a crown and a cross joined to a circle. They are evidently Christian symbols; many tombs of the fifth and sixth centuries A.D. were cut into the walls here in a kind of catacomb.

The tunnel emerges at the east side of the acropolis directly facing the tunnel through Mount Grillus to Lake Avernus; between the two tunnels is the forum of Cumae. A Roman road connecting the two tunnels has partly survived. Clearly this is part of the transformation of Cumae into a bastion for Octavian's forces.

The tunnel through Mount Grillus, currently closed because of a partial cave-in during World War II, is the greatest of all ancient subterranean passages. It is more than half a mile long, wide enough for two carriages to pass in opposite directions and about 15 feet high. Light and air are provided throughout the tunnel by six shafts cut through to the hill's surface; four of these are

vertical, two oblique. The largest shaft is nearly 100 feet deep. The passage emerges on the northwest shore of Lake Avernus. Its purpose was to provide safe passage for troops between Cumae and Lake Avernus, and it revived the underground ways of the ancient Kimmerians. About 100 yards to the east of the Cumae entrance to the tunnel is the imposing Arcus Felix, a monumental brick-faced cut through the ridge of Mount Grillus built by the emperor Domitian to allow a new road to pass between Cumae and Puteoli and Naples.

Greek Cumae lay below the acropolis to the south, parallel to the beach. Whatever remains of it after many disasters is still buried. The Samnite and Roman town was mostly farther north and east, closer to the acropolis. Part of the forum there has been excavated and extensive Roman baths are visible. Near them are the ruins of a large Samnite temple, probably to Jupiter, which in the second or first century B.C. was modified by the Romans to serve as a Capitolium, with three separate naves for Jupiter, Juno and Minerva; their colossal statues stood on elevated platforms at the back of their respective naves. The huge heads of these statues have been found and are in the museums at Naples and Pozzuoli. A law-court basilica and other civic buildings were in the forum.

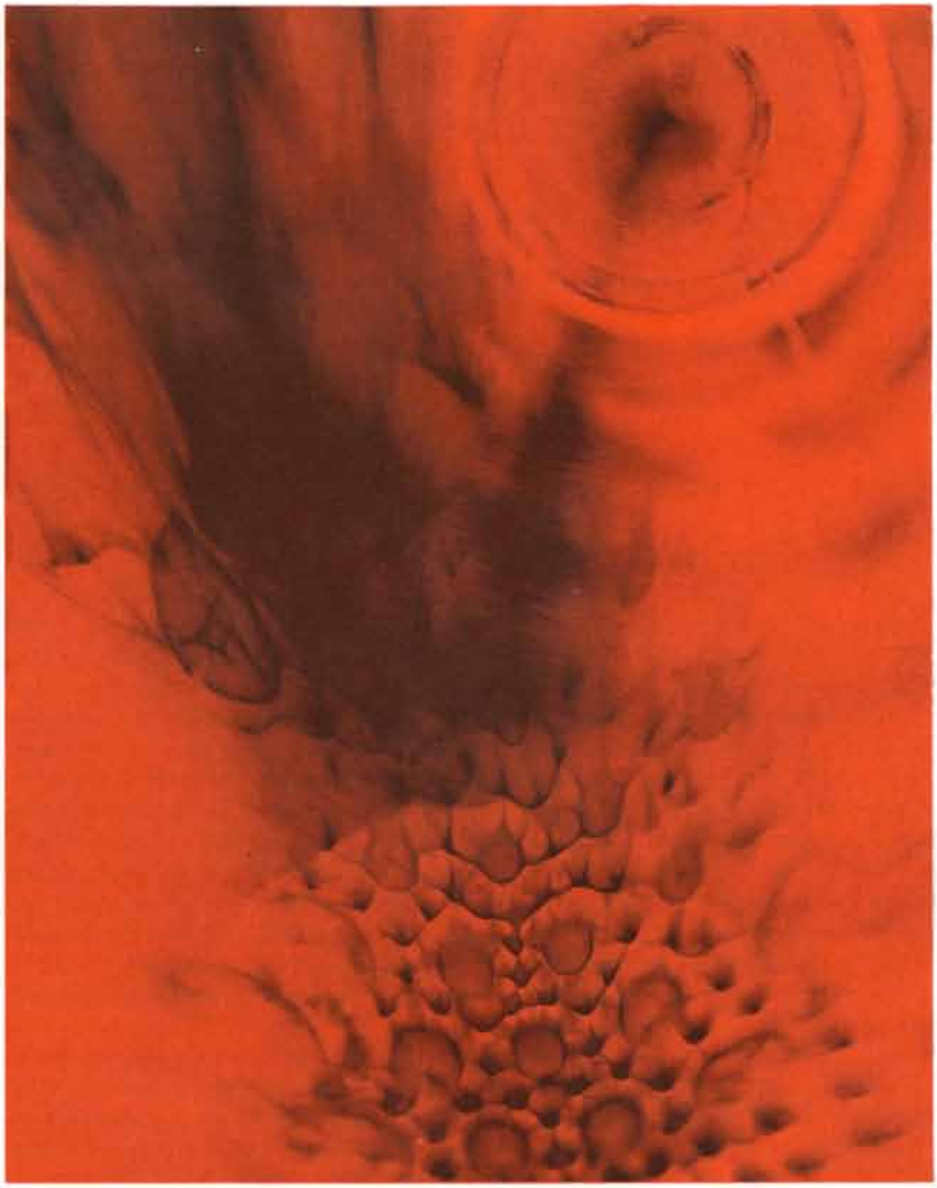
Considerably to the southeast is the amphitheater, not yet excavated but clearly visible among the vines planted within it. It stood outside the walls at the southern extremity of Roman Cumae. Like the amphitheater at Pompeii, it has no undergalleries, and it was probably built early in the first century B.C., making it possibly the oldest amphitheater anywhere. It has 21 rows of seats, the dimensions of the oval structure being about 440 by 360 feet. Near the amphitheater stood a small temple dedicated to Mercury, perhaps in his function as guide of souls to Hades at nearby Lake Avernus. In the same region the remains of another structure, probably a Samnite temple, have also been found.

Lake Avernus is just over the low range of Mount Grillus to the east. It lies in a deep volcanic crater five miles in circumference, with sheer walls ringing the water to a height of more than 100 feet except for a gap at the south. The water comes mostly from mineral springs; it is dark and brackish and has a sulfurous aroma that was apparently much stronger in ancient times. (It was said that birds were unable to fly across

it.) Dense forests covered the steep slopes of the lake, intensifying its aspect of dark mystery. A hot mineral spring near the lake was said to be the waters of the Styx, and the dread entrance to Hades was along Avernus' shore, from which Charon's boat took souls to the realms below.

Of the great shipyard built at Lake Avernus by Agrippa in 37 B.C. only meager ruins survive, but perhaps more is under the water of the lake, the level of which is now considerably higher. The canal built to join the port to the adjacent Lake Lucrinus and the bay has been filled up, largely by the sudden emergence of the volcano Monte Nuovo in 1538. West of the canal another tunnel passed through the hill between Lake Avernus and Lake Lucrinus; it was long thought to be the Sibyl's grotto, until the true one was discovered by Maiuri on the acropolis at Cumae. Some massive Roman ruins on the eastern shore are the remains of a great establishment of hot mineral baths and steam rooms heated by boiling sulfur pits.

With so long and diversified a history and such imposing monuments, Cumae deserves lasting memory. This has been assured by Vergil. His great epic of Rome's origins is centered on Cumae. By making Aeneas first touch Italian soil at Cumae, Vergil associated the founding of Rome with the cultural impact of the first Greek colony in Italy. Aeneas is brought to Cumae by Apollo's counsel to learn from the Sibyl how to achieve his destiny and Rome's. Vergil's description of the Sibyl's oracular trance is vivid and profound, and his picture of the grotto is both imaginative and based on direct knowledge of the site. He speaks of it as "cut into the side of the Euboean cliff" with "many openings from which come forth the responses of the Sibyl." She gives Aeneas some enlightenment, then guides him by a secret dark path to the shores of Lake Avernus to learn more from the ghost of his father, Anchises, who reveals to Aeneas the future history and grandeur of Rome and her civilizing mission in world history. There is much more about Cumae and Avernus in the *Aeneid;* the point is that Vergil's brilliantly poetic treatment of the area and its spiritual significance has made Cumae immortal in Western civilization. "The gentle Mantuan poet whose fame shall last as long as the world," as Dante saw, is still our best guide to a deeper appreciation of Cumae's entirely fascinating remains and history.



Photographic Interpretation by William Thonson

MAGNETIC MONOPOLES

They are fundamental particles that are predicted by conservation and symmetry principles but have not been detected. This apparent violation of physical theory has stimulated a new search for them

by Kenneth W. Ford

Some 30 years ago the theoretical physicist P. A. M. Dirac suggested that there might be elementary particles of magnetism, just as there were elementary particles of electricity (the electron and the proton). A magnetic particle would have a "magnetic charge"; since the charge would be either "north" or "south," the supposed particles have been called magnetic monopoles.

The magnetic monopole would bring to electricity and magnetism a symmetry that is lacking in our present picture. As theoretical physicists see it, magnetism in our world is merely an accidental by-product of electricity; it exists only as a result of the motion of electrically charged particles. An electric particle gives rise to an electric field, and when it moves it produces a magnetic field as a secondary effect. For symmetry's sake there should be magnetic particles that give rise to magnetic fields and in motion produce electric fields in the same way that moving electric particles create magnetic fields. Magnetic particles would emit and absorb electromagnetic radiation (for example light) as electrons do. Furthermore, just as energetic photons can create pairs of oppositely charged electric particles, such as an electron and a positron, so also can they produce a pair of magnetic monopoles.

Dirac's idea of the magnetic particle, proposed at about the same time that he predicted the existence of the positron, has inspired a number of investigations by both theoretical and experimental physicists. So far the magnetic monopole has frustrated all its investigators. The experimenters have failed to find any sign of the particle. The theorists, on the other hand, have failed to find any good reason why it should not exist. This may seem a rather slender basis for maintaining anyone's interest in the hypothetical particle, but actually it is an excellent reason. One of the elementary rules of nature is that, in the absence of a law prohibiting an event or phenomenon, it is bound to occur with some degree of probability. To put it simply and crudely: Anything that *can* happen *does* happen. Hence physicists must assume that the magnetic monopole exists unless they can find a law barring its existence. Discovery of such a law would be as exciting as discovery of the particle itself.

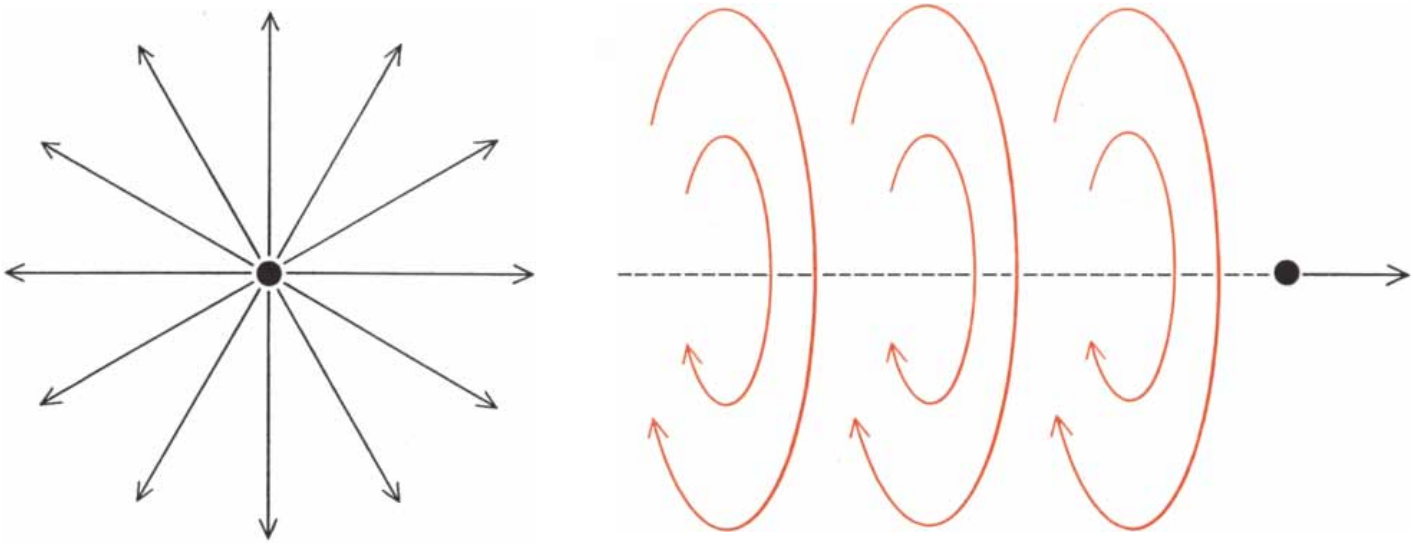
This is what has kept interest in the monopole alive for more than 30 years. It has remained a fascinating tidbit of modern physics but has been kept simmering at low heat on the back burner of research. Physicists have looked into it only sporadically, because monopoles must be rare indeed in our world, and their very existence seems doubtful.

Two recent developments, however, should heighten interest in the elusive particle. One is the increasing power of tools that offer the possibility of creating and trapping monopoles. These tools are the great new particle accelerators —the 30-billion-electron-volt Brookhaven and CERN machines and the 70-Bev machine under construction in the U.S.S.R.—and new techniques for searching for monopoles in cosmic rays. The second reason for renewed interest in the monopole is the marked change in philosophical outlook that has come about in physics in the past few decades as the result of the discovery of the creation and annihilation of a myriad of different particles. The change in philosophy (which we shall consider further later in this article) has intensified the interest of physicists in the laws of conservation, which to a large extent govern what is possible and what is not possible in the physical world. From this point of view the nonexistence of the monopole and the question of whether or not its existence is prohibited become matters of considerable importance.

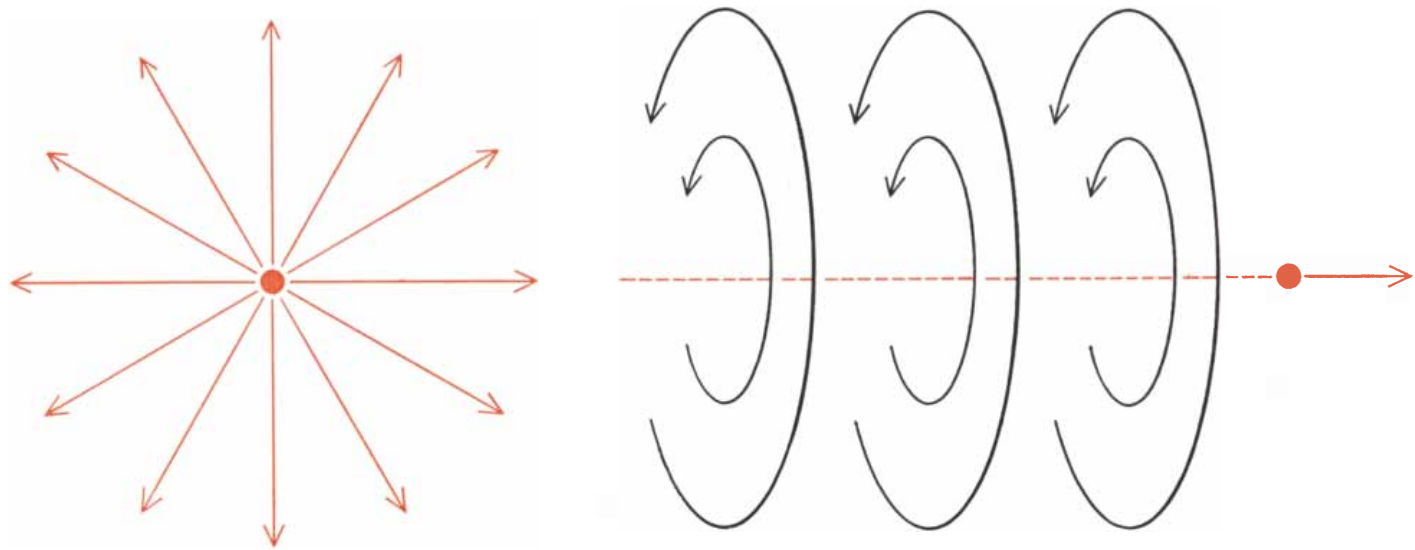
The problem of the asymmetry of electricity and magnetism is a century old. It stems from the merger of electricity and magnetism into the single theory of electromagnetism by James Clerk Maxwell. His theory was one of the greatest triumphs of 19th-century science. It seemed a marvelous simplification that from electric charge alone flowed all electric and magnetic effects. Nevertheless, ever since Maxwell's elegant formulation of the equations of electromagnetism in 1862, the absence of "magnetic charge" to balance electric charge in the equations has seemed somewhat perplexing.

Maxwell's equations actually provided a natural slot for magnetic monopoles. As usually written, the equations are four in number [*see upper illustration on page 124*]. In one equation the right-hand side is equal to the density of electric charge; in another the right-hand term is the current of moving electric charge; in the remaining two equations the right-hand side is zero. To give symmetry to the four equations, one of the zeros should be replaced by the density of "magnetic charge" and the other by the current of moving "magnetic charge." In short, the zeros represent the slot waiting for monopoles. No new equations would be required to describe the monopole; Maxwell's are ready and waiting, if monopoles exist.

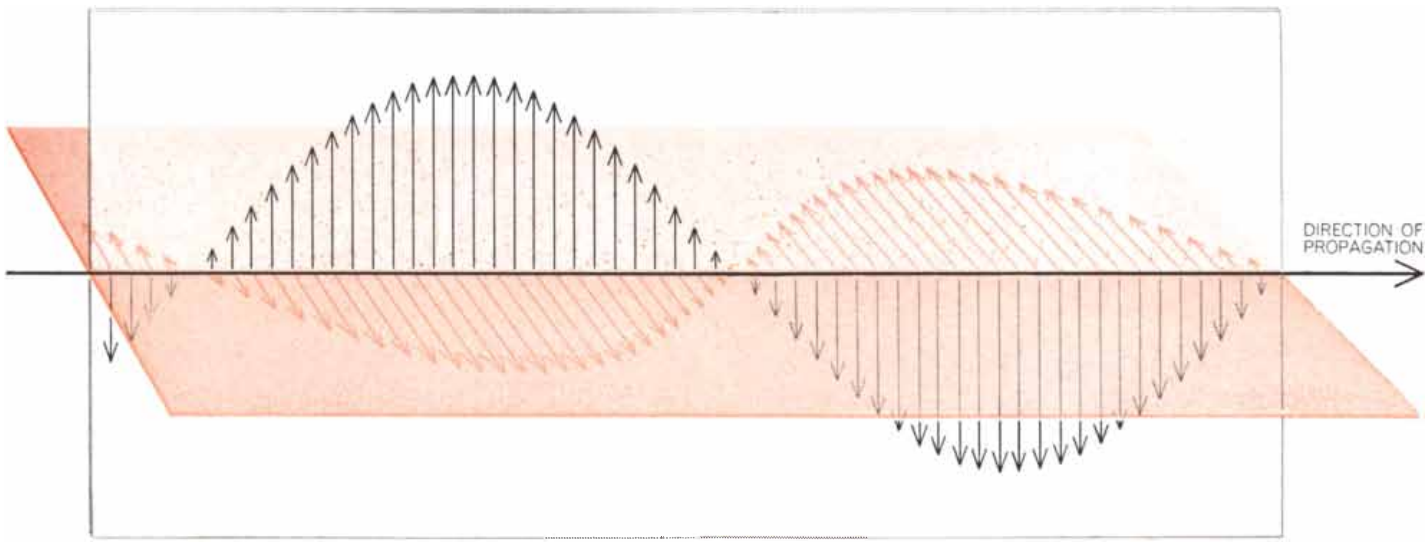
The monopole slot is even more evident in the equations as they are stated in terms of the theory of relativity. Then there are just two equations, one with an electric-source term, the other with a



PROTON (*black dot*) sets up an electric field (*black arrows*) around itself when standing motionless (*left*). In motion (*right*) it creates both an electric field (*not shown here*) and a magnetic field (*colored arrows*). The magnetic field is weaker than the electric field and is oriented differently. In actuality the electric field in the drawing at the left extends in three dimensions.



MONOPOLE (*colored dot*) would create a magnetic field around itself when stationary (*left*) and an electric field when in motion (*right*). A north monopole is shown here; the electric field around a moving south monopole would be in the opposite direction. For complete electromagnetic symmetry "magnetically charged" monopoles as well as electrically charged particles would have to exist.



ELECTROMAGNETIC WAVE propagating in free space consists of oscillating electric and magnetic fields of equal intensity in a perfect state of balance. Such a wave can be created by an accelerated charged particle (a proton or an electron); it could also be created by an accelerated north or south monopole. In this diagram the electric field is vertical and the magnetic field horizontal.

zero that would be replaced by a magnetic-source term.

Nothing in the framework of classical electromagnetic theory accounted for the asymmetry of electricity and magnetism. In 1931 Dirac asked the same question of the quantum theory: Is there anything in the quantum theory of electromagnetism that would bar the existence of magnetic charge? He found no such restriction. The quantum theory, like the classical theory, had room for monopoles.

Dirac's study of the mathematics of the situation produced the extremely interesting finding that if the monopole existed, its pole strength, like the electric charge on a particle, must be quantized. He was able to calculate the quantum of pole strength. Considering an interaction of a monopole and an electric particle, he deduced that the product of the pole strength of the former and the charge on the latter must be numerically equal to a certain value determined by fundamental constants (the constants involved being Planck's constant and the speed of light). In the "natural units" popular with physicists the smallest possible value of this product (aside from zero) is one-half, that is, charge times pole strength equals one-half. Since the smallest unit of charge (that on the electron or proton) is known to be one divided by the square root of 137 in the same units, the smallest possible pole strength carried by a monopole must be half the square root of 137. To put it another way, the quantum of pole strength is 68.5 times greater than the quantum of electric charge. Therefore two monopoles would exert on each other a force 68.5 times 68.5, or 4,692, times stronger than the force exerted on each other by two elementary charged particles the same distance apart. This theoretical result is of considerable significance because it is a unique kind of prediction in physics; so far no one has succeeded in predicting the strength of any other force that acts between elementary particles.

Dirac's theoretical calculation of the monopole's pole strength is the only property that can definitely be assigned to this hypothetical particle. From the pole strength alone, however, we can derive interesting conjectures about other possible properties of the monopole and its behavior. For instance, it appears that the monopole may be heavier than any elementary particle so far discovered. As a general rule the strength of interaction of particles increases with their mass; the heaviest particles interact most strongly. The monopoles, with their large pole strength, would interact with each other even more strongly than the heavy nuclear particles. Consequently it would not be surprising if the monopoles were more massive. The experimental efforts to create monopoles have shown, indeed, that if the monopole exists, it must be at least three times more massive than a proton.

It should be added that there is no good reason to speak of "the" monopole as if there were only one species. If monopoles exist at all, there is every reason to suppose there should be many different kinds, just as there are different kinds of electrically charged particles, some more massive than others, some subject to nuclear forces and some not, some with spin and some without.

Let us now suppose monopoles do in fact exist. How are they born, how do they live and die? Where might they be found?

Concerning their birth and death, we can be reasonably confident of one thing: They must obey a law of conservation of pole strength. Like the conservation of electric charge, conservation of pole strength is an inevitable result of Maxwell's equations. This means that a monopole, once formed, cannot vanish—unless it encounters another monopole whose pole strength is of opposite sign. (In our world, where monopoles are exceedingly rare if they exist at all, such en-

$$\nabla \cdot E = 4\pi\rho \qquad -\frac{1}{c}\frac{\partial E}{\partial t} + \nabla \times B = \frac{4\pi}{c} J$$

$$\nabla \cdot B = 0 \qquad -\frac{1}{c}\frac{\partial B}{\partial t} - \nabla \times E = 0$$

MAXWELL'S EQUATIONS of electromagnetism are written here in the notation of vector calculus. The electric field is indicated by E and the magnetic field by B. The symbols ρ and J refer respectively to the density of electric charge and the current flow of electric charge; c denotes the speed of light and the symbols resembling sixes turned backward are partial derivatives. If magnetic monopoles exist, the zeros on the right side of the bottom pair of equations must be replaced by magnetic-charge terms analogous to the electric-charge terms in the top pair of equations. This would bring a greater symmetry to the equations.

$$\partial_\mu F^{\mu\nu} = \frac{4\pi}{c} J^\nu \qquad \partial_\mu F^{\dagger\mu\nu} = 0$$

MONOPOLE "SLOT" is more evident if Maxwell's equations are written in the notation of special relativity. The symbols $F^{\mu\nu}$ and $F^{\dagger\mu\nu}$ designate various components of the electric and magnetic fields; the sign preceding each denotes a derivative with respect to a co-ordinate in space-time; J^ν is the four-dimensional electric current. Because monopoles have not yet been discovered, the right side of second equation remains zero. With monopoles, this zero would be replaced by a magnetic-current term.

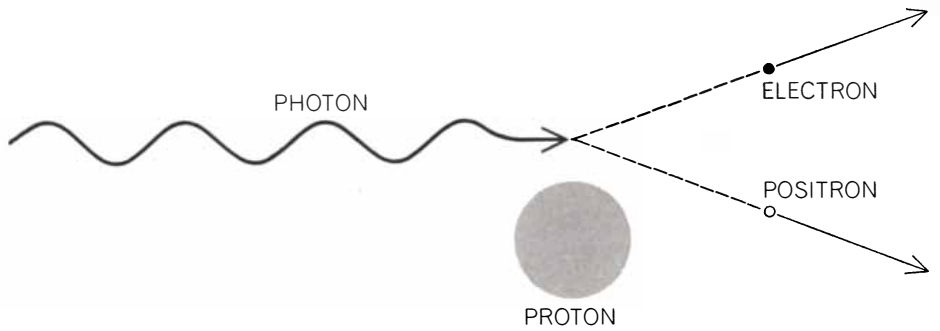
counters must be rarer still and a monopole would live virtually forever.) If a north monopole and a south monopole do meet, they annihilate each other, but there is no change in total pole strength; for the oppositely "charged" pair the net pole strength was zero before the annihilation as well as after. The same conservation law implies that monopoles can only be created as twins: a north monopole with a south monopole. The total pole strength then is still zero, as it was before the creation. Thus pole strength is conserved in the same way that charge is in the creation of an electron-positron pair, with a total charge of zero.

Monopoles (still supposing they exist) presumably are created, as pairs of charged particles are, by energetic collisions between other particles. One kind of collision that could do the job is the interaction of a very-high-energy photon with a proton. The photon would have to carry enough energy to create the mass of two monopoles. Our giant accelerators may eventually produce photons of the required energy. A more likely source of monopoles is the high-energy cosmic rays—either the primary particles (mainly protons) or the secondary photons generated by collisions of the primaries with the nuclei of atoms in the air. Both of these classes of projectiles often carry so much energy that, on colliding with a nuclear particle, they could create pairs of monopoles even if the monopole were hundreds of times more massive than a proton.

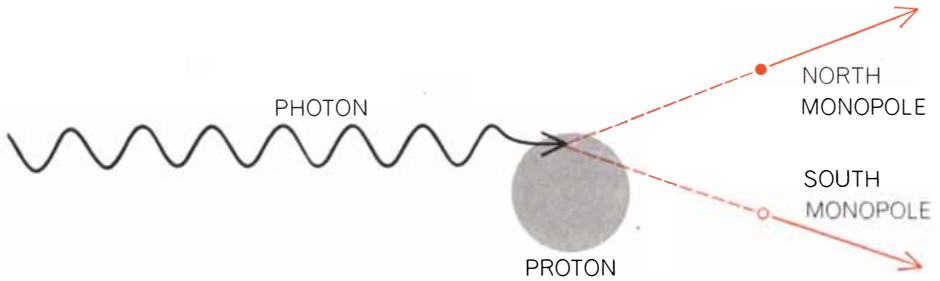
Monopoles themselves could come to the earth from space. It is possible that they are present in the cosmic rays in space as a comparatively rare component, or that they are trapped in meteorites and arrive by that route. Both of these possibilities have been studied by Eiichi Goto of the University of Tokyo.

First, he finds that any cosmic ray monopoles arriving at the earth would have phenomenally high energy. Because of their large pole strength, monopoles would be very effectively accelerated by a magnetic field—far more effectively than protons are. In the vacuum and vast distances of interstellar space even the weak magnetic fields of the cosmos would accelerate monopoles to an average energy of about 100 billion billion electron volts. At such energies monopoles would drive right through the atmosphere and plunge deep into the earth.

Incidentally, this suggests that monopoles, if we could only generate a supply of them, would be ideal projectiles for a laboratory accelerator. Calculations indicate that a magnetic field of 10,000 gauss (easily achieved in the laboratory today) could add energy to a monopole at the rate of 200 million electron volts per centimeter. Thus a monopole accelerator six feet long would surpass in energy the most powerful existing accelerators, which require a circular track half a mile long. Moreover, a relatively small supply of monopoles would suffice, because they could be extracted from the target and used again and again. With care a monopole accelerator might operate almost indefinitely on its original supply of projectiles.



ELECTRON-POSITRON PAIR can be produced in a particle accelerator when a photon, the quantum unit of electromagnetic radiation, approaches a charged particle such as a proton. The photon's energy must be sufficient to supply mass energy of the new particles.

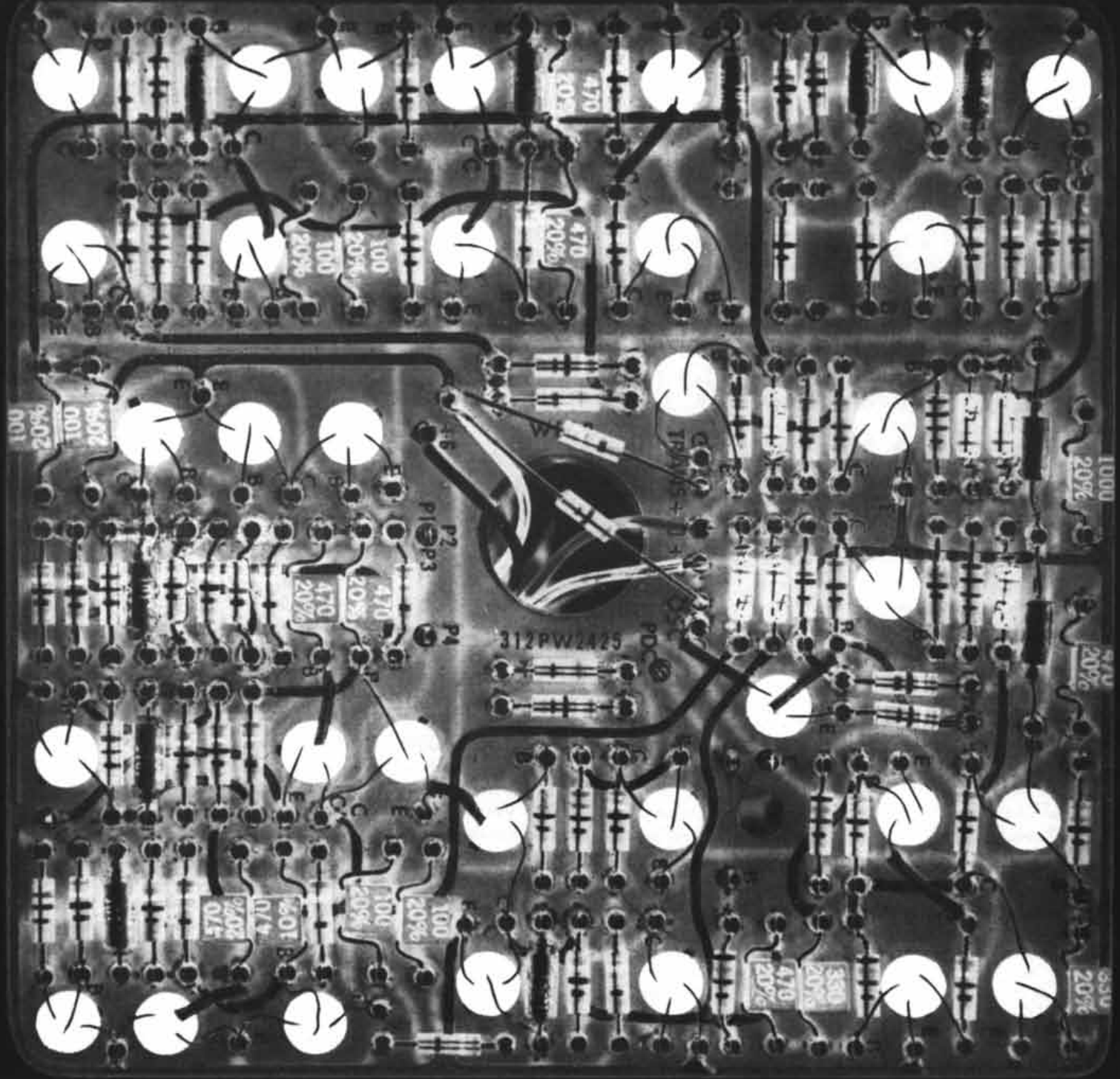


MONOPOLE PAIR, consisting of a north and a south monopole, could also be produced in a photon-proton collision. Because they are probably very massive, monopole pairs would be produced much nearer to the center of the proton and would require a photon of higher energy and shorter wavelength than is required to produce an electron-positron pair.

As for monopoles in meteorites, Goto notes that an occasional pair of monopoles might well be created in these space travelers by cosmic rays. When they were produced, they might fly apart, and if they were separated by as little as a thousandth of a centimeter in an iron meteorite they would not interact to annihilate each other. Once created and trapped in the meteorite, the monopoles should survive and remain bound in it indefinitely. They would be prevented from escaping by a force analogous to that which holds electrons in metals. Because of the monopole's large pole strength, it would be bound to iron with an energy several hundred times greater than that holding electrons.

Iron and stony-iron meteorites have been cruising about in the solar system, it is believed, for hundreds of millions of years. During that long period the continual bombardment of cosmic rays may have produced monopoles in many of them. Consequently some of the meteorites now reposing in museums or lying about on the earth's surface may contain the magnetic particle, awaiting discovery.

Goto has suggested another place where monopoles might be found on the earth. Suppose incoming cosmic rays create a pair of monopoles high in the atmosphere. As the particles dash through the air they are slowed down. (Because of their large pole strength monopoles would lose energy very rapidly in passing through matter; in iron, to take an extreme example, this loss for a high-speed monopole would amount to about 60 billion electron volts in each centimeter of travel.) After slowing down, the north monopole is driven gently northward by the earth's weak magnetic field (less than one gauss) and the south monopole moves southward. Eventually each monopole, following a line of force in the earth's field, comes to earth at a comparatively low speed. If it happens to land on a piece of iron ore on the surface, it will be trapped there by the iron's magnet-



The Lincoln Laboratory, a research center of the Massachusetts Institute of Technology, is engaged in theoretical and experimental investigations in advanced electronics, with emphasis on technological applications to national defense and space exploration. The program in *Space Communications* is directed toward the discovery and development of methods for long distance communication resistant to disruption by natural or man-made disturbances. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. Lincoln Laboratory, Massachusetts Institute of Technology, Box 18, Lexington 73, Mass.

Solid State Physics
Information Processing
Radio Physics and Astronomy
Radar Design
Control Systems
Space Surveillance Techniques
Re-entry Physics
Space Communications

A description of the Laboratory's work will be sent upon request.

ism. Surface iron ore, therefore, may be a good place to look for monopoles.

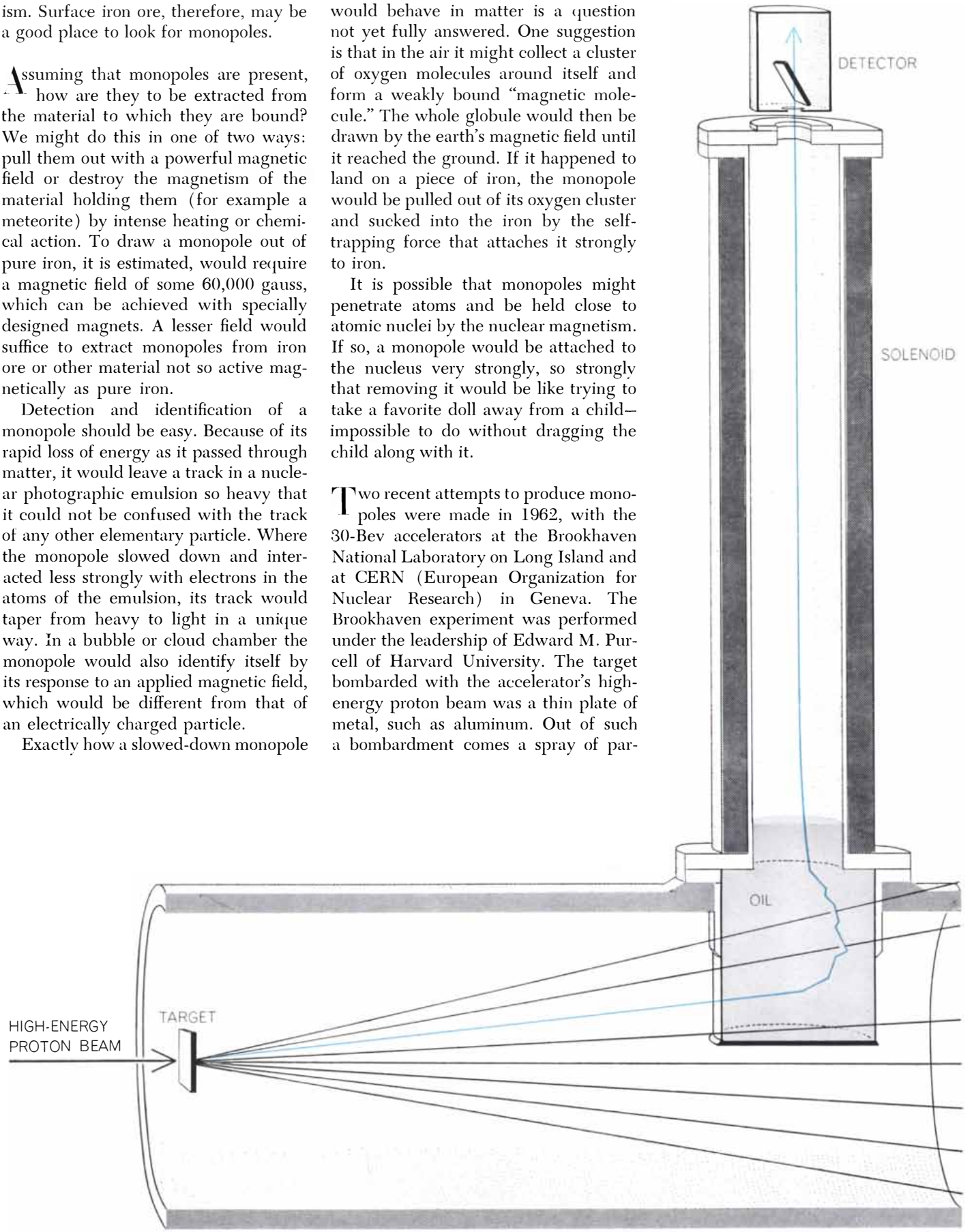
Assuming that monopoles are present, how are they to be extracted from the material to which they are bound? We might do this in one of two ways: pull them out with a powerful magnetic field or destroy the magnetism of the material holding them (for example a meteorite) by intense heating or chemical action. To draw a monopole out of pure iron, it is estimated, would require a magnetic field of some 60,000 gauss, which can be achieved with specially designed magnets. A lesser field would suffice to extract monopoles from iron ore or other material not so active magnetically as pure iron.

Detection and identification of a monopole should be easy. Because of its rapid loss of energy as it passed through matter, it would leave a track in a nuclear photographic emulsion so heavy that it could not be confused with the track of any other elementary particle. Where the monopole slowed down and interacted less strongly with electrons in the atoms of the emulsion, its track would taper from heavy to light in a unique way. In a bubble or cloud chamber the monopole would also identify itself by its response to an applied magnetic field, which would be different from that of an electrically charged particle.

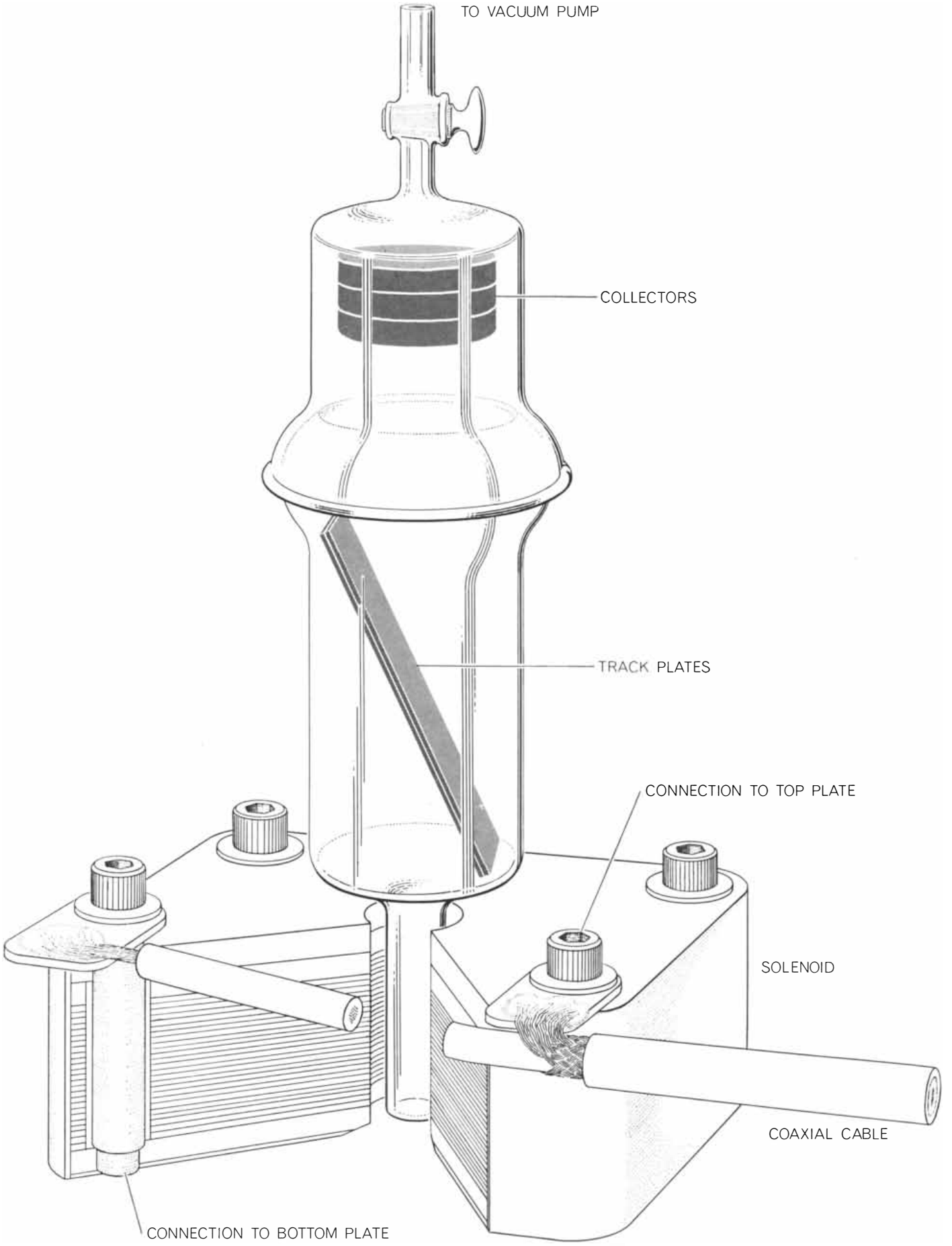
Exactly how a slowed-down monopole would behave in matter is a question not yet fully answered. One suggestion is that in the air it might collect a cluster of oxygen molecules around itself and form a weakly bound "magnetic molecule." The whole globule would then be drawn by the earth's magnetic field until it reached the ground. If it happened to land on a piece of iron, the monopole would be pulled out of its oxygen cluster and sucked into the iron by the self-trapping force that attaches it strongly to iron.

It is possible that monopoles might penetrate atoms and be held close to atomic nuclei by the nuclear magnetism. If so, a monopole would be attached to the nucleus very strongly, so strongly that removing it would be like trying to take a favorite doll away from a child—impossible to do without dragging the child along with it.

Two recent attempts to produce monopoles were made in 1962, with the 30-Bev accelerators at the Brookhaven National Laboratory on Long Island and at CERN (European Organization for Nuclear Research) in Geneva. The Brookhaven experiment was performed under the leadership of Edward M. Purcell of Harvard University. The target bombarded with the accelerator's high-energy proton beam was a thin plate of metal, such as aluminum. Out of such a bombardment comes a spray of par-



BROOKHAVEN EXPERIMENT, performed in 1962, was designed to create monopoles as a result of high-energy nuclear collisions. A beam of protons in the 30-billion-electron-volt accelerator was directed against a thin aluminum target (*left*), producing a spray of various elementary particles. A monopole in the spray (*colored line*) could strike a container of oil (*bottom right*), where it would be slowed to a low speed and then pulled by a magnetic field to the surface of the oil. Once free of the oil, the monopole would be accelerated vertically within a hollow electromagnet, again reaching a high speed. Finally it would fly through a detector, which in this case is a nuclear photographic emulsion (*top right*). No monopoles were detected in the experiment.



MONOPOLE TRAP was used by the author to search for monopoles lodged in iron ore at the surface of the earth. The pulsed electromagnet (a solenoid) exposed about five square centimeters of ore surface to a magnetic field of 60,000 gauss. The pulse, which lasted about one ten-thousandth of a second, could be repeated once per minute. Any monopoles located within a few centimeters of the surface would have been extracted from the ore, accelerated through a pair of nuclear-emulsion plates and then retrapped in iron collectors at the top of the vacuum chamber. No monopoles were detected in 1,000 square centimeters of ore surface.

ticles that is known to include pi mesons (pions), antiprotons and many other products. The experimenters hoped to find a few monopoles in the debris. To trap the monopoles they interposed in the path of the spray a container of hydrocarbon (ordinary pump oil) eight inches thick. According to calculation this was sufficient to stop any monopole created by the beam. An electromagnet (a solenoid) connected to the container was to draw the monopoles, if any, out of the liquid and send them on to a detector. Two kinds of detector were tried. One was a scintillation chamber: a liquid-xenon-filled tube that emits tiny flashes of light when particles pass through it. Here monopoles would be detected by the fact that they would produce more intense scintillations than any electrically charged particles do. The other detector, used in a separate series of trials, was a nuclear emulsion; in this any monopoles would be identified by their exceptionally heavy tracks.

Altogether some six million billion high-energy protons were hurled at the targets in the Brookhaven experiments. Not one monopole was detected. (The proton beams were not "wasted"; their spray of products was being trapped and studied in other experiments at the same time.) A similar search with the CERN accelerator also failed to produce any evidence of monopoles. The energies used in both accelerators were capable of creating monopoles with a mass up to three times that of a proton. On the basis of these experiments it seems safe to say that there are no monopoles below this mass; if they exist at all, they must be more massive.

Recently Goto, Henry H. Kolm and I went searching for such monopoles as possible products of cosmic rays. Our experiments, sponsored by the Massachusetts Institute of Technology National Magnet Laboratory, were performed on exposed iron ore and on meteorites. To an iron ore site in the Adirondack Mountains of New York we took a small but powerful magnet with portable generating equipment that could deliver brief pulses of magnetism as intense as 60,000 gauss. This was sufficient to extract any monopoles trapped in the ore surface. Our equipment was designed to accelerate the extracted monopoles to an energy of more than a billion electron volts, let them fly through a pair of nuclear emulsions and then trap them again in an iron backstop for further study.

The iron ore did not yield any monopoles. Nor did meteorites, although we

subjected the meteoritic samples (lent to us by Harvard's Peabody Museum) to a magnetic field of 100,000 gauss.

So we are once again in a situation such as has confronted physics fairly often in recent years. In 1953 it was a puzzle about the newly discovered strange particles. Although they were readily produced, the heavy strange particles did not decay rapidly into lighter ones. The absence of this decay could not be accounted for by any known law. This led two young physicists, Murray Gell-Mann and Kazuhiko Nishijima, to invent the law of conservation of "strangeness." Since then their law has been verified by many experiments.

In 1962 there was a similar impasse involving the mu meson, or muon. The muon is like the electron in all respects except that it is about 200 times heavier. It was expected that a muon might decay into an electron by emitting a gamma ray photon. Yet no such decay was detected, in spite of the repeated efforts of experimenters. The explanation emerged in 1962 as the result of an experiment conducted with the Brookhaven accelerator by a group of Columbia University physicists. They discovered that muons are associated with a special kind of neutrino, not the same as the one associated with electrons, a fact that provides a basis for understanding the impossibility of the muon's gamma decay into an electron. Muons together with their neutrinos, it appears, are governed by a law of conservation of their total number, so that one member of the muon family cannot vanish unless another appears [see "The Two-Neutrino Experiment," by Leon M. Lederman; SCIENTIFIC AMERICAN, March].

In the same way the apparent nonexistence of magnetic particles now presents physicists with a paradox they cannot drop until they have found an explanation. It may seem unreasonable that the nonoccurrence of something in nature should excite investigators as much as or even more than what does occur. Yet that is exactly the situation in present-day physics. Basically it has come about as a result of the two fundamental 20th-century advances in physical theory: quantum mechanics and the theory of relativity.

Quantum mechanics has contributed to the new view by bringing to light the probabilistic character of events at the level of elementary particles. Experiments performed each time in identically the same way may produce different results, each with its own probability. For

example, an isolated K meson may decay in more than half a dozen different ways: it may break down spontaneously into a muon and a neutrino; into two pions; into three pions; into a pion, an electron and a neutrino, or into certain other combinations of products. Every conceivable result of a given experiment will occur with some probability (however small) unless it is prohibited by a physical law. In that case, of course, its probability is zero. In the example just cited we are sure that the probability of the K meson decaying into an electron and a muon is zero, because this is barred by a known law of prohibition (which has been verified in other ways).

Obviously the events in nature that are forbidden hold a special interest for the physicist. Their nonoccurrence is particularly provocative because of the possibilities they offer for discovering new laws of nature.

The theory of relativity has contributed to the new trend in thinking by focusing attention on the principles of symmetry and conservation; the special theory itself is founded on the symmetry of space-time. In all aspects of theoretical physics symmetry principles and the conservation laws are coming more and more to be regarded as the most powerful guides to the study of nature [see "The Conservation Laws of Physics," by Gerald Feinberg and Maurice Goldhaber; SCIENTIFIC AMERICAN, October]. This naturally places great importance on forbidden processes, because in its impact on particle transformations a conservation law acts primarily as a law of prohibition.

All this of course does not mean that physicists are concerned about any nonoccurrence in nature that the mind might dream up; they are not, for instance, hunting for laws to account for the fact that the earth has only one moon or that Venus has no moons at all. But the apparent absence of magnetic monopoles is worrisome—even more worrisome now than when Dirac first predicted them—and for good reason. We need not be disturbed by the plain fact that the world we live in is constructed without monopoles, only of electrically charged (and uncharged) particles. What concerns the physicist is that, in defiance of symmetry and all the known laws, no magnetic particle so far has been created or found anywhere. It can safely be predicted that physicists will go on searching until they either find magnetic monopoles or discover a good reason for their nonexistence.

The Aerial Migration of Insects

A few insects migrate seasonally over great distances rather like birds. Recently it has been learned that most other species also migrate by simply beating their wings while the wind carries them

by C. G. Johnson

The literature of entomology, beginning with the Bible, records many astonishing accounts of the migration behavior of insects. Locusts in the desert, mosquitoes in the Arctic and the Tropics and butterflies, moths, beetles, bugs and dragonflies almost everywhere have been seen in sudden mass flights, often involving millions of insects all traveling in the same general direction at the same time. Particularly in the case of the desert locust of Africa and the monarch butterfly of North America—insects that can make seasonal flights of more than 2,000 miles—this behavior has been likened to that of migratory birds. The spectacular character of these flights has invited explanation in terms of a migration instinct that would cause the individual insects to congregate in response to overcrowding or to some other unfavorable change in the environment, and has inspired speculation about sensory mechanisms that would enable the individuals to orient themselves in space, navigate and hold course toward distant destinations. Migratory flight thus more or less elaborately defined became one hallmark of a few species and much controversy has flamed from efforts to distinguish "true" migrators from mere drifters whose populations were dispersed by the wind.

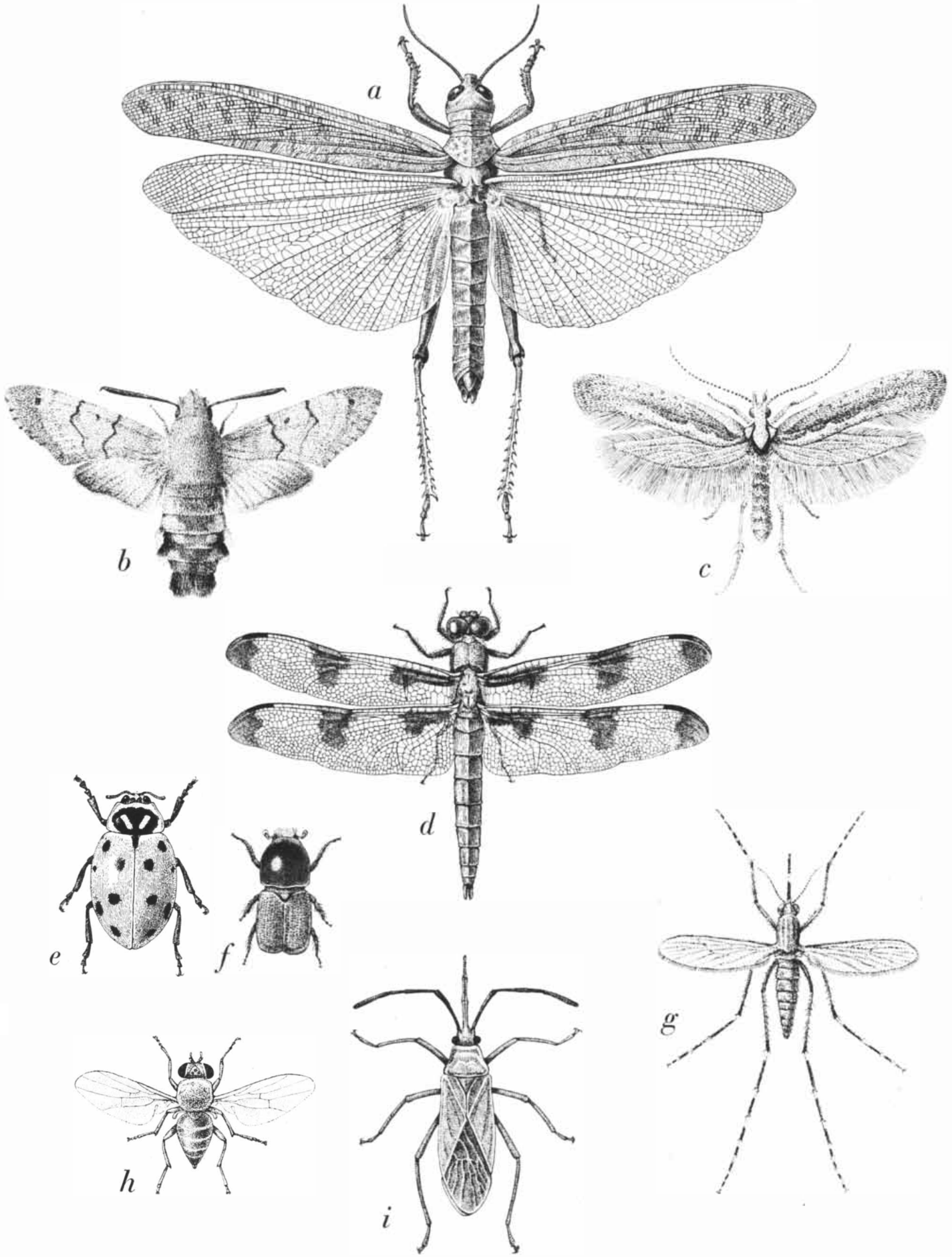
It was closer acquaintance with the desert locust—established with the aid of photographic film interpreted by R. C. Rainey and Z. V. Waloff of the Anti-Locust Research Centre in London—that helped to set modern studies of insect migration on an entirely new and more fruitful course. Locusts are insect migrants par excellence. Vigorous fliers, they give an observer the strong subjective impression of concerted, purposeful progress in a direction under their own control. The camera too will show whole groups of insects headed in one direction. In successive images registered on the same film, however, individuals headed in one direction are seen to be carried in another direction by the wind. Within a swarm there will be many groups of similarly oriented insects flying in different directions, but the swarm as a whole will move with the wind, albeit more slowly.

The discovery that locust swarms are wind-borne eliminated the need to postulate mechanisms of orientation and navigation as essential features of insect migration. What is common to all migrants, as J. D. Kennedy of the Agricultural Research Council in Cambridge, England, has insisted, is an intense "locomotory drive" that sets the insect off on a relatively prolonged and undistracted flight compared with other kinds of flight associated with egg-laying or feeding. The drive arises from the internal physiology of the individual in a way not yet understood, but it is associated somehow, at least in females, with sexual immaturity. With the behavior of individuals synchronized by the simultaneity of their development, the migratory flight seems to have evolved as an adaptation designed primarily to relinquish habitats destined to become unsuitable and to secure new ones. This often leads to dispersal of the species. In this view migratory behavior appears as a key phase in the life history not of merely a few species of insects but of a large proportion of winged species. To the universal cycle of birth, reproduction and death must be added the process of migration or dispersal, with the winged adult as the essential, mobile element in the system.

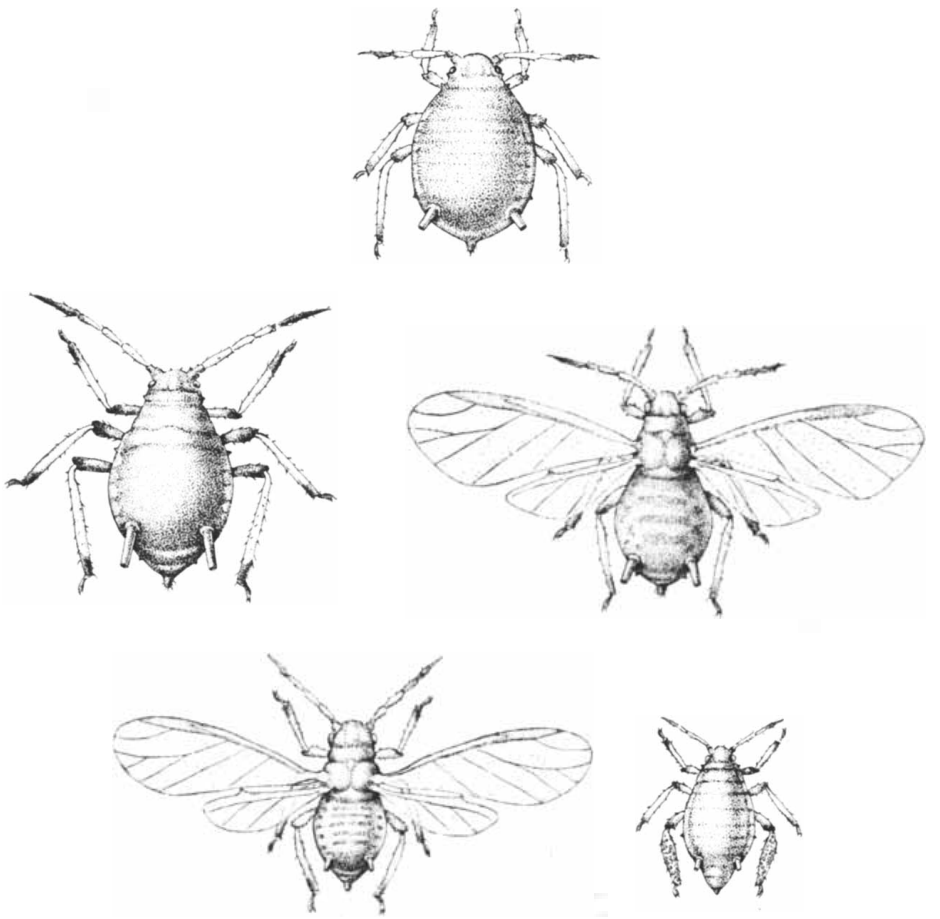
For an understanding of migratory behavior in a generalized form, the lowly plant-sucking aphid provides a most typical and instructive example. Aphids move on the wind. In spring and summer some species called the migratory aphids feed and deposit their larvae on herbs (these aphids are viviparous, delivering small larvae rather than eggs), and in fall and winter they transfer their activities to woody shrubs. These insects have been under intensive study by our group at the Rothamsted Experimental Station and by other workers at the Agricultural Research Council in Cambridge.

At the end of the larval stage the aphid molts into either a wingless or a winged adult [*see top illustration on page 134*]. The wingless form stays where it is, but every new winged adult, after waiting for some hours until its cuticle hardens, takes off on a strong vertical flight, attracted by the blue light of the sky. It is caught by the wind and, still flying actively, may be carried hundreds or thousands of feet aloft and often many miles overland. Typically the locomotory drive begins to fail within an hour or two and the aphid starts its fortuitous descent. If the plant on which it lands is one to which it is adapted, the insect feeds for the first time since leaving its birthplace. Then it may begin to deposit larvae. If the flight has been short or if the plant is unsuitable, the aphid may take off again. It may make several flights and cover many miles in the few days before it is finally grounded by the dissolution of its wing muscles. The migratory flight thus spreads the species to new habitats and effects the seasonal transfer of the population from green herbs to woody shrubs, even though the direction and distance of travel depend in part on the wind.

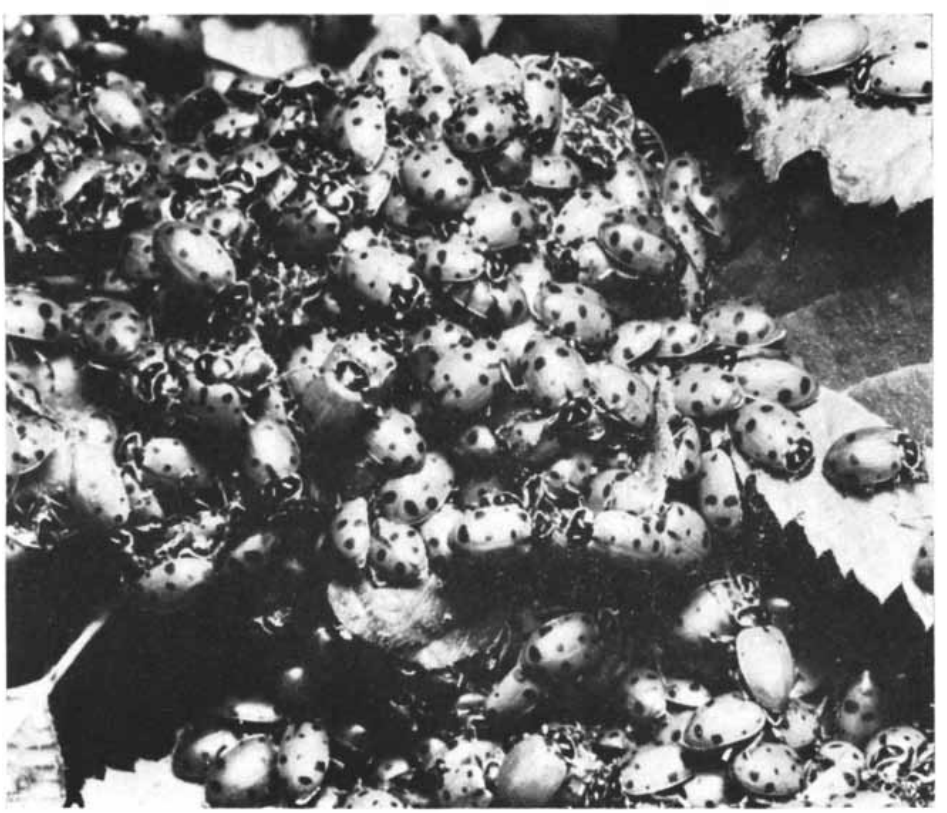
All other migrants share some elements of this behavioral routine with the aphid. Characteristically, most insects make their migratory flight soon after completion of their metamorphosis and



MIGRATORY INSECTS include (*a*) desert locust, *Schistocerca gregaria*, (*b*) hummingbird hawk moth, *Macroglossa stellatarum*, (*c*) diamondback moth, *Plutella maculipennis*, (*d*) dragonfly, *Libellula pulchella*, (*e*) ladybird beetle, *Hippodamia convergens*, (*f*) elm bark beetle, *Scolytus multistriatus*, (*g*) mosquito, *Aëdes taeniorhynchus*, (*h*) frit fly, *Oscinella frit*, and (*i*) tropical cotton stainer, *Dysdercus suturellus*. Although these insects are not drawn to exact scale, they are shown in their approximate relative sizes.



APHIS FABAE, a migratory species of aphid, occurs in many forms during a year. The five shown here are the fundatrix (*top*), which hatches in spring from an overwintering egg and founds a new line; a wingless female that gives live birth to new larvae (*center left*); a winged female that migrates and gives live birth (*center right*); a male (*bottom left*) that mates with an egg-laying female (*bottom right*). Species changes host plants with season.

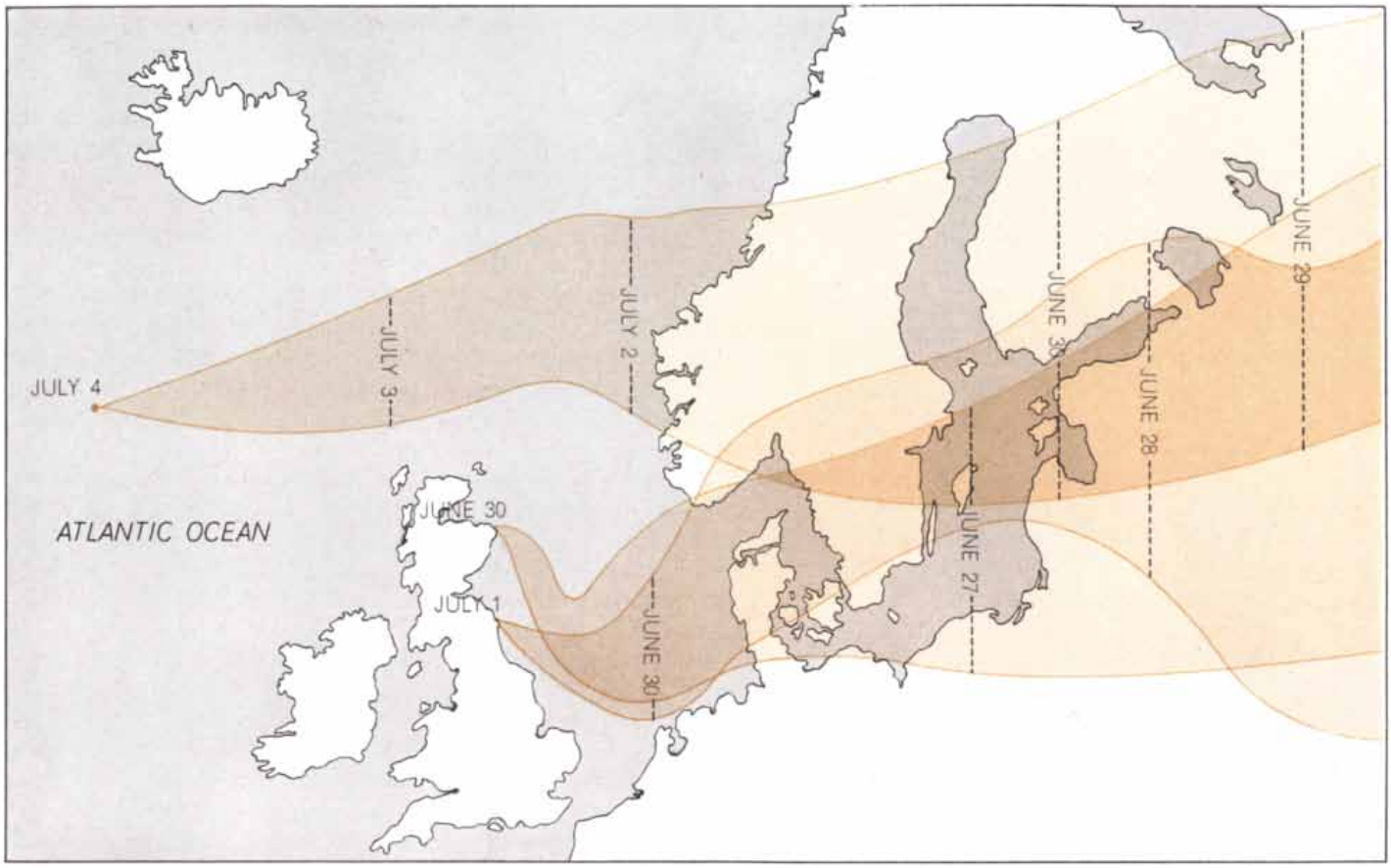


LADYBIRD BEETLE SWARM, wintering in California, "clumps" on bushes in state of semihibernation. Such beetles live two or three years and probably migrate several times.

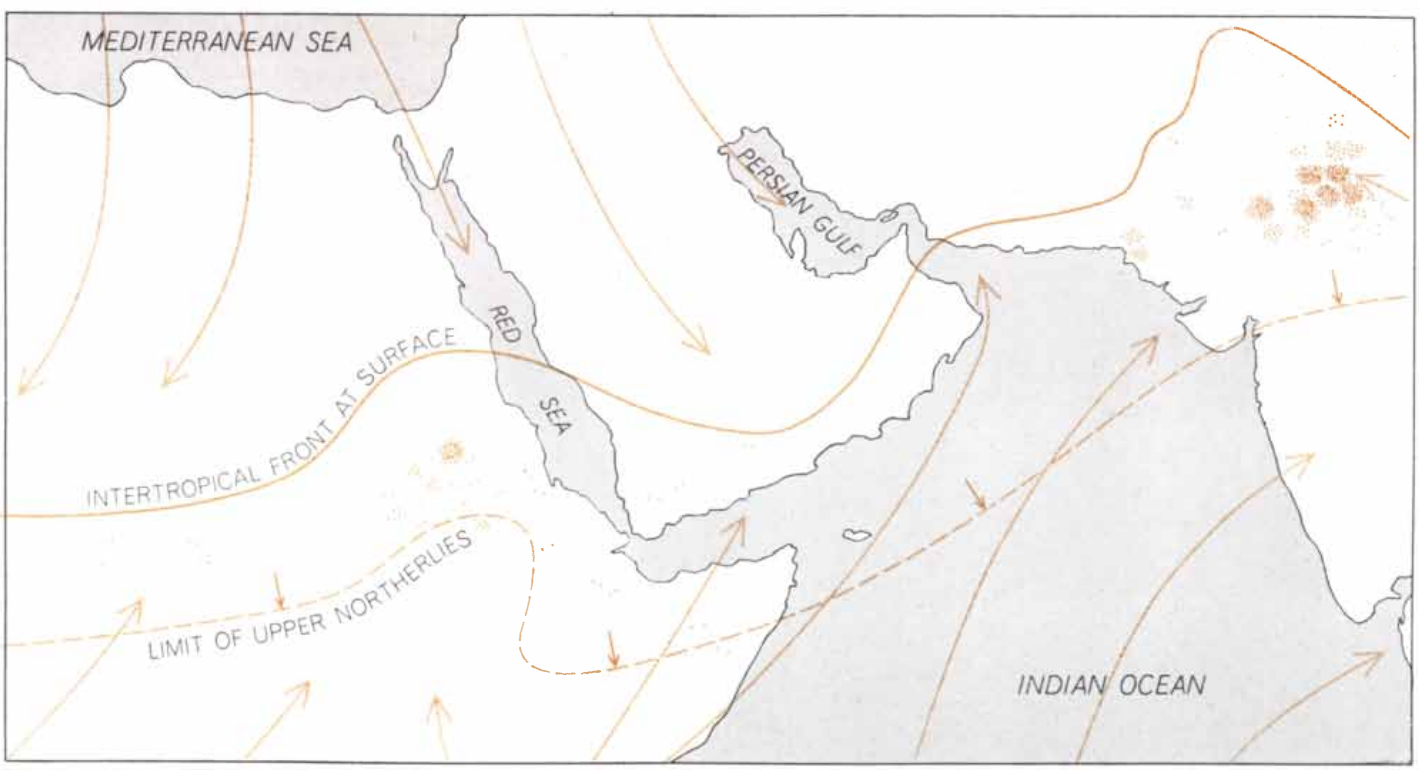
before they enter the reproductive phase of their life history. The mosquito *Aëdes taeniorhynchus,* studied in Florida by Maurice W. Provost, E. T. Nielsen and James S. Haeger, begins its migration with its first flight after emergence and may travel up to 20 miles in a direction strongly influenced by the wind. The butterfly *Ascia monuste*, also observed in Florida, makes a few preliminary feeding flights, but these gradually lengthen into a prolonged migratory flight along the coast in the shelter of the dunes. Although the individual insect normally migrates only during the first 24 hours of adult life, it may travel nearly 100 miles. Thereafter it settles down and makes many short local feeding and egg-depositing flights. The literature contains numerous reports of early migratory flights in other orders, including dragonflies and beetles. Of equal importance, species not usually regarded as migrants have been observed to do the same thing. Winged ants and termites make an intense first flight in the adult form. Although short in duration, these flights enable them to establish new colonies at some distance from their natal habitat.

Other insects, such as some scolytid beetles, hibernate after they emerge and, still sexually immature, migrate months later. Many insects, including some moths, thrips and beetles, migrate first to sites where they hibernate and then migrate again at the end of hibernation. Most adult insects live for less than a year, some for only a few days, but certain ladybird beetles live up to two or three years. They are believed to undertake several migratory or dispersal flights during their lifetime and not simply one flight after emergence. These are some of the insects that have attracted attention by their habit of migrating simultaneously and massing together during hibernation and therefore prior to remigration.

In their migratory flight aphids do not excite as much wonder as the same behavior does in the case of larger insects. They appear against the sky as tiny elements in the aerial plankton, part of the busy swarm of "gnats" that may lend visual discomfort to the heat of a summer's day. At Rothamsted we have developed suction traps to plot the diurnal rise and fall of the aphid population in the air. Suspended at measured heights from steel towers or from barrage balloons, these traps suck in the air and collect the insects in a tube. Disks are dropped into the collecting tube at preset intervals in order to divide the catch



MASS MIGRATIONS of diamondback moth were observed June 30 and July 1, 1958, at two points on the northern coast of Britain, and on July 4, 1958, by a weather ship at sea, when thousands of tiny moths appeared on the bridge. The colored shading marks the air masses that carried the migrating moths. Dates indicate approximate positions of these air masses on days before observations of migrations. Presumably the moths came from the region where the three air masses overlap. Moths observed at sea had evidently traveled 1,000 miles from the coast of Norway, beating their wings all the time. If they reached America, they flew for two more days.



INTERTROPICAL CONVERGENCE ZONE, where winds from north meet those from south (*colored arrows*), producing rain, provides moisture that enables locusts to breed. The rain also brings growth of vegetation, on which locust larvae can feed. Thus, travel with the wind serves ecological needs. Each colored dot denotes a report of a locust swarm between July 12 and July 31, 1950.

into fractions over periods of time. A count of the insects on each disk reveals the shifts and changes in the concentration of the air-borne population of aphids (and other insects) throughout the day.

By this technique we have found that aphid flights have a daily rhythm that frequently shows two peaks. We have also established the underlying mechanism of this cycle and thereby the explanation of the massing of the aphids in their migratory flight. The aphids that molt from the larval stage during the night are inhibited from flying by the cold and darkness. When the light and temperature rise above flight thresholds in the morning, the new adults that have accumulated all take off at the same time. Their exodus is recorded by our suction traps as a midmorning peak. Meanwhile the individuals whose maturation has been slowed by the low temperatures of the last hours before dawn mature more quickly as the day grows warmer. Their simultaneous departure yields another peak of migration in the early afternoon. By evening the fall in temperature and intensity of light from the sky brings a corresponding drop in the number of air-borne aphids. Since the temperature threshold for maturation is lower than that for flight, however, the next morning's crop of aphids now begins to accumulate. Trevor Lewis of Rothamsted has found that the mass migrations of another insect, the thrip, also occur in the warmup after a period of low temperature. Thus many mass insect flights must be regarded as gushes of newly emerged and waiting winged adults, released by a rise in temperature.

These observations can be matched to the recorded behavior of many classical and well-recognized migrants. As long ago as 1880 S. B. J. Skertchly noted an early-morning emergence of thousands of painted butterflies (*Vanessa cardui*); within an hour they all flew off together in the same direction. It is now known that such migrants as locusts, monarch butterflies, *Aëdes* and *Ascia* similarly emerge together at their breeding sites and then depart on the simultaneous flight that is featured in the literature on insect migration. The analogy so often drawn with bird migration in these cases fails to take into account the fact that all the individuals are of the same age; in contrast, flocks of birds may contain adults of all ages, and they may have congregated, unlike insects, from different places.

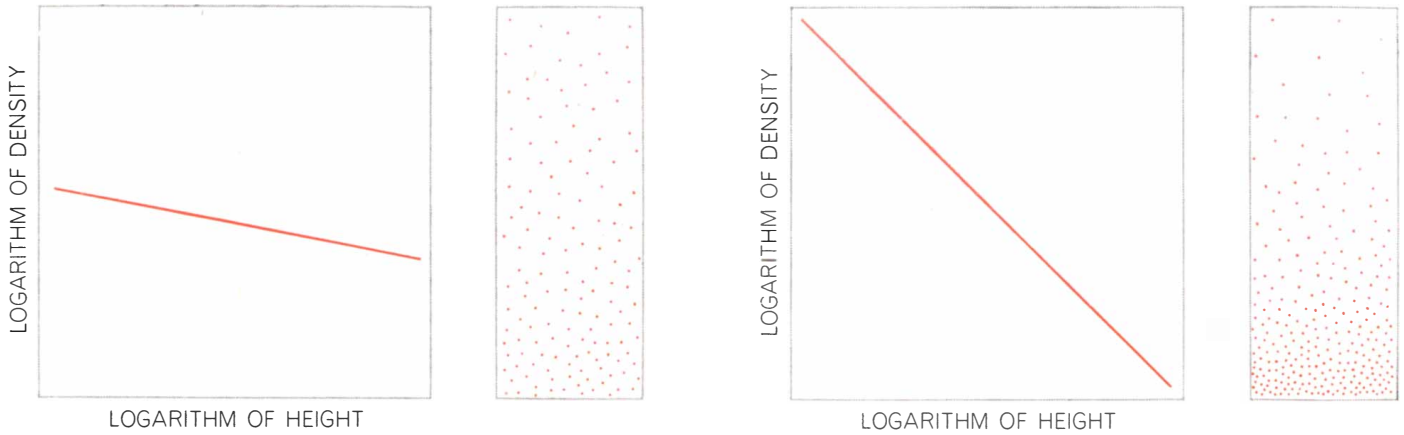
The strength and direction of the wind play an important but not necessarily crucial role in determining how far wind-borne migrants will go. The contribution of the insect—the duration of its locomotory drive—constitutes an equally important variable, for most insects must beat their wings if they are not to fall out of the air. The desert locust, geared to travel great distances, refueling as it goes, spends most of its adult life migrating, after which it lays eggs and dies. In contrast, termites migrate for only a few minutes but spend months reproducing. The travel of aphids (at least of those with temporary wing muscles) is limited by their initial fuel (fat) supply; they cannot refuel during migration.

In laboratory studies of flight capacity some insects turn in extraordinary performances. For example, although aphids are weak fliers, A. J. Cockburn of Rothamsted has shown that some can continue to beat their wings for 16 hours nonstop, until all their fuel is exhausted. These intrinsic performances, however, bear little relation to distances traveled in nature. An analysis of daily flight rhythms of aphids at different altitudes at Cardington in England shows that the average flight lasts for only one to three hours. In elegant flight-chamber experiments by J. S. Kennedy, aphids permitted to fly freely stay up for about the same length of time. Height-density studies of aphids and other insects reveal that the general aerial population, at least over Britain, resembles a daily explosion, with millions of insects thrown up, often to great heights, followed by an almost complete settling-out by nightfall.

In contrast with the short, daylight-only flights of the insects in the aerial plankton over Britain, desert locusts have been known to travel across the sea for 24 to 60 hours, going as many as 1,400 miles in one hop. This greatly exceeds their records for tethered flights in the laboratory. R. A. French and J. H. White have reported an observation by a ship 1,000 miles at sea of millions of tiny diamondback moths. Apparently they had been going for at least two days nonstop [*see top illustration on preceding page*], carried irresistibly by the wind at 20 miles per hour, beating their wings all the time in order to stay up.

The distance traveled overland does not necessarily reflect the duration of the insects' flight for another reason: the air currents may carry them upward as well as horizontally. In vigorous convection currents locusts form towering cumuliform swarms thousands of feet high. When convection is low, the swarms become flat and remain near the ground. As would be expected, smaller insects are even more sensitive to air currents. In still, stable air crowds concentrate near the ground; this accounts for dense swarms observed at eye level on quiet summer evenings. In rising currents they go up for thousands of feet. There is an approximately linear inverse relation between the logarithms of the density of the air-borne population and altitude, as

DESERT LOCUSTS in this swarm covered 400 square miles of Ethiopia in October, 1958. Locusts are a form of grasshopper. They travel in swarms and decimate vegetation as they go.



INSECT DENSITY varies with height according to turbulence of air. Rising currents carry insects up and slope of graph of logarithm of density plotted against logarithm of height is small (*left*). Still air produces a steep slope (*right*) because the insects remain near the ground. The colored dots in the accompanying panels represent insects and illustrate the density associated with each graph.

would be expected in plotting the turbulent diffusion of small particles. The slope of the curve, when density is plotted against height, correlates well with the degree of atmospheric stability [*see illustration above*] and makes it possible to calculate from measurements of air currents the density of insects in particular altitude zones. These calculations show, for example, that in Britain in the middle of a typical summer day half of the population of frit flies (*Oscinella frit*, a cereal pest hitherto thought to fly only near the crop) is above 1,300 feet!

Travel in air currents is haphazard and many insects are lost in unfavorable places. Perhaps only a few reach a good site, but these are enough to perpetuate the species. Even this seemingly fortuitous system of movement can be highly adapted for survival, as Rainey has shown for the desert locust. Their migrations are associated with the movement of the convective air currents of the intertropical convergence zone, a region in which winds from the north and from the south converge, tend to ascend and so produce rain. As this zone moves across Africa and the Middle East with the change of seasons, the winds coming into it from the desert carry locusts from dry areas into wet areas [*see bottom illustration on page 135*]. Locust eggs must have moisture to survive and the larvae need vegetation when they hatch. Thus the apparent haphazard movements of the swarms are geared to their basic ecological requirements.

In all other species it can be anticipated that migratory behavior will prove to be correspondingly adapted to placing them in the right habitat at the right time in their life cycles. Some insects, such as the monarch butterfly, migrate long distances to overwintering sites and so escape adverse seasonal changes in climate and food. The migratory aphid, by moving a short distance from herbs to woody plants as the season changes, is doing the same thing. Adults of other species merely scatter in successive generations, without a regular change of host or complete change of habitat. In every case, however, the species engages in migration or adaptive dispersal (sometimes in both, since some classical migrants disperse en route) in order to relinquish a habitat that would eventually become untenable. T. R. E. Southwood of the Imperial College of Science and Technology in London has recently shown that species occurring in relatively temporary habitats produce more migrant adults than species living in more permanent situations. Many migratory dragonflies, for example, live in ponds that dry up periodically, whereas nonmigratory species tend to inhabit rivers. Agricultural pests are wide-ranging and mobile because nearly all crops are temporary, annual plants. Hence pests are here today, gone tomorrow and where they come from often seems to be a mystery. It is not so mysterious, however, when one realizes that millions of individual insects of the aerial plankton rain down almost everywhere on the earth day after day.

Whereas adaptive advantages of migration are found in study of the ecological relations of each species, the cause of the behavior must be sought in the individual insects. In some cases a currently unfavorable environment induces the insects to leave; froghoppers have been known to move from cut vegetation and locusts have been thought to respond to dryness. Nevertheless, most mass migrations do not seem to be in direct response to any current adversity. Monarch butterflies, ladybird beetles, hover flies, noctuid moths and other species that go into winter quarters begin to migrate long before cold weather sets in. Neither food shortage nor "intolerable overcrowding" are evident to the human observer at the time of departure of aphids, *Ascia* and many others. The migration, therefore, usually comes in advance of any obvious change for the worse in living conditions.

The recognition that many mass migrations are made by fresh adults soon after emergence suggests that the cause be sought in the physiology and developmental history of the individual. It is well known that many insects are polymorphic: the adults of the same species differ in appearance either because of difference in sex (sexual polymorphism) or in structure, as in the various castes in a colony of termites or ants. Locusts reared in crowds produce adults of the phase *gregaria*, which are migrants and differ structurally to some extent from individuals reared in isolation, the phase *solitaria*. In migratory aphids the polymorphism takes the form of winged or wingless adults (alary polymorphism).

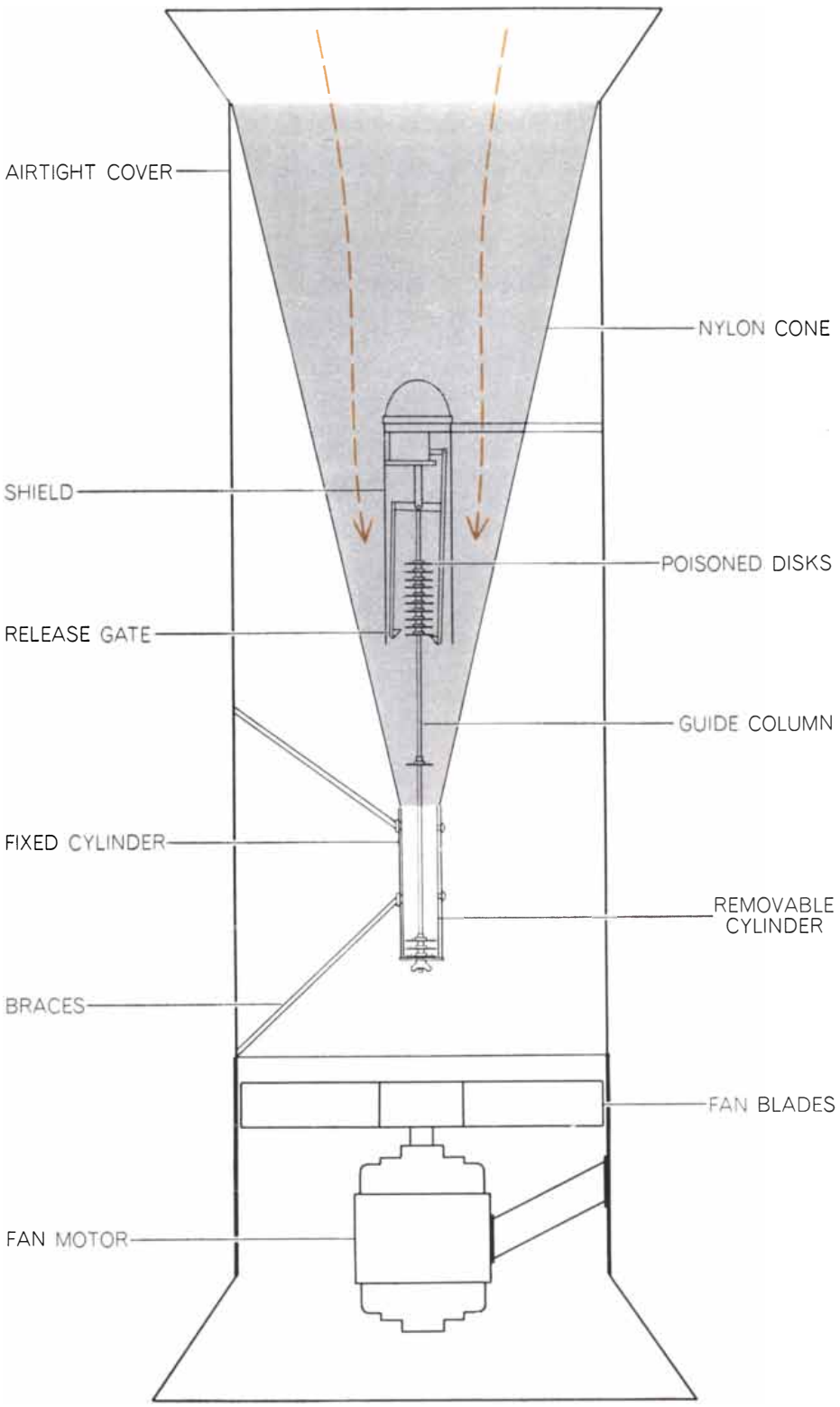
It has been observed that a small aphid population produces few winged adults, but as the population becomes large and dense the proportion with wings increases. This may be caused in some unknown manner by the increase in amount of direct contact between individuals or by other factors. Perhaps change in the quantity or quality of food influences development one way or the other. Be this as it may, winged aphids all migrate; as far as is known, none stay behind. Migration is obligatory once the winged form appears.

Many insects, however, produce only

winged adults; then it is the proportion that migrates that varies from year to year, and some generations may have no migrants. This has been another mystery of migration. Yet perhaps the mystery is no deeper than that associated with aphid migrations. It is certainly not unreasonable to assume that if aphids produced winged individuals in response to the environmental pressures that induce migration, the insects that always produce winged adults can generate some individuals with a "behavioral polymorphism" that endows them with the locomotory drive necessary to migration. These polymorphs would appear when the ecological situation of the species demanded it, just as the winged aphids appear.

The principal physiological clue to the triggering of the locomotory drive is the finding that it is associated with delay in the development of ovaries and of the endocrines that control ovary development. Most migratory flights are made by sexually immature females. Among migratory insects it is always the females that engage in migration, because it is they that spread the species. Males present different and distinct problems since even in some migratory species the males never migrate.

It is known that several factors, such as crowding, a short day or poor food (particularly protein deficiency) all delay development of the ovaries. It is also known that many insects cease migrating when ovaries mature. It should be possible, therefore, to make experimental tests of whether or not changes in such factors as length of day, food and temperature produce the postulated behavioral polymorphism. If they do, this would bring us back to the old idea that migration and adaptive dispersal are induced by overcrowding, changing seasons or poor food, but that the mechanism is in the biochemical rather than the sensory responses of the individual insect.



SEGREGATING SUCTION TRAP pulls in air and insects (*arrows*). **At preset intervals, poisoned disks drop, dividing catch. This gives a direct measure of aerial density of insects at a given time. Various types of trap are suspended from posts, towers and balloons.**

Still awaiting investigation by entomologists are some of the real puzzles of nature that surround such highly specialized migrants as the monarch butterfly. How, for example, do vast numbers of different species make their way seasonally along well-defined routes, often in mountain passes? What are the factors that determine the orientation of migrants that fly at a certain height when it is relatively calm and so control their own direction?

It will be difficult to find the means of attacking such problems. On the other hand, recent progress in the study of migratory behavior in insects has opened up equally interesting new questions to investigation. It remains to be determined, for example, if there is any general connection between the length of the period before egg-laying begins and the tendency to undistracted migration in different species. We must study the effect of length of day, larval crowding and quantity and quality of food on the length of the migratory period and also find out how these factors relate to the attraction of the sky that takes the migrating insect into the windy air. Finally, we should like to know how many species are in the aerial plankton by accident and how many by adaptation. I suspect that far more are there by adaptation than is commonly believed.

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MATHEMATICAL GAMES

How to use the odd-even check for tricks and problem-solving

by Martin Gardner

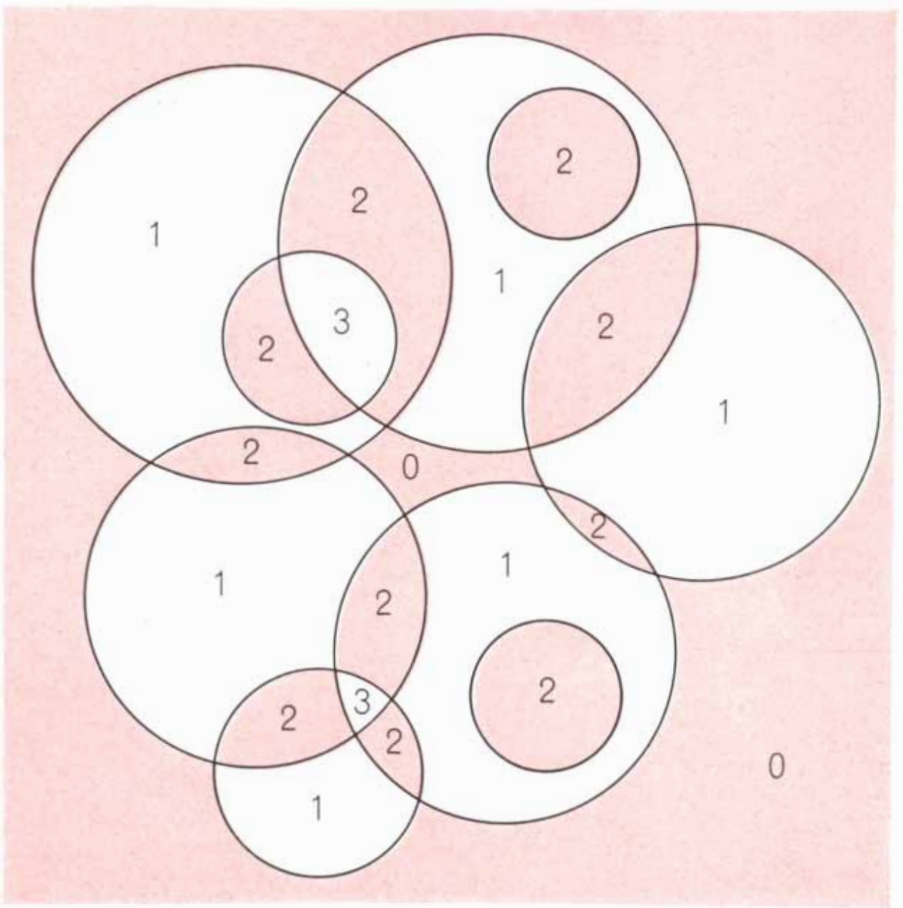
She took me to her elfin grot,
And there she wept and sigh'd full sore,
And there I shut her wild, wild eyes
With kisses four.

"Why four kisses, you will say . . ." wrote John Keats in a letter, commenting on the above stanza from his well-known poem *La Belle Dame sans Merci.* "I was obliged to choose an even number that both eyes might have fair play. . . . I think two a piece quite sufficient. Suppose I had seven; there would have been three and a half a piece—a very awkward affair."

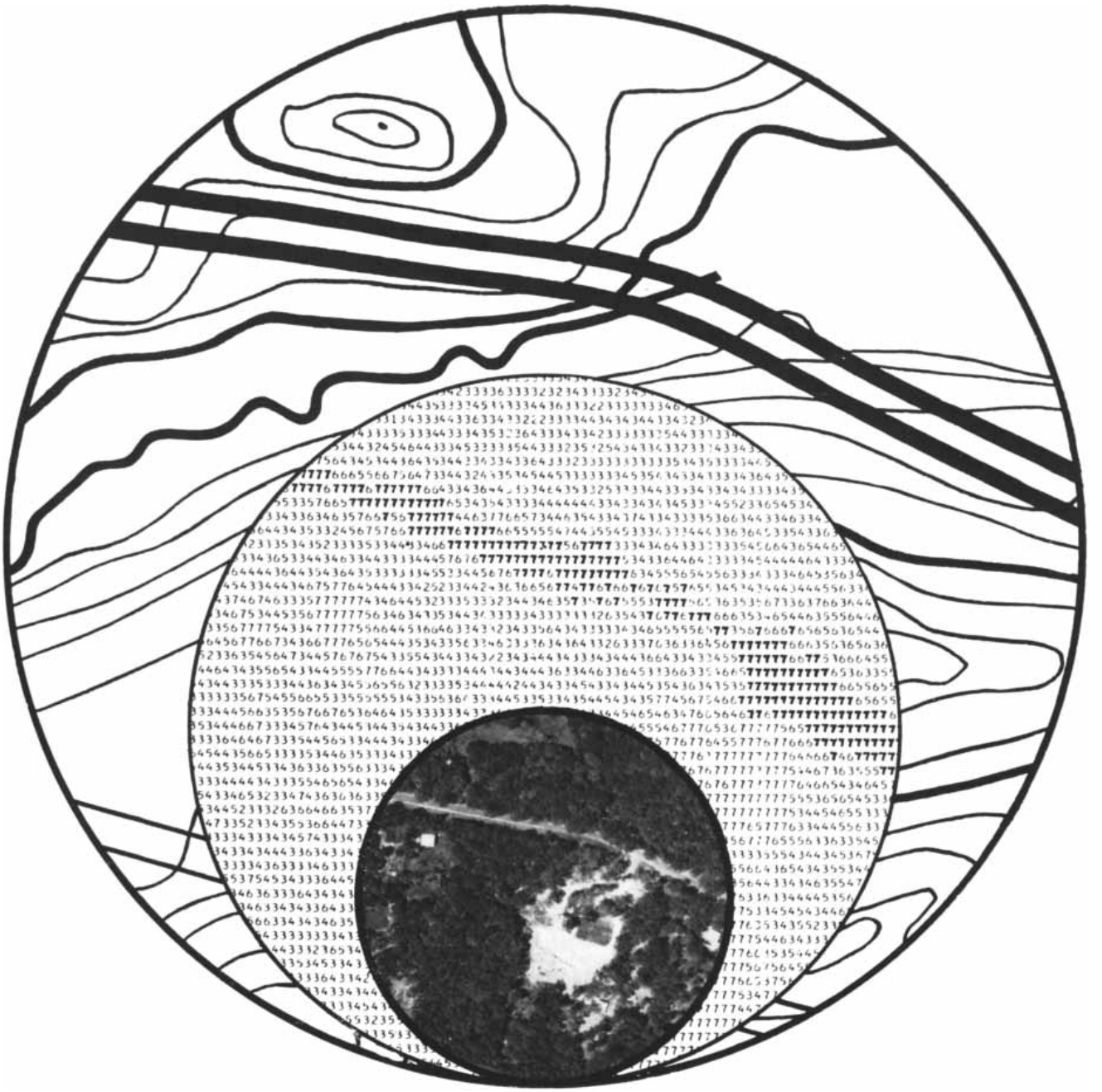
If we had been told that Keats's pale knight kissed the lady's eyes 37 times, would it be necessary to make an empirical test to determine if each eye could receive the same number of kisses? No, 37 is an odd number, not evenly divisible by 2, so that we know at once that one eye must have been kissed at least one more time than the other.

An old joke along similar lines tells of a graduate student in mathematics who was on a spring outing with his girl. She plucked a daisy and began to pull off the petals while she recited "He loves me, he loves me not . . ."

"You are really going to a great deal of unnecessary trouble," said the young



A two-color map theorem



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man. "All you have to do is count the petals. If the total is even, the answer is negative. If it is odd, the answer is affirmative."

We have here two trivial applications of what mathematicians sometimes call a parity check. It is one of the most powerful tools in mathematics. Whenever a problem involves odd and even, or two mutually exclusive sets that can be identified with odd and even numbers, a parity check often furnishes a quick, elegant proof for something that might otherwise be extremely difficult to establish.

The classic instance in number theory is provided by Euclid's proof, which may go back to the Pythagoreans, that the square root of 2 cannot be expressed as a common fraction (a fraction with an integer above and an integer below the line). Since the diagonal of a unit square has a length equal to the square root of 2, this means that no ruler, however finely graduated, that accurately measures the side of the square will accurately measure the diagonal.

The proof is easy to follow. Assume that there *is* such a common fraction, n/m, which has been reduced to its lowest terms. Since the square of this fraction is 2, we can write the equation

$$(1) \qquad 2 = n^2/m^2$$

and then rearrange the terms to

$$(2) \qquad n^2 = 2m^2 .$$

The right side of this equality is an even number (because it is a multiple of 2); therefore the left side, n^2, is even. Only an even number gives an even product when multiplied by itself; therefore n also is even. We turn our attention to m. Is it odd or even? It cannot be even because n and m would then both be even and we would be able to simplify the fraction n/m by dividing both terms by 2. This, however, would contradict our original assumption that n/m had already been reduced to its lowest terms. We must assume, then, that m is odd.

Since n is even, we can express n in the form $2a$, letting a stand for another integer. Substituting $2a$ for n in equation (2), we have

$$(3) \qquad 4a^2 = 2m^2 ,$$

which reduces to

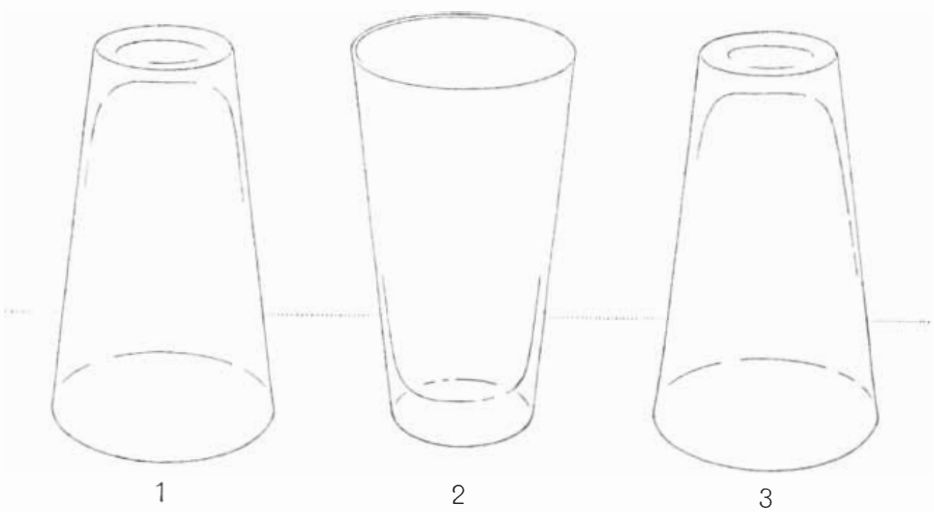
$$(4) \qquad 2a^2 = m^2 .$$

By the same argument used above, m cannot be odd because its square equals the even number expressed by the left side of the equation. We previously saw that m cannot be even. Now we see that it also cannot be odd. Since every integer must be even or odd, m cannot be an integer. Our initial assumption must be false; there is no common fraction n/m that is the square root of 2. The number we seek is irrational, a term that reflects the shock of the discovery of such numbers by the ancient Greeks. Note also that equation (2) has been shown to be one that cannot be satisfied by integers. In other words, no square integer is exactly twice another square integer. This too is an important theorem that would be hard to prove without the astonishing power of a simple parity check.

In every branch of mathematics an odd-even check often supplies an efficient, short-cut proof. The following problem in topology is typical. Draw as many circles as you like, of any size, wherever you wish on a sheet of paper. Can such a "map" always be colored with two colors in such a way that no two regions with a common border are the same color? One way to prove that the answer is yes (for a different way see this department for September, 1960) is to consider any pair of adjacent regions, A and B. They will be divided by an arc of a circle, which we will call X. One of the regions will be inside X, the other outside. Aside from X, A and B will be inside either no circles or the same number of circles; therefore one of the two regions is sure to be inside one more circle than the other. If we label each region with the number of circles it is within [*see illustration on page 140*], one of every pair of adjacent regions is sure to be even and its partner is sure to be odd. We color the even-numbered regions one color and the odd regions another color and the job is done.

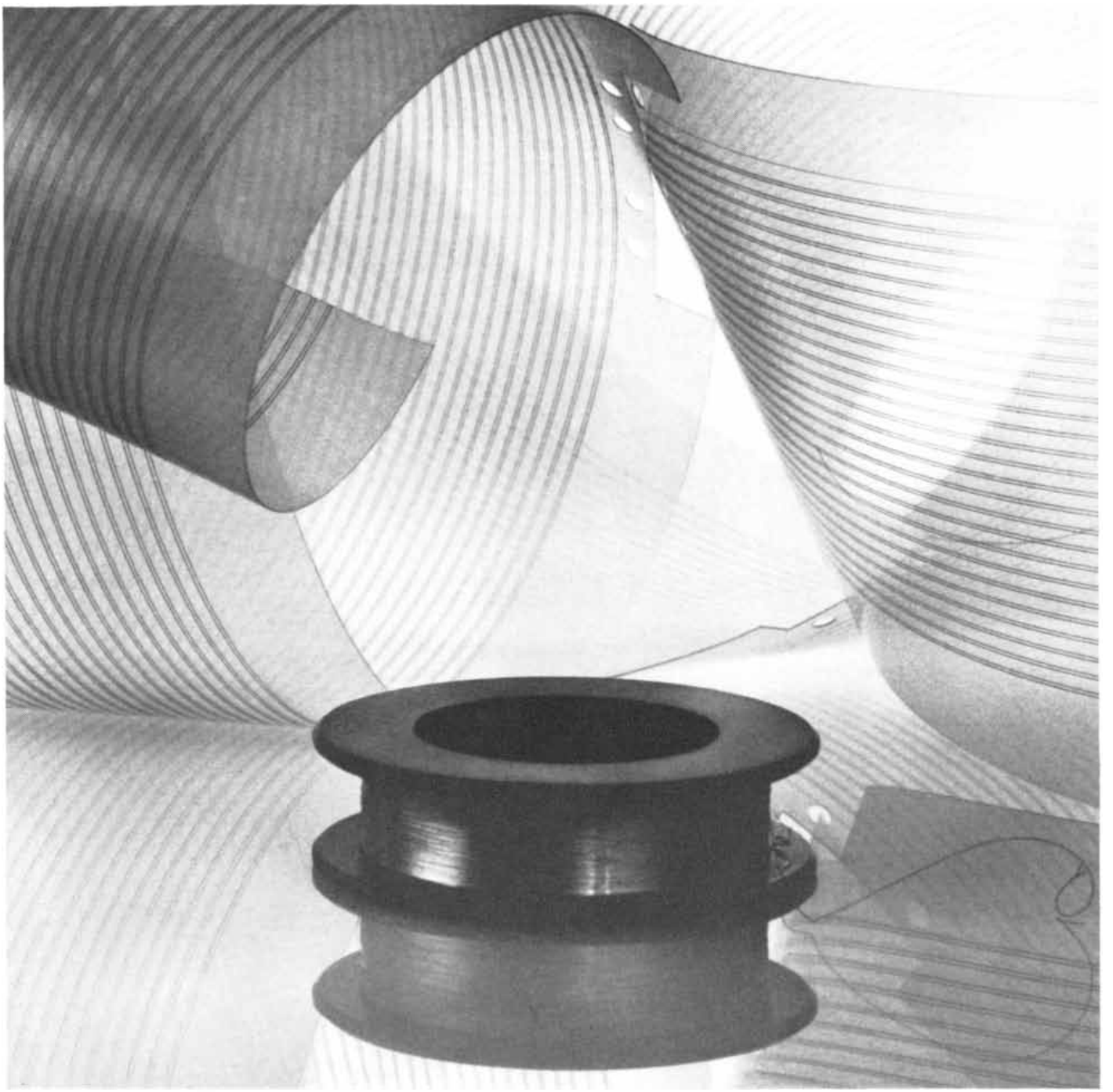
In the physical world things frequently have a mathematical pattern to which the familiar properties of odd and even numbers apply. An amusing instance is supplied by a parlor trick with three empty drinking glasses. Place the glasses as shown in the illustration on this page. The puzzle, you explain to your audience, is to turn over two glasses simultaneously, one with each hand, and in three such "moves" bring all the glasses upright. To demonstrate: Turn glasses *1* and *2*, then *1* and *3*, then *1* and *2* again. All three glasses will then be right side up. Now comes the sneaky part. Casually invert the center glass and invite someone to try. Few people will notice that the starting position is no longer the same as before. A simple parity check shows that from this new position the problem cannot be solved in *any* number of moves.

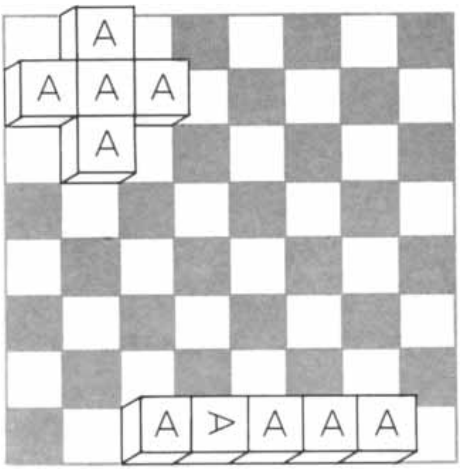
The proof is as follows. Whenever an even number of glasses (zero or two) are upright, we say that the "system" has even parity. When an odd number are upright, the system has odd parity. It is easy to see that turning any two glasses cannot change the system's parity. No amount of turning in pairs will convert the initial state of even parity (two up) to the desired state of odd parity (three up). If a spectator follows your moves exactly, he will bring all the glasses *down*. Should he accidentally set them up properly for a new attempt, step in quickly, make another fast demonstration of how it is done and



Setup for the glass trick

TWISTOR. The new computer memory component known as the twistor is a hair-like copper wire on which is wound a spiral of molybdenum-permalloy tape, giving the device the required magnetic properties. Developed by Bell Telephone Laboratories, the twistor is manufactured by Western Electric as the primary component of digital-computer memory modules that direct missiles and electronic switching systems. Measuring only four thousandths of an inch in diameter, this new device presented many manufacturing difficulties. One such problem involved the lamination of parallel twistors between polyethylene and Mylar tape. In order to place the units in the laminate with a variation of no more than one thousandth of an inch per inch of width, a totally new concept was evolved of guiding and placing the wires at the very point of lamination. With the solution of this problem, Western Electric provided another unique manufacturing contribution to America's growth in communications and space. **WESTERN ELECTRIC**





A problem for parity analysis

leave him again with the incorrect starting position.

If there are 10 glasses (or any even number not divisible by 4) arranged alternately up and down, is it possible to make a sequence of moves that will bring all the glasses up or all down? No, because in either case an impossible change in the system's parity (from, say, an odd five to an even 10) is demanded.

As long as the glasses behave politely, according to our notion of their structure, it is inconceivable that this parity-conservation law would be violated. But nature, particularly on the subatomic level, is under no obligation to conform to our notions of structure. In 1957 a parity law that for 30 years had been found applicable to the wave functions of quantum mechanics turned out not to hold in the case of the weak interactions of particles. Physicists are still recovering from the shock. It was as if someone had stepped up to 10 alternating glasses, turned them in pairs and brought all 10 upright!

An entertaining coin trick of the extrasensory-perception variety exploits the same underlying principle as the glass trick. Someone is asked to take a handful of coins from his pocket and toss them on the table. While you look away, ask him to turn over the coins at random but always two coins simultaneously. He continues as long as he pleases, doing it silently so that you have no idea how many turns he makes. He then covers one coin with his hand. You turn around, glance at the other coins and immediately tell him whether the concealed coin is heads or tails.

The method (explained by Al Thatcher in a recent issue of a magician's periodical, *The New Phoenix*) could not be simpler. At the outset an even number of heads indicates even parity; an odd number, odd parity. If coins are turned in pairs, parity must be conserved. For example, suppose five heads show at the beginning. At the finish, when one coin is hidden, the parity of the system must still be odd. Thus if you see an even number of heads, you know the concealed coin is a head. If you see an odd number of heads, the concealed coin must be a tail. As a variation, let a spectator cover *two* coins and then tell him whether they match or not.

Sometimes the underlying parity structure of a system is so well camouflaged that only the most alert mathematician is able to spot it. A sterling example is provided by the following unusual problem adapted from *Unterhaltsame Mathematik,* a brilliant collection of puzzles by the German mathematician Roland Sprague. (An English translation by Thomas H. O'Beirne will soon be published in London by Blackie & Son Ltd.) Five alphabet blocks, all exactly alike and each with the letter *A* on one face only, are first placed on a checkerboard in the cross formation shown at the upper left of the board in the illustration at the top of this page. The *A* sides of all five blocks are uppermost. The blocks are now moved from square to square by being tipped over along one edge, as one might move a large, heavy cubical box. In other words, each block is moved by a series of quarter turns each of which tips it from one square to an adjacent square. It is impossible, if one moves the blocks in this fashion, to arrange them in a row, anywhere on the board, with the *A* faces uppermost and all with the same orientation. It *is* possible to arrange them as shown in the row at the bottom of the board. Which block in this row started out as the center block of the cross formation?

One could, of course, obtain five alphabet blocks and find by actual test which block it must be, but with the right insight into the odd-even structure of the system the correct block can be identified simply by studying the picture. Moreover, the parity check provides a proof the empirical test does not. The test merely shows that one block in the row *could have been* the center one; it does not prove that no other block could have been if the right sequence of turns had been made. The parity proof will be explained next month.

Perhaps an easier odd-even problem, also to be answered next month, concerns the work of an eccentric U.S. architect, Frank Lloyd Wrong. To annoy a wealthy client, Wrong designed a house shaped like an enormous shoe box. It was divided by floors into three levels, and on each level the floors were divided by vertical walls into seven rectangular rooms. There were no hallways, staircases or closets, there was no basement or attic. The house consisted entirely of 21 rectangular, box-shaped rooms.

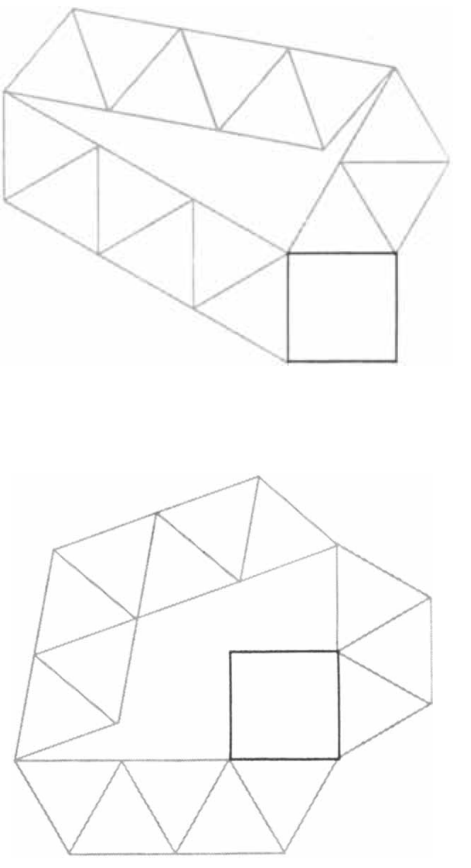
The doors of the house were of two types:

1. Conventional doors that enabled one to go from one room to a neighboring room, or from a first-floor room to the grounds outside.

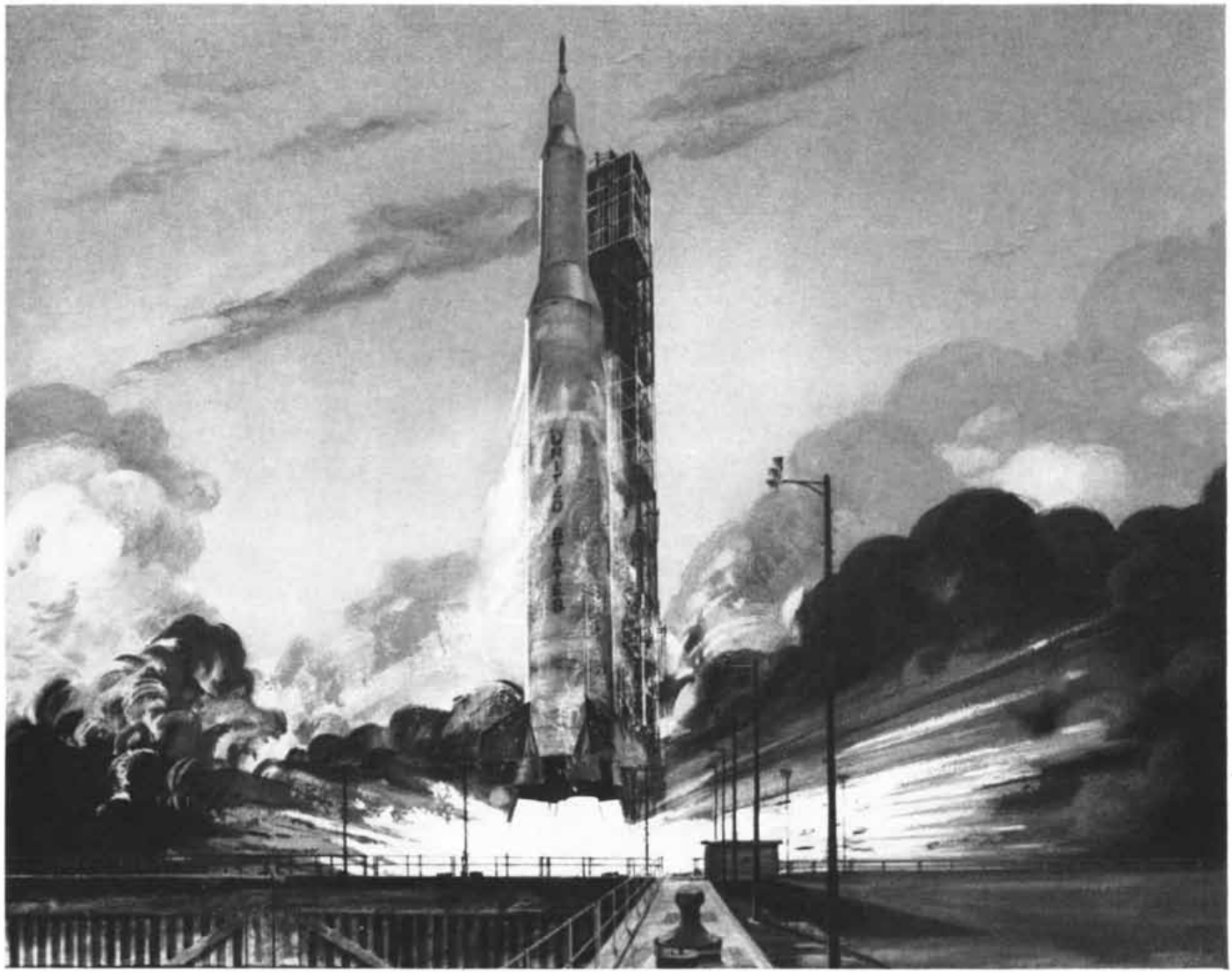
2. Trap doors that allowed one, with the aid of ladders, to go from one room to a room directly above or below.

The doors were placed at random. One room might contain a dozen or more doors or (like the Other Professor's room in Lewis Carroll's *Sylvie and Bruno*) as few as no doors at all. Wrong was careful, however, to see that each room had an even number of doors. (Zero is considered even.) The problem is to prove that the number of outside doors, leading from first-floor rooms to the grounds, is even.

This year's cryptic Christmas message, suggested by C. R. J. Singleton, an English mathematician, presupposes fa-



Solutions to square-bracing problem



SATURN V, pictured in drawing above, will be the free world's largest rocket, standing tall as a 30-story building and measuring 33 feet in diameter. A National Aeronautics and Space Administration program, Saturn V will be used to launch men and equipment into earth orbit, lunar orbit, moon landings and deep space. Saturn will be able to place 100 tons in earth orbit, or transport several tons of instruments to Mars. Boeing holds NASA contract to develop, build and test the S-IC first-stage booster, comprising five F-1 engines developing a total thrust of 7.5-million pounds, equal to about 160-million horsepower.

Capability has many faces at Boeing

TWIN TURBINE Chinook, new Boeing-Vertol tactical transport helicopter, now in operation with U.S. Army. Chinooks carry 33 fully equipped troops, cruise at 150 mph.

LUNAR LABORATORY and living quarters for four research men on moon, based on Boeing study. Also, under NASA study contracts and its own research programs, Boeing is studying manned orbiting research stations, ferry vehicles, lunar explorations and deep space probes.

AMERICA'S NEWEST jet, the short-range Boeing 727, enters service early next year. The 727 will be able to serve cities now bypassed by the big jets. Airlines have already ordered 140 Boeing 727s.

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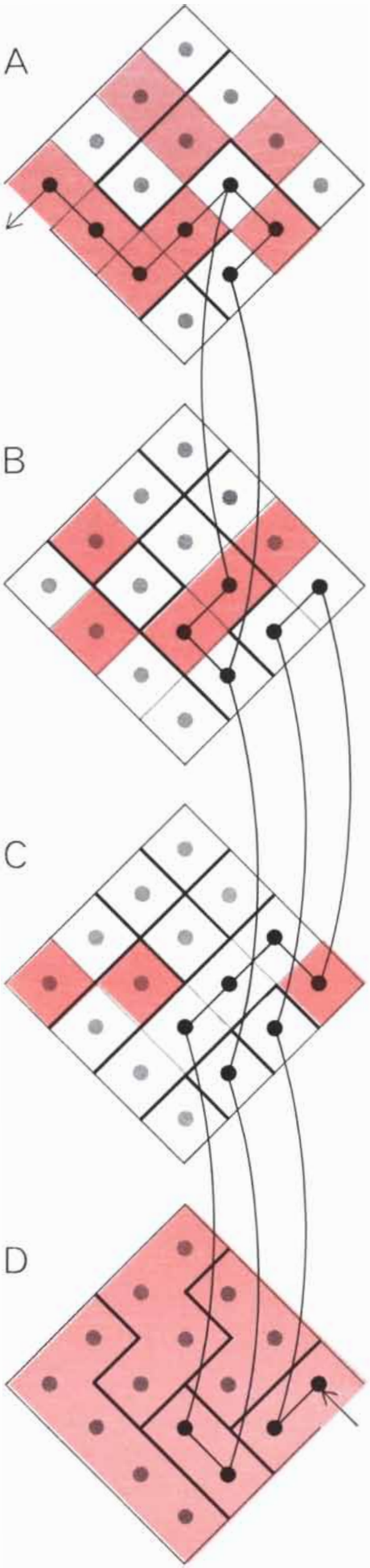


Three-dimensional maze solution

miliarity with the term "complementary angles." Two angles are complementary if their sum is a right angle (for example the two acute angles of every right triangle). Decode the following message:

$$\frac{(90^\circ - C_1)(90^\circ - C_2)(90^\circ - C_3)\ldots(90^\circ - C_n)}{2u}$$

Nine short mathematical problems were presented in this department last month. The answers follow.

1.

Raphael M. Robinson's best solution to his problem of bracing a square on the plane with the minimum number of rods, all equal in length to the square's side, calls for 31 rods in addition to the four used for the square. The bottom illustration on page 144 shows two of several equally good patterns.

2.

Bill spins one penny, John two. John wins if he has more heads than Bill. A tabulation of the eight equally probable ways three coins can fall shows that John wins in four cases and loses in four, so that his chances of winning are 1/2, which is what they would be if a single coin were spun. His probability of winning remains the same whenever he has one more coin than Bill. Thus if he has 51 coins and Bill has 50, each man still has an equal chance of winning.

3.

The simplest paper-and-pencil way to solve Robert Abbott's three-dimensional maze is to place a spot in each cell and then draw lines from spot to spot to represent all open corridors. Since a maze involves only topological properties of the pattern, it does not matter how these lines twist and turn as long as they connect the spots properly.

The next step is to erase all blind-alley lines and all loops that do no more than take one from spot to spot in a roundabout way when a shorter path is available. Eventually only the shortest route remains. This path is shown at the left. Note that two loops near the top offer two different routes of equal length. Each of the long curved lines connecting the spots is, of course, only one unit in length in the actual maze, therefore the entire maze can be run by a path 19 units long.

An alternate method of finding the shortest path in any type of maze is to make a model of the network out of string. Each segment of string must have a length that is in the same proportion to the length of the corridor it represents, and it must be labeled in some way so that the corridor can be identified. After the model is completed, pick up the "start" of the network with one thumb and finger and the "end" of the network with the other thumb and finger. Pull the string taut. Roundabout loops and blind alleys hang loose. The taut portion of the model traces the path of minimum length!

4.

The traveler with a 23-link gold chain can give his landlady one link a day for 23 days if he cuts as few as two links of the chain. By cutting the fourth and 11th links he obtains two segments containing one link and segments of three, six and 12 links. Combining these segments in various ways will make a set of any number of lengths from one to 23.

The formula for the maximum length of chain that can be handled in this way with n cuts is

$$[(n+1)2^{n+1}] - 1 .$$

Thus one cut (link 3) is sufficient for a chain of seven links, three cuts (links 5, 14, 31) for a chain of 63 links, and so on.

5.

As promised last month, a report on attempts to square the word "circle" will appear in the February 1964 issue.

6.

The quickest way to prove that all three hands of a watch with a sweep second hand are together only when they point to 12 is to apply elementary Diophantine analysis. When the hour hand coincides with one of the other hands, the difference between the distances traveled by each must be an integral number of hours. During the 12-hour period the hour hand makes one circuit around the dial. Assume that it travels a distance x, less than one complete circuit, to arrive at a position with all three hands together. After the hour hand has gone a distance of x, the minute hand will have gone a distance of $12x$, making the difference $11x$. In the same period of time the second hand will have gone a distance of $720x$, mak-

ing the difference $719x$. All three hands can be together only when x has a value that makes both $719x$ and $11x$ integral. But 719 and 11 are both prime numbers, therefore x can take only the values of 0 and 1, which it has at 0 and 12 o'clock respectively.

Aside from the case in which all three hands point straight up, the closest the hands come to pointing in the same direction (defining "closest" as the minimum deviation of one hand when the other two coincide) is at 16 minutes 16 and 256/719 seconds past 3, and again at 43 minutes 43 and 463/719 seconds after 8.

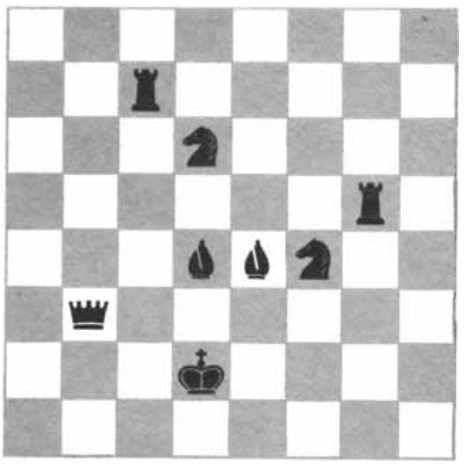
The two times are mirror images in the sense that if a watch showing one time is held up to a mirror and the image is read as though it were an unreversed

```
      9 9
  ×   9 9
  -------
    8 9 1
  8 9 1
  -------
  9 8 0 1
  +   1 9 9
  -------
1 0 0 0 0
```

```
      1 7
  ×     4
  -------
    6 8
  +   2 5
  -------
    9 3
```

```
    1 7 9
  × 2 2 4
  -------
    7 1 6
  3 5 8
3 5 8
-------
4 0 0 9 6
```

Solutions to cryptarithms



Board setup for maximum chess moves

clock, the image would indicate the other time. The sum of the two times is 12 hours. In both instances the second and hour hands coincide, with the minute hand separated from them by a distance of 360/719 of one degree of arc. (The distance is 5 and 5/719 seconds if we define a second as a sixtieth of the distance of a clock minute.) In the first instance the minute hand is behind the other two by this distance, in the second instance it leads by the same distance.

7.

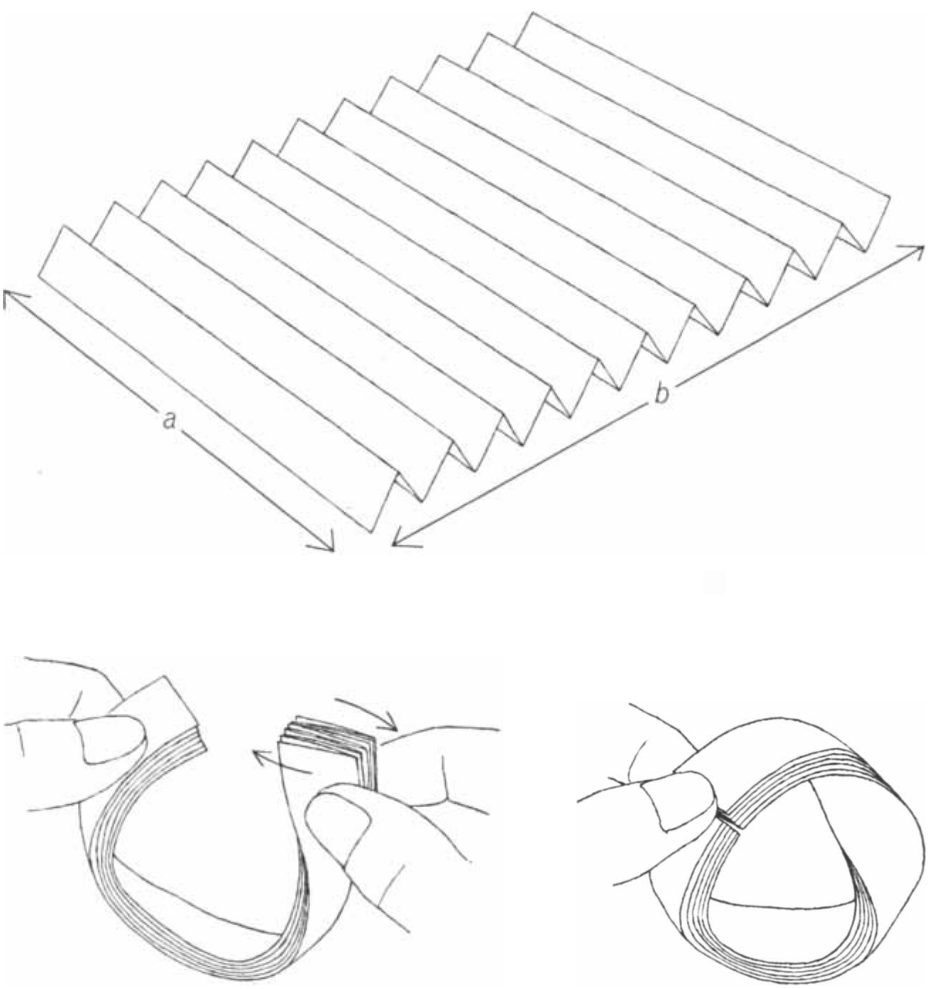
The three cryptarithms have the unique solutions shown in the illustration on the preceding page. The first was devised by Stephen Barr, the second is the work of the English puzzlist Henry Ernest Dudeney and the third is from Frederik Schuh's *Wonderlijke Problemen,* published in Holland in 1943.

8.

If eight chess pieces of one color are placed on the board as shown at the top of this page, a total of exactly 100 different moves can be made. According to T. R. Dawson, the English chess problemist, this question was first asked in 1848 by a German chess expert, M. Bezzel. His solution, the one shown here, was published the following year. In 1899 E. Landau, in another German publication, is reported to have shown that 100 moves is the maximum and that Bezzel's solution is unique except for the trivial fact that the rook, on the seventh square of the fourth row from the top, could just as well be placed on the first square of that same row.

9.

A paper rectangle is of height a, width b. What is the smallest value of a/b that allows one to join the b edges into a Möbius band? The surprising answer is that there *is* no minimum. The fraction a/b can be made as small as one pleases. Proof is supplied by a folding technique explained in Stephen Barr's *Experiments in Topology*. The strip is pleated as shown at the bottom of this page to form a narrow strip with ends that show twofold symmetry. After this narrow strip is given a half-twist the ends are joined. *Voilà!*

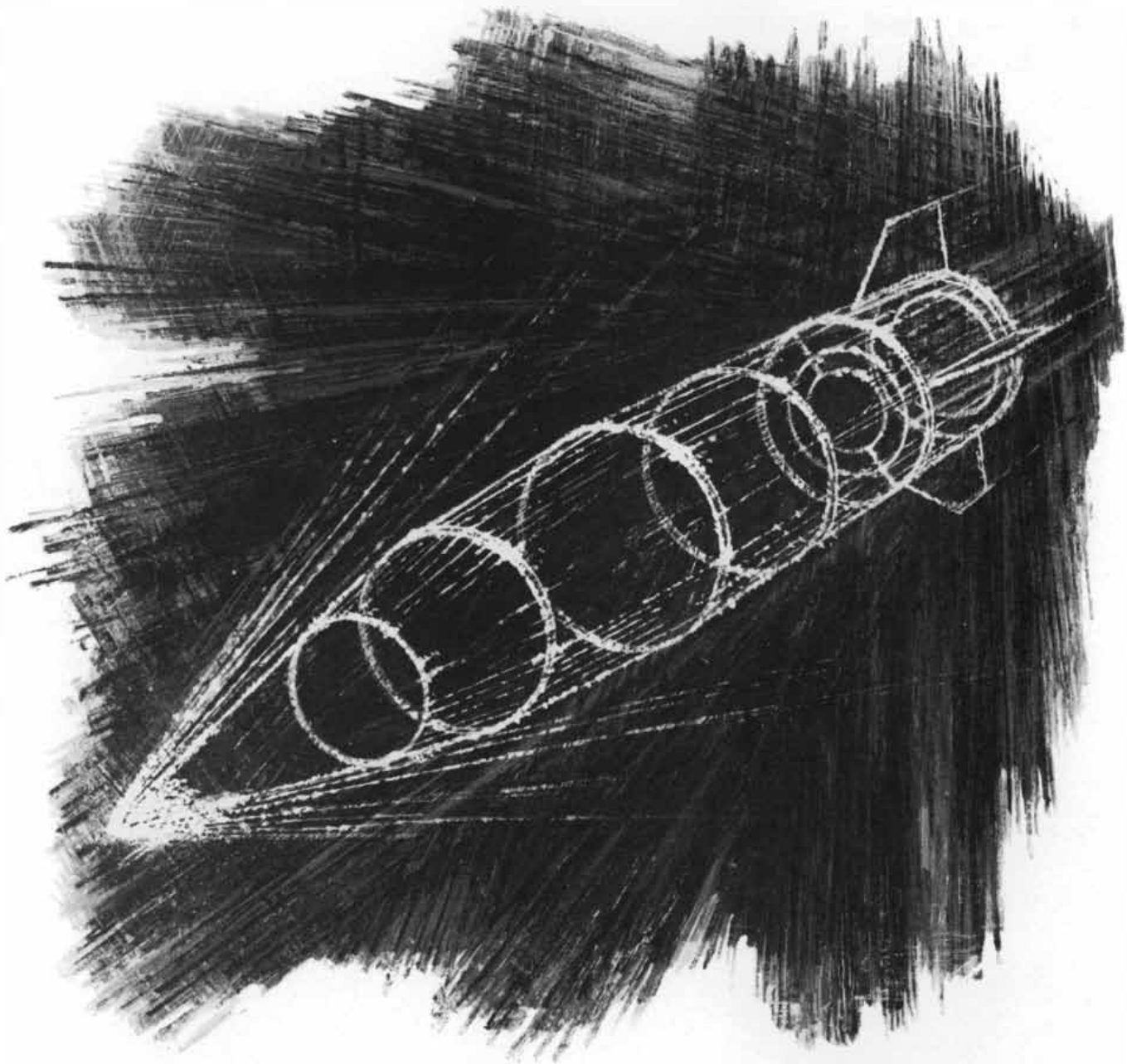


Möbius-strip solution

William M. Daly, of the Minneapolis-Honeywell Regulator Company, using a Honeywell 800 computer, was the first to verify Charles W. Trigg's proof (reported here last August) that the Adams magic hexagon is unique. Running time: 30 minutes 20 seconds. Wilfred J. Hansen, using a computer at the Yale Computer Center, made the confirmation in one minute, but it took 12 hours to work out the equations and another 12 to code the problem in the computer language Fortran. Computer confirmations were also reported by G. W. Anderson and Friend H. Kierstead, Jr. John R. A. Cooper wrote to say that the hexagon had been independently discovered in England by Tom Vickers, who published it, without comment, as a note in *The Mathematical Gazette* for December, 1958 (page 291), without knowing that the pattern was unique.

Correction: The path of the bouncing ball inside the equilateral triangle (September department) was incorrectly called cyclic. The ball does return to the point of origin, but the path does not then repeat unless the ball has touched the mid-points of all three sides. Donald E. Knuth of the California Institute of Technology was one of many readers who pointed out the error. In an interesting analysis Knuth was able to show that if the ball continues to bounce after completing one round trip from point x to point x, the path will eventually repeat if and only if x is at a rational distance from the vertex of the triangle.

ALL TRIUMPHS BEGIN IN THE MIND'S EYE



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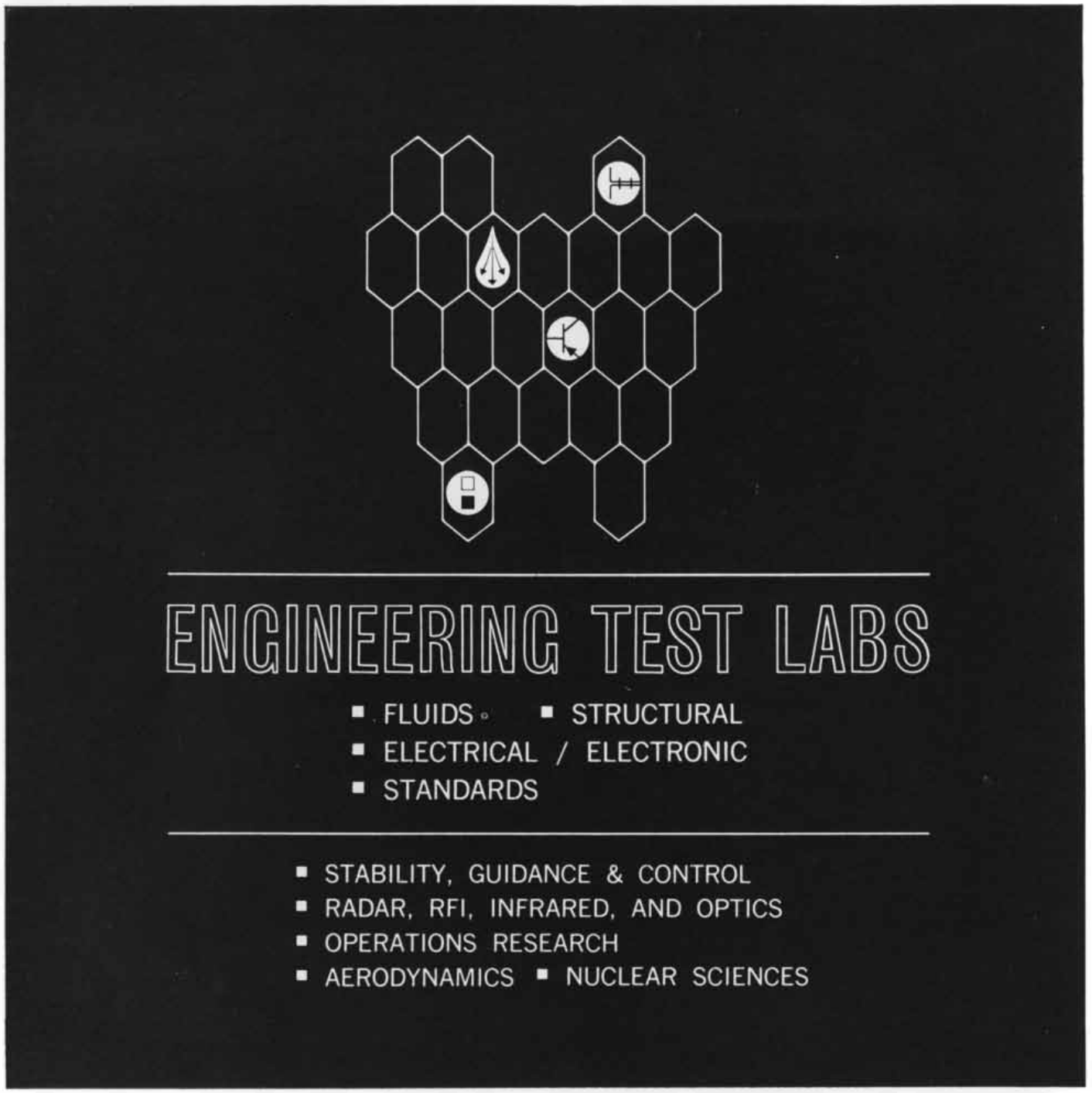

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GENERAL DYNAMICS | FORT WORTH

THE AMATEUR SCIENTIST

Some experiments on the effects of ionizing radiation on plants

Conducted by C. L. Stong

With industrial and medical X-ray apparatus now accessible in most communities, enterprising amateurs can investigate some of the fascinating effects of ionizing radiation on living plants. In general, ionizing radiation damages organisms, stunts their growth or kills them outright. Occasionally, however, an organism will benefit from exposure to X rays; desirable changes are induced as they are when plants are beneficially "damaged" by drugs or the pruning knife. The beneficial effects of radiation include sterilization, insect eradication and the induction of desirable mutations. The key requirement for success in making radiation experiments is careful preparation. Amateurs who take pains designing an experiment and demonstrating its objectives should have little difficulty enlisting the co-operation of those who control the X-ray apparatus for irradiating the specimens. The required materials are no more complex or costly than those normally used for germination experiments. To encourage amateur experimentation Thomas S. Osborne, associate professor of plant genetics at the University of Tennessee, has prepared the following introduction to the field.

"These experiments," he writes, "require a source of X or gamma rays. In general the irradiation facilities of universities and Government agencies cannot be diverted for amateur use because they are fully occupied by research programs. Medical and industrial radiation sources, however, seem to be sufficiently numerous and widespread so that occasional access to them can be had if the experimenter has prepared the specimens with an eye to conserving the time of X-ray technicians and if he can demonstrate the value of his objectives. It was with these considerations in mind that seeds were selected for the experiments that follow. Seeds—actually dormant plant embryos—are attractive experimental materials in a number of respects.

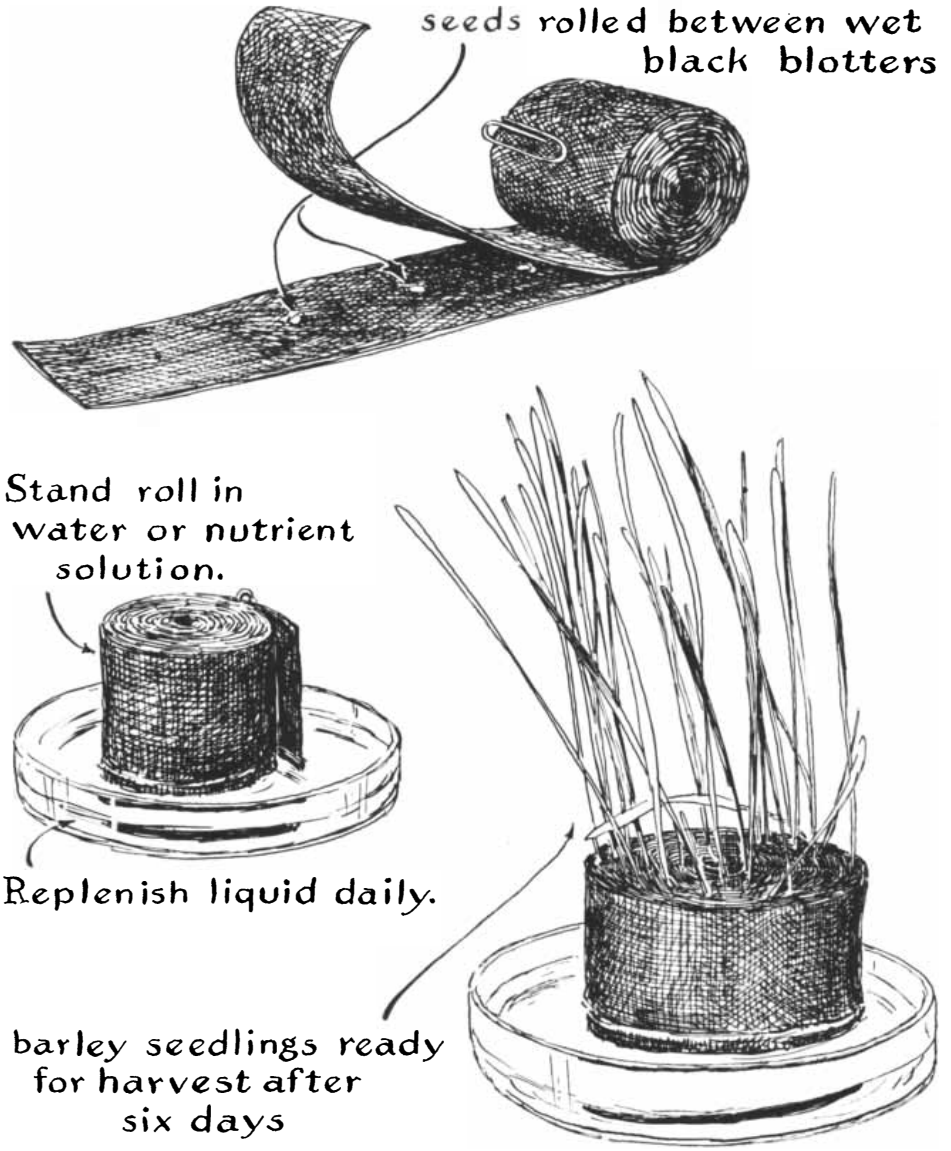
"A seed is in a state of suspended animation; when provided with an environment that encourages germination, it becomes a typical living system. A seed is a complex, multicellular organism that is obedient to the laws of heredity. This means that all individual plants that grow from seeds of a 'pure line,' particularly those of a self-pollinating species, are almost identical genetically. They contain all the types of cells of the future plant telescoped into a small volume. Since these cells are in a resting state the experimenter can make identical observations over an extended period. In general seeds tolerate extremely harsh treatment; they can therefore provide biological assays of treatments severe enough to kill most other living organisms, such as extremes of radiation, harsh chemicals and high or low temperatures and pressures. Unlike mature plants, seeds can be manipulated conveniently and a large number can be irradiated simultaneously by a compact source. Of most interest, the experimenter can measure the effects of radiation by counting the number of seeds that germinate, measuring the rate of seedling growth, counting the number of plants that survive to maturity and observing such characteristics as fertility (in terms of seed set), chromosomal aberrations in cells, pollen abnormalities and mutations in the second and later generations.

"The seeds of different plants vary greatly in their sensitivity to radiation. Cabbage, for example, can withstand 200 times more ionizing radiation than an onion or a lily. The reasons for such variations are of deep biological significance and their discovery by experimental methods can be a challenging and deeply satisfying experience. In an environment of increasing radiation it is important to learn the effects of radiation on seeds and to find methods of utilizing and modifying their consequences.

"The selection of seeds is the first step in planning a radiation experiment. Specimens should be genetically uni-

SEEDS	"SIGNIFICANT DOSE" (KILOROENTGENS)						
	.5–2	3–7	6–12	15–20	25–35	50–80	100 OR MORE
	LILY	ONION	RYE	WHEAT	COTTON	CARROT	CABBAGE
	PINE	BROAD BEAN	CORN	OATS	RICE	CAULIFLOWER	MUSTARD
			FESCUE	BARLEY	TOMATO	RADISH	MOST CLOVERS
			SNAPDRAGON	PEANUT	CUCUMBER	COSMOS	
			SUNFLOWER	BEAN	LETTUCE		
			PEA	SOYBEAN			
				IMPATIENS			

Approximate radiation sensitivities of selected seeds



Germination medium made of blotting paper

form; otherwise the effects induced by radiation might be confused with existing genetic differences. Radiation botanists customarily use seeds of a self-pollinating species that can be traced to a single genetically pure ancestral plant. Certified agricultural seeds or those of varieties that can be procured from a reputable firm are adequate for the suggested experiments that follow. Seeds sold by the pound are less costly than those that are sold in small, colorful packages. The selection of seed species for radiation experiments is limited principally by the energy of the radiation source. If a high-energy machine is available, almost any species can be used, but if the source is of low voltage or if exposures must be kept short for economy or other reasons, sensitive seeds should be chosen. The accompanying table [*preceding page*] lists the relative radiation sensitivities of some common plants. The indicated doses are approximate, because seedling response varies with the age, variety and moisture content of seeds, the kind of radiation source, filters, if any, growing conditions and other factors.

"Having selected one or more species, first sort the seeds by hand and discard any that are broken, discolored, outsize or otherwise abnormal. Larger seeds of a given species in general produce more growth than smaller seeds. Mixed sizes can lead to subsequent error when the effects of radiation are assessed. Time spent in hand-picking seeds will be rewarded by the increased validity of the results.

"The number of seeds used for each experiment is determined by the size of the seeds, the medium in which they are grown and the purpose of the experiment. As a rule, variations in both seeds and X-ray machines are large enough to obscure radiation effects in a sample of 10 seeds or fewer. Fifty seeds per treatment is a reasonable number, although 100 is the minimum for mutation studies. An unirradiated group of seeds must always be grown as a reference, or 'control.' The control should always consist of the same number of seeds as the treated lot, selected with the same care and grown with the same amount of water, nourishment and cultivation.

"After the seeds have been counted, packaged and labeled for treatment, each group should be spread on the growing medium in a single disk-shaped layer that corresponds to the size of the X-ray beam. The intensity of the beam may not be uniform. If the intensity varies from area to area within the beam, either choose a small region of uniform intensity for the exposure, place the seeds on a small motor-driven turntable for treatment or interrupt each treatment several times during irradiation and shift the position of the seeds. (An experiment for determining the uniformity of the X-ray beam will be described later.)

"If some factor other than radiation is to be varied, such as moisture or the gaseous environment, each sample should be sealed in a material such as plastic kitchen wrapping, heavy polyethylene or glass to maintain the desired environment. When preparing such packages, remember to keep the seeds in a single layer for irradiation unless the source of radiation is highly energetic (one million electron volts or more) to assure penetration to a depth of several centimeters.

"In these experiments the amount of radiation to which the seeds are exposed will be specified in kiloroentgens, or thousands of roentgens. The roentgen is the amount of radiant energy required to dislodge electrons from approximately two billion molecules in one cubic centimeter of air at a temperature of 32 degrees Fahrenheit and a pressure of 760 millimeters of mercury. Thus one roentgen generates two billion ions in one cubic centimeter of air. Observe that time is not a factor of the unit. A low-energy X-ray source can create two billion ions just as effectively as a high-energy source if the machine operates long enough. Few medical and industrial X-ray machines are calibrated in roentgen units; exposures are based on quantities such as voltage and time.

"The output of X-ray machines varies with many factors, including the kind of tube and its age, the applied voltage and current and the distance from the tube to the specimen. Most X-ray technicians have 'R' meters, however, and can measure the energy of the beam in terms of

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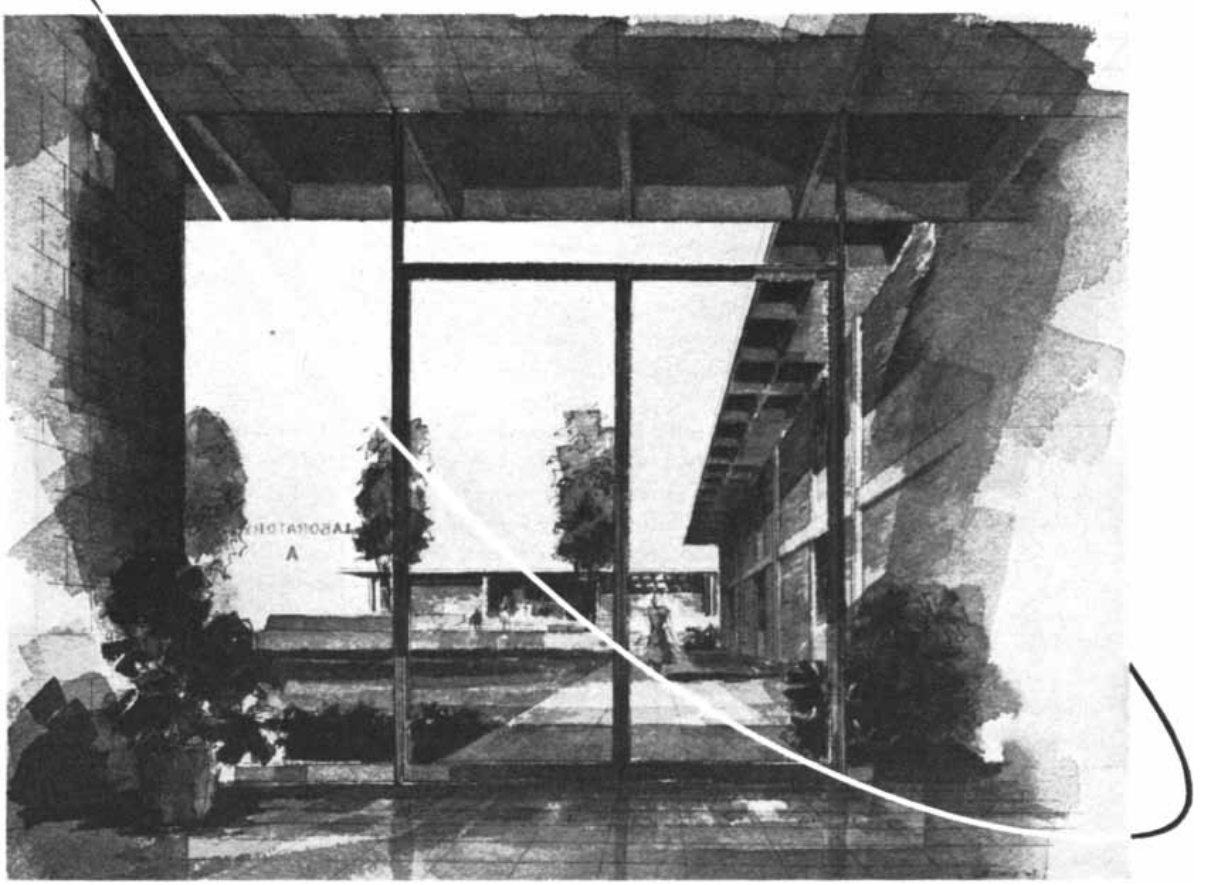

Artist's sketch looking through double doors of Material Sciences office and Laboratory Building

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roentgens at a desired distance from the tube. (Recently the 'rad' has become a popular unit of radiation, principally because of its convenience in making computations. The rad corresponds to the absorption of 100 ergs of energy by each gram of tissue, whereas the roentgen corresponds to the absorption of 93 ergs. To convert roentgens to rads multiply by .93.)

"Most seeds require only water and air for germination at room temperature (60 to 70 degrees F.). Those of wheat and beans have sufficient stored food to support growth for two to three weeks, but smaller seeds may require prompt nourishment when they sprout. Seeds can be grown in shallow boxes of sand, peat, perlite, soil or mixtures of these materials. The growing medium should be kept moist but not soggy and should be fertilized every three or four days with a soluble plant food; commercial preparations that are recommended by seed dealers will do.

"Seeds with abundant stored food can be grown to sufficient size for seedling studies in paper towels or blotters that are rolled and placed in shallow containers of water [*see illustration on page 152*]. The correct temperature must be maintained, measured in the soil. Seeds normally sown in late spring or early summer, such as corn, cotton and soybean, require a soil temperature of about 70 degrees, whereas those that sprout in the fall or early spring, such as spinach, onions and most grasses and clovers, thrive at 60 degrees or less. Proper germinating conditions for most field and garden seeds are listed in the publication *Rules and Regulations under the Federal Seed Act*, which can be obtained from the U.S. Department of Agriculture.

"If seeds with little stored food are used, the blotters should be made narrow, perhaps an inch wide, so that the roots will soon contact the liquid in the dish. Remember that roots need oxygen. Oxygen escapes from a liquid in a few hours, but it can be replaced by changing the nutrient solution daily. Always place new solutions in large bottles with plenty of air space and before use shake them vigorously for several minutes so that they will absorb the maximum amount of oxygen. When the first leaves appear on the plants, rotate the roll of blotters and shift the dishes in a regular daily pattern to minimize the effects of unequal light and temperature.

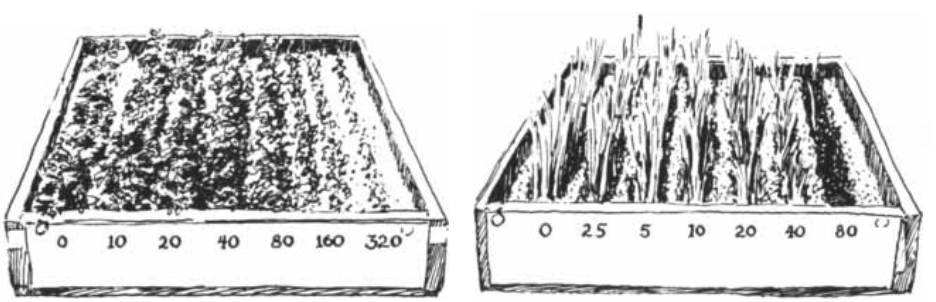
"You will quickly observe that mere sprouting, or germination, is a poor criterion of radiation damage. Virtually all seeds germinate, even those subjected to lethal doses of radiation. They do so because most germination results from the elongation of cells already present in the embryo; it is a further increase in size that depends on cell division, which can be inhibited by radiation. For this reason radiation damage can be assessed reliably only by measuring the growth of seedlings. A reasonably accurate indication of radiation damage in the case of 'monocots' such as wheat and onion, which send up a single first leaf, can be obtained by measuring the height of all irradiated seedlings when the leaf of the control group is fully extended.

"Damage is more difficult to measure in the case of 'dicots' such as spinach and beans, which raise two seed leaves by elongation before growth by cell division begins. In the case of these plants the distance between the original location of the seed and the leaves remains relatively constant through a wide range of radiation dosage, and growth above the leaves may amount to only a few millimeters in three weeks. In such plants the dry weight of the tops is a reliable measure of growth. The optimum time for harvesting is determined by observing the growth of the controls. It will vary from about 10 days for wheat or beans, which grow four to six inches during this interval, to about four weeks for clovers, which will have reached a height of scarcely two inches.

"A graph made by plotting seedling growth against time takes the form of an S-shaped curve, and the time to harvest is when the curve of the control begins to flatten out. Clip the seedlings at 'ground level,' chop up the plants from a given irradiation treatment, place them in a drying dish of known weight and label them. Dry the material in an oven at 150 degrees for 24 hours and remove to a desiccator for cooling. Weigh each cooled dish and subtract the weight of the dish from the total weight. The dry weight of the irradiated seedlings divided by the dry weight of the controls and multiplied by 100 equals the percentage of growth of the treated group in relation to that of the control group. Record this percentage in a notebook for each group.

"These techniques are similar to but simpler than those employed by radiation biologists. Gross differences of behavior must be expected even among control groups when single measurements are made of small numbers of seedlings. In some experiments plants from heavily irradiated seeds may appear to have grown more than those that received a lower dose, or a lower dose may seem to have promoted better growth than a control. Such observations can usually be traced to faulty technique: miscounting seeds, mislabeling treatments, differences in light or temperature, mistakes in watering and so on. Random variation, or 'error,' is always greater in small samples than in large samples. To learn how much natural variation to anticipate make an experimental run with six to 10 groups of untreated controls. To detect subtle changes induced by ionizing radiation you must use large numbers of seeds and, in particular, repeat experiments at least four times. Only then can statistical tests be applied with confidence.

"For a simple introductory experiment select two species, one known to be sensitive, such as onion or rye, and one that is resistant, such as mustard or cabbage. After hand-picking, divide the seeds into four groups of 50 or 100 seeds per group, depending on how many seeds the X-ray machine will accommodate when specimens are spread as a single layer. Package each group separately and label for species and radiation treatment. Irradiate the seeds of both species simultaneously, reserving one group of each for controls. The treated groups should receive doses of one kiloroentgen, 10 kr and 100 kr respectively. Measure the dry weight of all seedlings to compare the response of the two species to irradiation. Differences of response have been ascribed to the genetic structure of the organisms,



Response of alfalfa (left) *and barley* (right) *seeds to increasing dosages*

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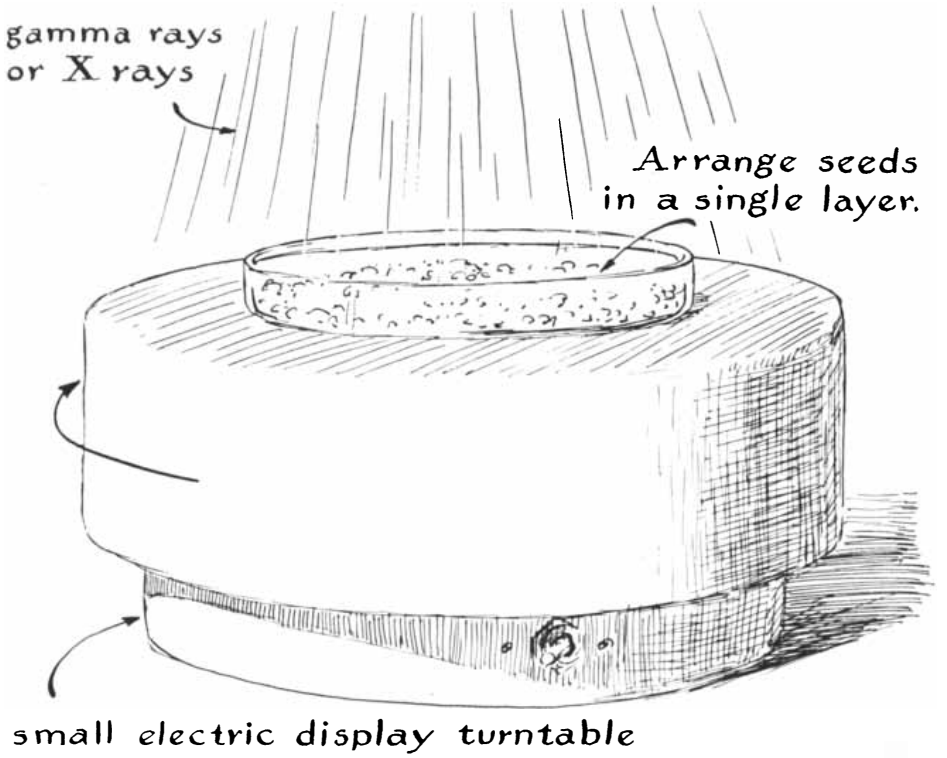

Turntable for irradiating seeds evenly

but this does not explain the responsible mechanism. Some recent evidence indicates that 'target sizes' and differences in the geometry of cells and nuclei are involved, as well as 'sensitive sites' in the cells, but the question of why some plants are more sensitive to radiation than others remains open.

"A second experiment, for determining the uniformity of the X-ray beam, can be run simultaneously. Cut a disk of cardboard equal in diameter to the beam of the X ray, draw a circle in the center of the disk equal in diameter to the radius of the disk and divide the area outside the circle into four equal parts. Select seeds of a plant of fairly high sensitivity, divide the seeds into five equal groups and place them as single layers in the five inscribed areas of the cardboard.

"One axis of the pattern should be placed perpendicularly to the long axis of the X-ray tube and a note made of its position with respect to the tube. Label each group of seeds and administer a significant dose of radiation as listed in the table. Grow the groups separately and compare the dry weight of the seedlings in each group with that of a single unirradiated control group. Finally, make a note of the percentages of relative growth in each area of the cardboard disk. X-ray beams characteristically take the form of nonuniform cones of radiation of highest intensity on the anticathode side of the X-ray tube. If the beam is producing growth differences of more than 25 per cent in different areas, special steps will have to be taken to compensate for the disparity during subsequent experiments. Either shift the seeds periodically during irradiation or rotate them on a small turntable such as those used for advertising displays.

"Resistance to radiation damage appears to vary not only from plant to plant but also from day to day in a plant that is germinating. To observe this difference start two lots of labeled seeds. On the following day start two more groups and on the third day start yet another pair. On the fourth day irradiate one lot of each pair with one-fifth of a significant dose. At the same time plant another two lots, having previously irradiated one of them. Grow and harvest the seedlings and measure their dry weights. Plot, as a graph, the days of germination prior to irradiation (zero to three) against the dry weight of each treated group as a percentage of its control; observe that the sensitivity of seeds to radiation damage increases as they become biologically active.

"Moisture also strongly influences sensitivity to damage. Store groups of seeds for at least a month in a series of controlled relative humidities. (Do not use seeds of rye, corn, barley, wheat, millet or other grasses for this experiment.) Controlled atmospheres can be set up in wide-mouthed glass jars equipped with close-fitting lids and inner devices for supporting the seeds above a fluid. Saturated aqueous solutions of the following salts will produce the indicated relative humidities: zinc peroxide, 10 per cent relative humidity; lithium chloride, 15 per cent; calcium chloride, 32 per cent; sodium bisulfate, 52 per cent; sodium chloride, 76 per cent, and potassium nitrate, 94 per cent. Care must be taken to maintain constant room temperature or condensation will moisten the seeds and destroy the experiment.

"At the end of the storage period quickly divide the seeds from each jar into four equal groups and seal immediately in plastic kitchen wrapping. (Do not take time to count the seeds at this juncture as they will tend to approach the humidity of the room.) Label each package for relative humidity and radiation dose. Retain one lot from each jar as a control. Irradiate the remaining three groups at the significant dose, twice the significant dose and five times the significant dose respectively. Grow and measure by the routine procedure, counting the number of seeds (not seedlings) as each group is harvested. Compute the growth of each group in terms of milligrams of dry weight *per seed sown*. Plot the results with the percentage of relative humidity as the horizontal axis and the growth as the vertical axis. Observe that the sensitivity of seeds to ionizing radiation varies with the humidity at which they are stored before and during irradiation. For each species there is a different optimum humidity, both for unirradiated growth and for resistance to radiation.

"Sensitivity appears to be similarly influenced by exposure to gases. To observe the effect place groups of selected seeds in plastic containers, such as the freezer bags normally used for preserving foods. Flush some lots for about two minutes with oxygen and an equal number with nitrogen or helium and seal the containers promptly. After allowing the gases to diffuse into the embryos for 24 hours or more, remove the seeds and immediately irradiate each group with a significant dose. Compare the seedling growth of each gas-treated group with its control and compare the gas-treated groups with one another. It can be shown by this experiment that radiation damage is caused in part by the reaction of induced radicals with oxygen to form active substances that induce hereditary changes in plants; seeds stored in air or oxygen are more severely damaged by radiation than those stored in inert gases.

"The experiments discussed so far

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were designed to show radiation damage as measured by seedling growth. Such damage is partly genetic and partly physiological. Only the genetic changes are transmitted to offspring, and virtually all genetic changes, or mutations, become visible only after a lapse of one generation or more. Any of the above experiments can be extended to an investigation of mutation with the addition of a few steps to the procedure.

"After irradiation sow the treated seeds and controls in a greenhouse or garden plot where they can grow to maturity. Take such steps as are necessary to encourage self-pollination. Depending on the species, this may require bagging each plant or the head of each, manipulating the heads at pollination time, actually transferring pollen from the anther to the stigma (as in the case of corn) or simply isolating the experimental plants from other varieties with which they might cross. Such self-pollination tends to encourage the concentration of recessive mutant genes in the plant and thereby hasten or increase the expression of altered characteristics. In some species inbreeding reduces the vigor of the plant and discloses hidden genes that are also expressed in altered characteristics such as changes in the shape, size or color of leaves or fruit. For this reason an adequate number of controls must be used for distinguishing between altered characteristics induced by radiation and those that can be traced to natural recessive genes.

"Harvest seeds from each mature plant and label by treatment and plant number. These seeds are called the R_2 generation; they were produced on R_1 plants and will in turn produce R_2 plants and R_3 seeds. Sow as many seeds as growing space permits from *each* R_1 plant when the next growing season arrives.

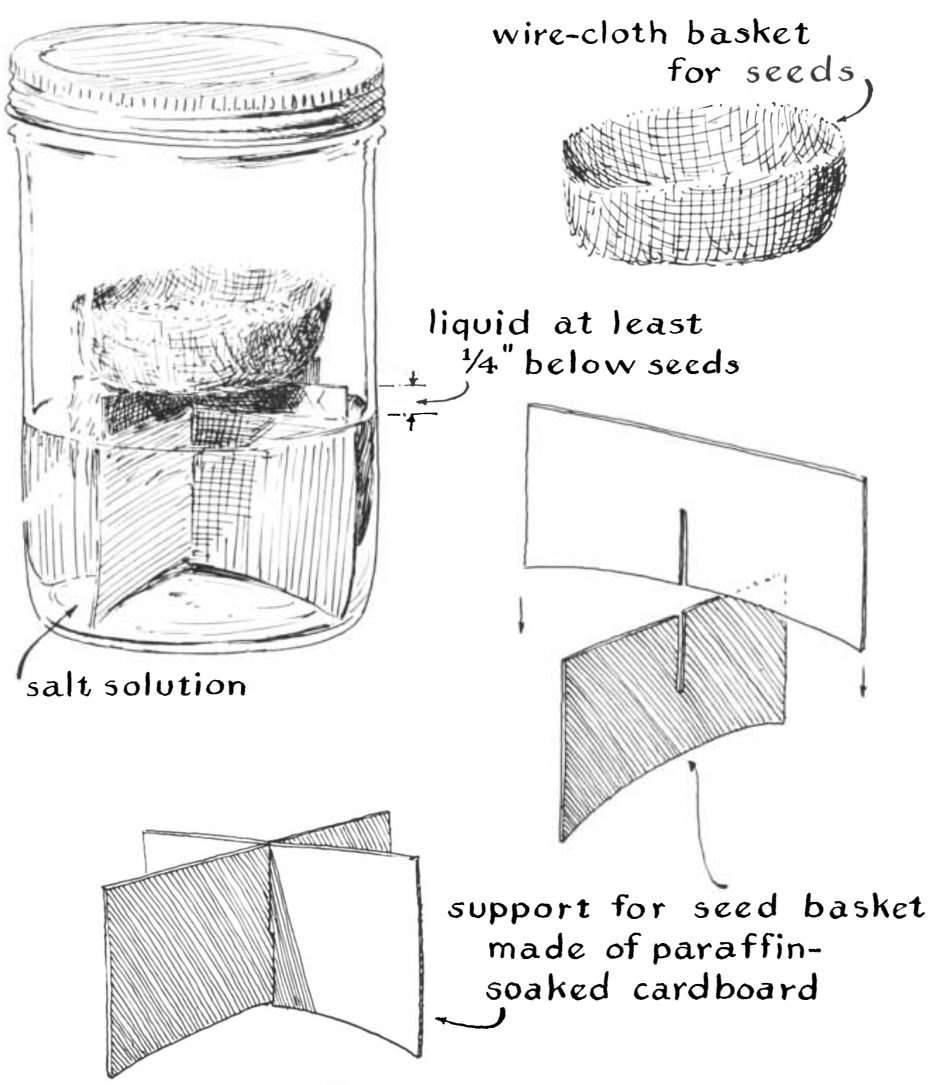
"Arrange the seeds from one plant in a single row, called a progeny row; if seeds from several plants or treatments are bulked, the mutation study becomes a needle-in-the-haystack puzzle. Examine the R_2 plants for potential mutants at intervals during the growing season. Look for differences in height and vigor, color and shape of leaves and flowers, date of maturity and so on. Keep careful records. Harvest seeds from as many R_2 plants as growing space permits and repeat the growing cycle the following year. Keep seeds from each plant in a clearly labeled envelope. The plants from these seeds will enable you to verify suspected mutants. Compare original radiation treatments with controls for the percentage of R_2 rows that contain mutants.

"To make a more detailed experiment on the genetic effects of ionizing radiation procure young cuttings or seedlings of a plant that produces showy flowers, such as snapdragon or tradescantia. With the help of a botanist or horticulturist select a variety 'heterozygous' for flower color, that is, one in which a different gene determining color is derived from each parent plant. Before any flower buds become visible irradiate the whole plants, with the exception of the roots, with one or more doses of from 100 to 1,000 roentgens. (Shield the roots with lead if possible.) Keep an unirradiated control group.

"Plant and cultivate, and as each flower reaches maximum size count the number of petal spots of altered color. Each spot so altered represents a single mutation that the geneticist would describe as a change from *Aa* to *aa*, the upper-case letter standing for a dominant gene and the lower-case letter for a recessive gene. If the plants were *AA* to start with, a change to *Aa* might occur but it would not be expressed by a change in color of the petal spots because the color is determined by the presence or absence of the dominant gene; an *Aa* would look like the original *AA*. If the experiment started with petal color determined by *aa*, then a change to *Aa*, called a 'dominant' mutation, would be expressed in altered flower color, but genetic changes in this direction almost never occur.

"Examine each spot at low magnification and count the number of mutated cells in the spot. You can now deduce how many cell generations ago the mutation occurred: a two-cell spot developed one cell generation ago; four cells indicate that mutation occurred two generations ago; eight cells, three generations, and so on. The larger the spot, the smaller the bud at the time of irradiation—the ultimate being a flower of uniform but changed color, indicating that the mutation occurred when the flower was a single cell.

"For additional data about these and other experiments with irradiated seeds



Apparatus for maintaining controlled humidity

I recommend the booklet *Experiments with Radiation on Seeds, Number 2.* This reference is available from the U.S. Atomic Energy Commission, Division of Technical Information Extension, Educational Materials Section, P.O. Box 62, Oak Ridge, Tenn."

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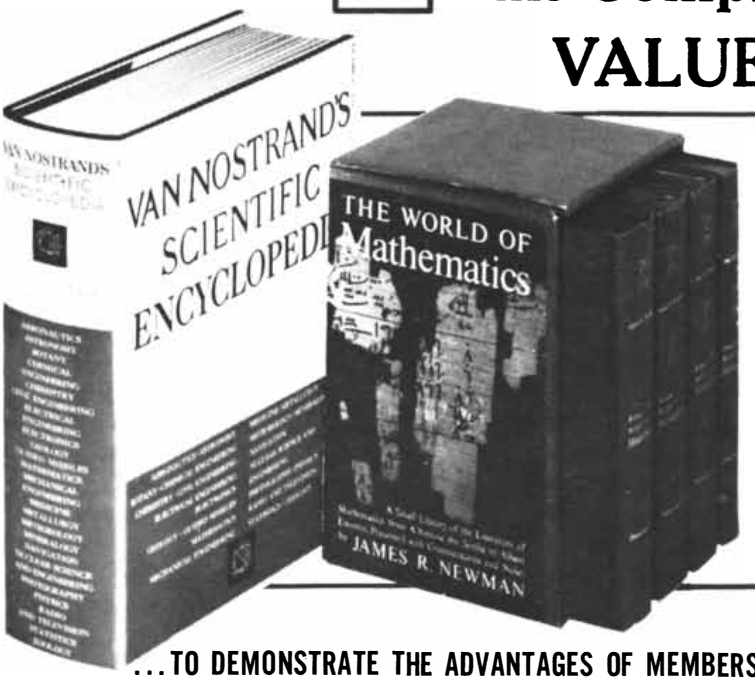

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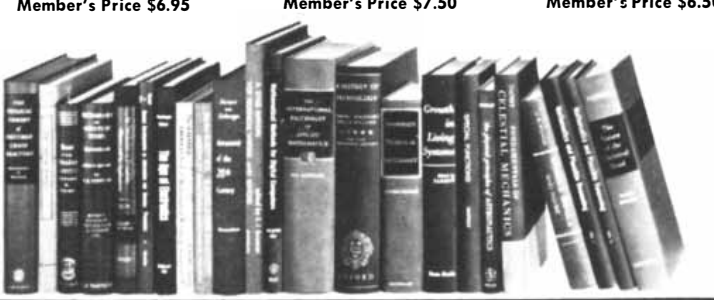

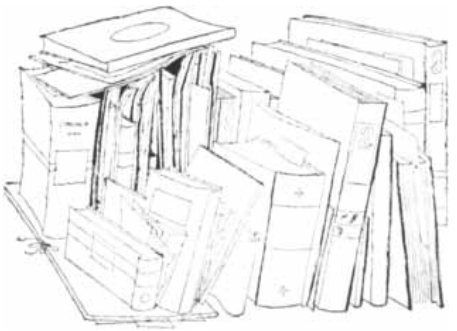

BOOKS

A Christmas survey of new books about science for young readers

by James R. Newman

This is the 14th annual SCIENTIFIC AMERICAN survey of children's books about science. Many are called but few are chosen. It would, indeed, be impossible to cover adequately the several hundred books in this category published each year were it not for the fact that only a small fraction deserve attention. As in past years, the great majority of the books are stale and unimaginative, neither entertaining nor particularly instructive; except for hat and stick, to borrow Sir Walter Scott's phrase, it is the same old wardrobe for the same old dummy. Briefly described below are a number of the exceptions. In a few instances books are mentioned that were published a little earlier than 1963 but escaped our notice. Occasionally the reader may be surprised at the designation of a book as a "children's book" when the publisher has not considered it in these terms, either in price or format or jacket copy; good popularizations, however, are often equally suitable for grownups and teen-agers, and it should prove helpful to teachers, parents and young people themselves to have such books included in this report.

Physical Sciences

A STUDY OF SPLASHES, by A. M. Worthington. The Macmillan Co. ($4.95). Some of the best writings on science accessible to the general reader have to do with everyday things. In this company are C. V. Boys's book on soap bubbles, Faraday's lecture on a candle, Thomas Huxley's essay on a piece of chalk. A. M. Worthington's *A Study of Splashes* is a similar classic about a familiar event. This volume contains a reprint of his book, published in 1908, and of his celebrated lecture delivered at the Royal Institution of London in 1894. Like Boys and Lord Rayleigh, Worthington gained fame in the 1890's by measuring small time intervals. Boys photographed bullets in flight at the exposure time of 13 millionths of a second; Rayleigh punctured a soap bubble and, a thousandth of a second later, took a clear photograph of the bubble's collapse. As one learns from the introduction by Keith Gordon Irwin, Worthington in 1894 "showed the drawings of a series of thirty stages in the splash of a ball of mercury falling through the space of three inches against a flat piece of glass. Since the stages followed each other faster than the eye could distinguish them, the lecturer had illuminated them individually by the vivid and virtually instantaneous flash of a lightning-like electrical discharge." One of his discoveries was that a large drop of mercury falling on a flat, hard surface becomes one drop surrounded by 12 small drops, all equal in size and spaced around it to form a delicate, jeweled crown. Worthington describes the mechanism of high and low splashes, how bubbles are formed by certain kinds of splashes, what happens below the surface, the transition from the smooth, or "sheath," splash to the rough, or "basket," splash, the splash effect of solid spheres, the phenomenon that appears with an increase in the velocity of entry of a rough sphere. He explains graphically the special and ingenious apparatus he had to make for his observations. The book is characterized throughout by extraordinary patience and curiosity and by a wonderful enthusiasm and innocence typical of first-class scientists from Archimedes to Einstein. For readers of any age from 11 or 12 on, and even younger children will enjoy the pictures.

THE LAWS OF PHYSICS, by Milton A. Rothman. Basic Books, Inc., Publishers ($4.95). Older teen-agers and grownups will find this a top-notch introduction to the laws, principles, hypotheses, models, paradoxes, philosophical enigmas and brilliantly successful theories of physics from the 18th century to the present. None of the major ideas are neglected, almost all are explained with exemplary clarity and the reader derives the elation of seeing the structure of physics as a whole with all the connections and interdependency of the parts. Rothman elucidates, among other things, the conservation laws and the laws of motion, forces and fields, relativity theory (extra-high marks for this), probability and entropy, the workings of quantum physics, the kaleidoscope of elementary particles. A little mathematics is introduced, but at the simplest level, and the author is so adroit that he can even open up the beautiful ideas of Hamilton and Lagrange without using any equations. Recommended.

THE NEW WORLD OF PHYSICS, by Arthur March and Ira M. Freeman. Random House, Inc. ($4.95). This book, based on an essay by March, late professor of theoretical physics at the University of Innsbruck, and published in 1957 in a German encyclopedia, is a skillful survey of the concepts of classical physics, the transition of modern physics, including the theory of relativity and the work of Max Planck, Niels Bohr and others, the founding of quantum mechanics, the crises of causality, the indeterminacy relations and the "dematerialization" of the physical world. Written with an intelligent appreciation of the nonspecialist's difficulties in following such heady stuff and of the need for periodically repeating and rephrasing various abstruse principles and concepts, the essay will be meaningful to serious adult readers and to bright high school students.

THE ABC's OF CHEMISTRY, by Roy A. Gallant. Doubleday & Company, Inc. ($3.95). A brief, large, illustrated dictionary defining about 500 terms from "abrasive" to "X ray" and including such features as a periodic table, a chart of the elements with dates of discovery, a list of Nobel prize winners and a caloric table. For readers from about 12 to 15.

MOLECULES TODAY AND TOMORROW, by Margaret O. Hyde. McGraw-Hill Book Co., Inc. ($3.25). A capable, factual report of what is known about

molecules, touching on such topics as molecular motion, low-temperature phenomena, giant molecules, DNA, viruses, ACTH and living molecules on other worlds. Twelve and over.

THE STORY OF OUR EARTH, by Arthur N. Strahler. Home Library Press ($2.95). A Columbia University geomorphologist explains the formation of the planet earth, the separation of the continents and ocean basins, the sources of the earth's heat, the structure of its interior, the knowledge to be gained from earthquakes, the earth's mantle and crust, the charting of the ocean floors and the building of mountains. It takes sureness and skill to explain the modern theories of earth science to readers not sophisticated in the subject; the author has both, and his book will answer many questions for young teenage readers. Fully illustrated with diagrams and eight pages of color photographs.

OUR QUAKING EARTH, by Elliott Roberts. Little, Brown and Company ($4.50). Stories of famous earthquakes, superstitious beliefs about earthquakes, how earthquakes happen, the spreading of earthquake waves, earthquakes under the sea, detection instruments and methods. A competent, well-written, pleasantly anecdotal popularization by a former official of the U.S. Coast and Geodetic Survey. Photographs. Twelve and up.

YOUR CHANGING EARTH, by Hy Ruchlis. Harvey House, Inc. ($2.50). How the earth began, how earthquakes and volcanoes help to make mountains, how heat, cold, wind, water and living things, including man, change the land. Palatable for ages six to 10.

MATHEMATICS: FIRST S-T-E-P-S, by Lillian R. Lieber. Franklin Watts, Inc. ($2.95). Mrs. Lieber's popularizations are inimitable. In the many books she has written about mathematics in collaboration with her late husband (who was the illustrator) she has made a place for herself in the popular literature of mathematics with her clear explanations and the peculiar format of the presentation. Each phrase is put on a separate line, which achieves not free verse but a kind of jerky rhythm that arrests attention and evidently pleases many readers. This book revolves around a single theme, namely that mathematics is like a game that uses certain equipment (the elements), consists of certain operations (addition, subtraction and so on) and follows certain postulates (the rules). Mrs. Lieber shows how this works out not only for arithmetic but also for algebra, simple and complex geometries, mathematical logic and even the theory of relativity. Her explanation is fairly convincing for arithmetic but somewhat superficial and not particularly enlightening for the higher branches. Altogether this book is inferior to most of Mrs. Lieber's other writings and rather old-hat if you have read a number of them. But a fan of hers or one who has never before sampled her work may find this volume instructive. For young teen-agers.

50 MATHEMATICAL PUZZLES AND ODDITIES, by Nicholas E. Scripture. D. Van Nostrand Company, Inc. ($2.50). To find out if a number is divisible by 4 it is only necessary to see if 4 is a factor of the last two digits of the number. If 8 is a factor of a number, its last three digits must be divisible by 8. If you write down any number and then subtract from it any smaller number that contains the same digits, the result will always be divisible by 9. There are many distinct ways of writing the nine digits so that the result is always 100. ($100 = 1 + 2 + 3 + 4 + 5 + 6 + 7 + (8 \times 9)$.) It is possible to find two fractions that will give the same answer whether they are multiplied or added together. (The algebraic form must be of the type x/y and $x/(x - y)$.) If you want to square a number ending with the figure 5, knock off the 5, multiply the number that remains by the next highest number and add 25 to the answer. If it were possible to take a sheet of paper a thousandth of an inch thick and double it over itself 50 times, how thick do you suppose the resulting wad of paper would be? (Answer: More than 17 million miles. Now go to the corner.) Scripture's thimble-sized book has 50 agreeable and instructive japes of different kinds taken from arithmetic, algebra, geometry and topology. All are pretty well known but they are nicely and simply presented and packaged, together with solutions. There is something here for almost anyone who can face a simple fraction without blacking out.

MATHEMATICAL DIVERSIONS, by J. A. H. Hunter and Joseph S. Madachy. D. Van Nostrand Company, Inc. ($4.95). About number relations and properties, simple paradoxes, magic squares, topological problems, Diophantine equations, geometric dissections, the ham-sandwich theorem, chess puzzles, alphametics (arithmetic puzzles done with letters), probability questions and logical exercises. Answers and solutions. For bright teen-agers and mathematically literate grownups.

Biological Sciences

TO KNOW A FLY, by Vincent G. Dethier. Holden-Day, Inc. ($3.75). This little book describes the fly with immense enthusiasm and even affection. The author is professor of zoology and physiology at the University of Pennsylvania and has spent years studying flies, doing experiments with and on them, learning their construction and their habits. A small fly (but not by any means the smallest) weighs about seven-millionths of a pound. Its wings serve both to keep it aloft and as a propeller. To remain air-borne it must beat its wings as many as 200 times a second. Among its remarkable accomplishments is its ability to land on the ceiling, a feat that puzzled entomologists for years and led to controversy as to whether the fly did this by executing a half-roll or an inside loop. Both views are wrong. It cruises close to the ceiling in a normal position and then "with incredible nimbleness" reaches up and back over its head with its front feet until they touch the ceiling, whereupon the fly somersaults into position. Experiments have been performed to ascertain if a fly has a sense of taste and, if so, how acute it is (it has a sense of taste that is mediated by its feet, certain of its hairs and its proboscis, and it likes things that taste sweet to us and rejects those that taste salty, sour or bitter to us); how much flies eat and drink; if males and females have different tastes (they do, partly: males prefer sugar, females protein during the first six or eight days of life when they are building their eggs, thereafter sugar); their methods of navigation (flies dance, as bees do, but the dance is not a method of communication, merely an efficient search pattern); if flies can learn or be conditioned (they cannot). As an example of the ingenuity of the experiments, one biologist was able to place a fruit fly in a chamber where he could measure its respiration during flight, and at the same time he equipped it with the following instruments: platinum electrodes to record the nerve impulses to its wing muscles, a glass needle connected to a phonograph pickup to record the mechanical movement of the muscles and a thermistor to measure changes in body temperature. Another experiment involved brain surgery to cut the nerve connected with the fly's crop and thus find out why it keeps eating long after

EXPLORATION discovery CONTROVERSY

The world of science in books

EARTH, MOON, AND PLANETS, Revised Edition *by Fred L. Whipple.* A distinguished astrophysicist brings us the latest information on the planets and satellites of the solar system – their atmospheres, temperatures, surface conditions. Includes detailed descriptions of the Moon's nature from sources such as the USSR's unmanned Moon rocket and Mariner II. 166 illustrations plus a star chart and planet finder current through 1970. *Harvard Books on Astronomy* $6.50

RADIO ASTRONOMY TODAY, *Edited by H. P. Palmer, R. O. Davies and M. I. Large.* An introduction to radio astronomy, taking the reader to the frontiers of knowledge in the field. $6.00

THE DISCOVERY OF NEPTUNE, *by Morton Grosser.* "The fullest, most detailed study both of the main circumstances and the side lights . . . a first-rate scientific report any reader can follow."—JAMES R. NEWMAN, *Scientific American* $4.95

A SOURCE BOOK IN PHYSICS, 8th Printing, *by William Magie.* The great physicists from the Greeks down through 1900 describe their famous discoveries. A reprint of a well-known and valuable work unavailable for several years. $10.00

SET THEORY AND ITS LOGIC, *by Willard Van Orman Quine.* The distinguished philosopher and mathematician presents a unique introduction to abstract set theory and to various axiomatic systematizations of the subject. *Belknap Press.* $5.95

DARWINIANA: Essays and Reviews Pertaining to Darwinism, *by Asa Gray; Edited by A. Hunter Dupree.* Amid a storm of controversy and protest from religious and scientific figures, Asa Gray, America's foremost 19th-Century botanist, supported Darwin's findings. These essays remain a distinguished contribution to Darwinian literature. *John Harvard Library.* $5.00

ANIMAL SPECIES AND EVOLUTION, *by Ernst Mayr.* "A truly great work . . . a landmark in the biology of our age."—THEODOSIUS H. DOBZHANSKY. "Indispensable for everyone interested in evolutionary biology."—SIR JULIAN HUXLEY. *Belknap Press.* $11.95

THE ARMS DEBATE, *by Robert A. Levine.* From advocates of total disarmament to those who urge preventive war, Levine examines what people really do think about arms policy and why. *Center for International Affairs.* $6.50

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its hunger has apparently been satisfied. In spite of the author's many jokes, which are not funny, and droll cartoons that are not droll, this is a superb natural-history book and is highly recommended for anyone 12 or older.

MANGROVE ISLAND, by Marjory Bartlett Sanger. The World Publishing Company ($2.95). The mangrove tree is one of nature's freakish inventions, a perfect example of the infinite ingenuity of biological adaptation. It flourishes in tropical areas, throughout the hot latitudes, on mud flats and in tidal estuaries, in salty marshes and lagoons. It is one of the few trees that grow in water, belonging to a group of plants called halophytes, literally "salt plants"; it does not merely tolerate salt but apparently receives nourishment from it. The mangrove preempted for itself a special ecologic niche where it need not fear competition from other trees. Its aerial roots lift it out of currents and tides and obtain oxygen from the air through tiny openings in their bark; other roots descend from the branches in a snakelike way and reach the sandy or muddy ground below the surface of the water. Its leathery leaves are fashioned for storing moisture to use when the rainy season is over. It produces a long, slender, slightly curved pencil-shaped seed pod that is viviparous and can sustain long ocean-current travels. When the seed finally strikes a submerged sand barrier, it can penetrate fairly quickly and take root. The mangrove is the great land-builder of the Tropics. Given half a chance it will grow, reproduce its kind quickly and by means of innumerable densely packed roots act as a trap for sand, soil and ocean debris, thereby slowly building up entire islands in the shallows of oceans and rivers. In mangrove forests, which are to be found in such places as the Malay Archipelago, the coast of Central America and the Ten Thousand Islands of southwest Florida, a remarkable variety of wildlife dwells. From time to time the islands are all but destroyed by tropical storms; if the mangrove builds too well and its island rises above the water level, other trees may dispossess it. But it is prolific and tenacious; its products, which include tannin, are not systematically collected by man, and the mangrove population is, for the time being at least, in no danger of exhaustion. Mrs. Sanger's book tells this story well. Recommended for young teen-agers as well as older readers.

THE FISHES, by F. D. Ommanney and the editors of *Life*. Time Inc. ($3.95). A good book in the Life Nature Library. Ommanney's narrative deals with many aspects of the life of the immense and immensely varied tribe of fishes, of which at least 20,000 species are known (there are very likely many others of whose existence we have no knowledge at all). He discusses the evolution of fishes and their extraordinary adaptations that enable them to live in lightless abysses, the various mid-depths "where no shore, no bottom and no surface is ever encountered," in the high Tropics and the polar regions, among rocks and reefs, along beaches, in bays, rivers, brooks, pools and torrents, in mud cocoons and even in black caves 1,000 feet underground; the methods of reproduction; the great migrations; the fascinating aspects of communal living in the sea, among which are the cleaning relations (at least 26 species are known to make cleaning and grooming of other fishes their "primary profession," including the small wrasse that "goes into a customer's mouth, works over the teeth and proceeds right on down into the gullet until its client signifies, by snapping its jaws a few times, that it is satisfied"), parasitism, schooling, predation and simple commensalism. Fine illustrations, many in color and quite spectacular. The pictures are for any youngster, and the text is for ages 12 and up through adulthood.

THE FIRST BOOK OF WEEDS, by Barbara L. Beck. Franklin Watts, Inc. ($2.50). Weed is what one calls a plant one does not like for any of several reasons—agricultural, aesthetic, economic and so forth. But dislikes are often mere provincialisms, and one man's weed may be another man's darling. Goldenrod, for example, is the official state flower of Kentucky and Nebraska; bluebonnets are weeds only in Texas. Miss Beck's book is an unpretentious, well-written primer that briefly describes a wide variety of plants (which here and there are savaged as weeds) such as crab grass, creeping buttercup, mock pennyroyal, wormwood, poison hemlock, poison ivy, spearmint, locoweeds, Queen Anne's lace, devil's-shoestrings, digitalis, fleabane, black nightshade, bouncing Bet, vegetable oyster, shepherd's-purse, goldenrod, horsetail, dog fennel, heal-all, scarlet pimpernel, clammy cockle, lady's-thumb, cocklebur, beggar-ticks, tumbleweed and chicory. Some species are useful as drugs, food or flavoring; some are poisonous; some swallow up insects; some help to forecast changes in the weather; some cause itching or sneezing or simply infuriate suburbanites by tak-

ing over their lawns. For anyone older than eight; attractive pictures.

HUMAN SEX AND HEREDITY, by Roger Pilkington. Franklin Watts, Inc. ($2.95). This is surely one of the best books ever written at the junior high school level on the subject of sex and heredity. All the things parents should tell teenage children about sexual anatomy, sexual function, sexual desires and sexual intercourse itself but, for a variety of reasons, frequently fail to tell are here set down in a perfectly clear, unassuming manner without a trace of prurience, false modesty or dewiness. Pilkington neither preaches nor advocates nor cautions; he simply explains and does a first-rate job. His book also discusses the central ideas of heredity as they are known to modern science. The illustrations are wholly inadequate, but as a self-educator for the young the book deserves a medal.

THE FRIENDLY DOLPHINS, by Patricia Lauber. Random House ($1.95). Miss Lauber has written a likable book about these likable mammals, without exaggeration or nature-fakery. The story concerns dolphin life, the behavior of dolphin infants, dolphin play and intelligence, dolphin echo-location and other things that students and trainers have learned about these remarkable creatures. Eight to 11.

CORAL REEFS, by Lois and Louis Darling. The World Publishing Company ($2.95). An agreeable introduction that describes coral polyps, how they feed and live, the limestone mountains they build, the main types of fringing and barrier reefs and atolls and the activities of people who live on the atolls. For ages 10 to 14.

EXPLORING BIOLOGY, by Tad Harvey. Doubleday & Company, Inc. ($2.95). A brief illustrated survey of living things and of some of the important ideas of biological science. Among the topics are the method of classifying plants and animals, the understanding gained through biochemistry of the functions of the cell, the laws of genetics and the emergence of man. An easy-to-read sampler that will appeal to young teen-agers.

OUR ANIMAL RESOURCES, by Frederick L. Fitzpatrick. Holt, Rinehart & Winston, Inc. ($2.50). An informative account for teen-agers of the economic importance of animals as food, sources of drugs, chemicals, leather, feathers, furs, fertilizers, oils and many other products.

Also discussed are conservation, breeding and the possibilities of new sources and new domestications. Photographs.

IN PREHISTORIC SEAS, by Carroll Lane Fenton and Mildred Adams Fenton. Doubleday & Company, Inc. ($2.95). Simple descriptive paragraphs about the creatures that lived in the prehistoric soup. Many pictures. For youngsters up to 12, particularly beachcombers, who can pick up shells of animals that are related to the ancient forms.

Social Sciences

THE SEARCH FOR EARLY MAN, by the editors of *Horizon Magazine* and John E. Pfeiffer. American Heritage Publishing Co., Inc. ($3.95). The story of the evolution of prehistoric man from about two million years ago to 8000 B.C. Discoveries in two regions, the Dordogne area of southwest France and Olduvai Gorge in East Africa, where pioneer work has been done by L. S. B. Leakey, his wife and other workers, are the basis of the account. The discoveries include the Lascaux cave murals, the most important examples of Paleolithic art that have yet been found, and fossil remains and tools dug up at Neanderthal sites at Combe Grenal and Abri Pataud. Excavations at Olduvai Gorge, which Pfeiffer calls the richest and most remarkable site for the remains of prehistoric times, have yielded the skull bones and several teeth of a formidable teen-age ape man to which has been given the name *Zinjanthropus boisei*. Zinj, as the experts chummily refer to it, shared Olduvai with a related species of ape man that had a brain of equal size but weighed only 40 to 90 pounds (Zinj was 120 to 150 pounds). From ape men of this type were descended the creatures that first appeared about 400,000 years ago, whose fossils have been found in Java, China, Germany, England and Israel as well as Africa, and that are now regarded as the earliest form of true man. Many illustrations—52 in color—of prehistoric paintings, carvings, fossils and artifacts, and a number of imaginative reconstructions, some of which are lurid. A commendable introduction to archaeology, anthropology and related disciplines. For junior as well as senior high school students.

THE STORY OF WRITING, by William and Rhoda Cahn. Harvey House, Inc. ($3.50). The Cahns' book is slightly misnamed; it is a mixed bag with chapters not only on writing but also on other aspects of communication. The story begins with the Altamira cave murals and courses through such topics as Sumerian pictorial tablets, the Peruvian tallying device called the quipu, cuneiform writing, Chinese letters, Egyptian hieroglyphics, the Phoenician alphabet, the Greek boustrophedon, the Roman, Russian and Hebrew alphabets, Amharic characters, runic, Arabic numerals, the Chinese abacus, the papyrus scroll, the wax writing tablet and stylus, reed pens used in the Near East, early graphite pencils, North American ideographic writing, medieval manuscripts, the invention of movable type, the evolution of type faces, and modern machines that can do everything from solving mathematical problems and printing pay checks to following missiles and elections. Fully illustrated and understandably written, with a bibliography and a glossary. Ages 12 to 16.

RIVERS OF THE WORLD: VOLUME II, by Geoffrey Whittam and others. Henry Z. Walck, Inc. ($3). Brief essays, pleasantly written, that describe the course, surroundings, history of exploration and economic importance of four famous rivers: the St. Lawrence, the Nile, the Rhine and the Murray—the only big river in Australia. Drawings. About eight to 12.

THE PICTURE HISTORY OF INVENTIONS: FROM PLOUGH TO POLARIS, by Umberto Eco and G. B. Zorzoli. The Macmillan Co. ($14.95). The collaborators on this volume, which is translated from the Italian, represent two strikingly different spheres of interest. Eco is professor of aesthetics at the University of Turin and Zorzoli is a nuclear physicist at the Polytechnical Institute in Milan. The two cultures produce a healthy and attractive offspring. Beginning with prehistoric tools and dwellings, the book traces the architecture of invention through mining and metallurgy, water and land transportation, weapons, the building of locks, canals and reservoirs, the harnessing of wind, the construction of cathedrals, glassmaking, printing, the measurement of time, the invention of the telescope and scientific instruments, steam, electrical and internal-combustion engines, the telegraph and telephone, photography, human flight, synthetic materials, the electronic and atomic age. A central narrative gives the social, political and cultural setting, the circumstances that have affected and have been affected by scientific and technical achievements. More than 800 illustrations (32 in color) are of course the backbone of the book; unfortunately

they are often too small or not sharply and cleanly reproduced. All the same, their number and variety make an engrossing display that draws the reader from page to page; their impact is enhanced by unusually informative captions. Grownups, teen-agers and even youngsters, who while unable to follow the text can appreciate the pictures, will find this a delectable book.

THE STORY OF DAMS, by Peter Farb. Harvey House, Inc. ($3.50). The author deals with several aspects of the subject of hydrology. He explains why we build dams and how they work; the difference between gravity, arch and buttress dams; methods of construction; how large rivers are harnessed, floods prevented, irrigation and drinking water provided, how electricity is generated. The highest dam in the world, one learns, is Grand Dixence in Switzerland (940 feet); the largest dam is Fort Peck in Montana (volume, 126 million cubic yards); one of the largest man-made lakes in the world was created by Hoover Dam, which can store 10 trillion gallons of water ("enough to furnish every person in the U.S. and in Canada with more than six railroad tank cars filled with water"). A new dam, Kariba on the Zambezi River in Africa, will surpass Hoover in water storage and will take six years to fill; the longest reservoir in the world, behind Oahe Dam in South Dakota, stretches for 250 miles; the new hydroelectric dam under construction in Bratsk in Siberia will, when completed in 1965, produce more than twice as much power as Grand Coulee, which itself turns out enough electricity to light a lamp in every home in the U.S. Photographs. Junior high school level.

CERAMICS: STONE AGE TO SPACE AGE, by Lane Mitchell. McGraw-Hill Book Co., Inc. ($2.50). This volume in the "Vistas of Science Books" series produced by the National Science Teachers Association is a sound summary of the development of ceramics from the brick-making of ancient times—long before recorded history, as one can tell from archaeological finds—to the highly sophisticated ceramic technology of today whose products are used in architecture, in many branches of manufacturing, in the building of dams, in the memory circuits of computers, in atomic physics, in the building of spacecraft. Many photographs. For both junior and senior high school students.

GLASS AND MAN, by Anne Huether. J. B. Lippincott Company ($4.50). The

author, an educational aide at the Corning Museum of Glass, tells the story of glass from ancient times and relates it not only to other scientific and technological advances made during various periods of history but also to surrounding social and political circumstances. Occasionally the historical packing seems a little contrived, but on balance this is an interesting record of the growth of glassmaking, of the evolution of methods of glass chemistry and glass cookery, of the development of glass as an art form, of its uses in everyday life, industry and science.

A HISTORY OF FLIGHT, by Courtlandt Canby; A HISTORY OF ROCKETS AND SPACE, by Courtlandt Canby. Hawthorn Books, Inc. ($5.95 each). These two books appear in the New Illustrated Library of Science and Invention. Each volume is about 100 pages long and has attractive illustrations, some old, some new, many in color. The text is hurry-up, discursive and not irreproachable as to accuracy. But it is not wildly wrong and it patters on more or less unobtrusively alongside the pictures. Either book would make a nice present for someone who wants to fly over these subjects but does not want to land to make a more careful examination of the terrain. For any reader who is older than 12 or 13.

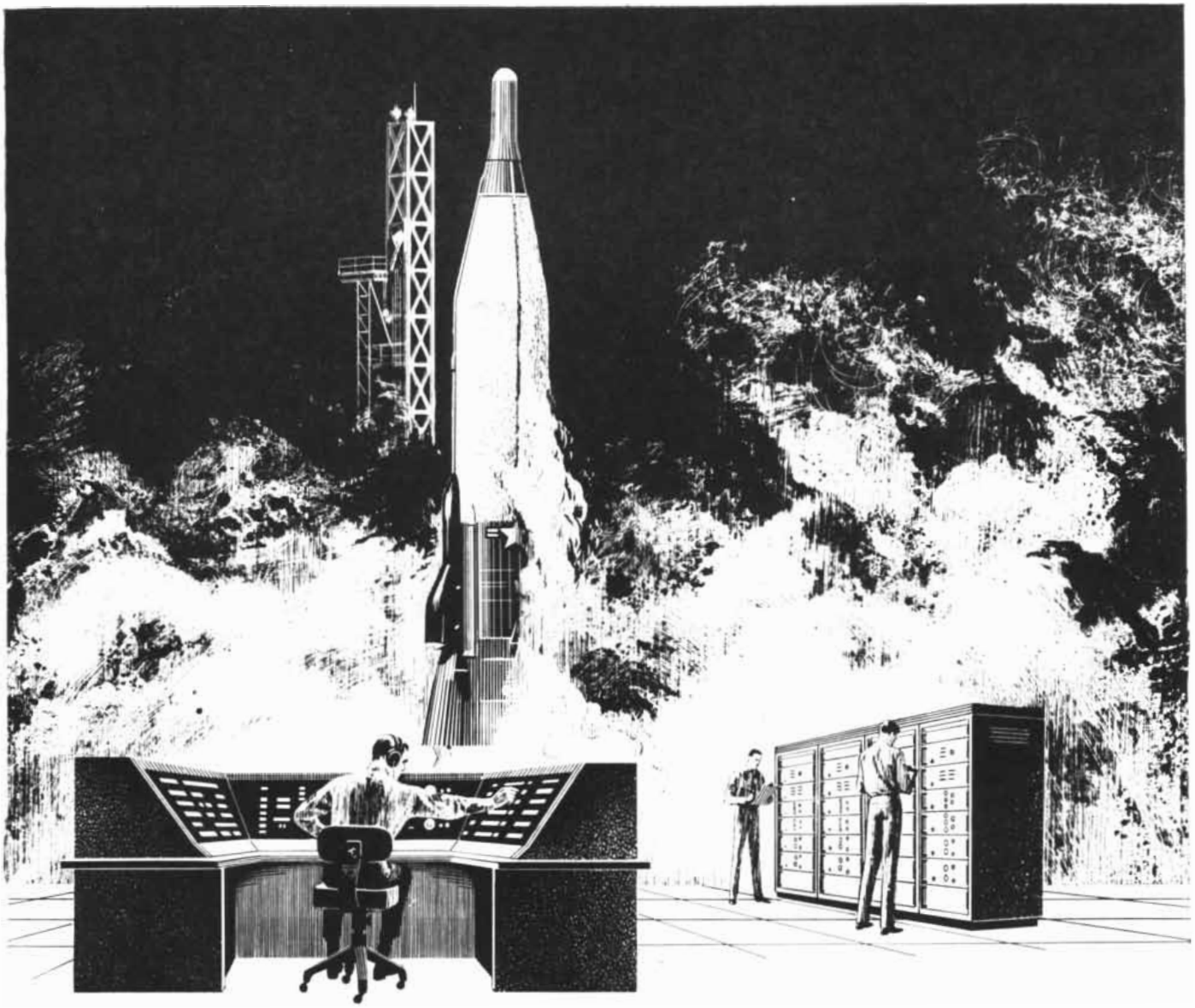
YOUNG SCIENTIST LOOKS AT SKYSCRAPERS, by George Barr. McGraw-Hill Book Co., Inc. ($3). One can pass a construction job every day for months, stop to watch it, become completely engrossed in the proceedings every time and still have only the fuzziest notion of how the building is going up, how the parts hold together, why the structure does not collapse and so on. Barr's book is an admirable clarifier and explainer, so good that it should come in pocket size, like a bird or flower guide, for sidewalk watchers. It tells about the building of the foundation, the different shapes of the structural parts, the methods of connecting steel, the assuring of vertical accuracy, the uses of cranes, air conditioning, the installation of the network of pipes and wires. The style is uncluttered and matter-of-fact; the coverage reaches to almost any question the average spectator could think of. Clean, draftsman-like illustrations. Ages 11 and up.

CAMERAS WORK LIKE THIS, by Maurice K. Kidd. Roy Publishers, Inc. ($2.95). Just what the title says, and reasonably open to the understanding of teen-agers who make pictures, would like to make better pictures and want to know something about the machinery, the materials and the processes.

General

DISCOVERING SCIENTIFIC METHOD, by Hy Ruchlis. Harper & Row, Publishers ($3.95). It is pushing matters to say that this book explains the nature of scientific method, whatever this exalted but controversial concept may mean. Nevertheless, the author has a nice idea and his book is not without originality. It sets before the reader a set of "science puzzle pictures," which are intended to bring out principles and procedures used in gaining knowledge about the physical world, in formulating hypotheses, designing experiments and taking measurements. For example, a photograph of a car on a flooded street looks crazy until the book is turned upside down and one realizes that the photograph as presented is not of the car itself but of its reflection in a pool of still water. Another photograph shows the shadow of a telephone pole cast in a southern Mexican city at noon; on the basis of one or two accompanying facts the reader is asked to determine which direction is north, using the shadow as a guide. Still another picture is that of a portion of the moon's surface, and one is required to determine from the variations of light and dark which are the craters, plateaus and mounds. A cloud-chamber photograph of the tracks made by subatomic particles is enlisted to explain interpretations in physical research; a photograph of two sets of girls raises the question whether they are in fact three pairs of identical twins or three girls and their mirror image. On the whole this approach works out well and should help to broaden the perspectives of alert youngsters 13 and up.

THE LANGUAGES OF SCIENCE. Basic Books, Inc., Publishers ($4.95). This book consists of eight essays based on talks given in England under the sponsorship of the Granada Television Network and the British Association for the Advancement of Science. Various facets of the present knowledge of communication are considered: John Wolfenden discusses the cultural gap between scientists and nonscientists; Hermann Bondi, the different forms of communication between scientists themselves; Eric Ashby, the popularization of science; George Beadle, the language of the gene; James Gray, the language of animals; Lord Adrian, the working of the brain; H. J. Eysenck, the effects on com-



Marquardt needs electronic engineers

Marquardt's latest assignment in the missile trainer-simulator field is to develop and produce the Atlas E and F missile launch crew procedure trainers for the Air Force Ballistic Systems Division. The new Marquardt trainer represents another advance in simulation technology since it is a completely solid-state digital system. It will accurately simulate all operational procedures — from alert to launch — and will encompass the complete spectrum of malfunctions. The Marquardt systems will be used at various SAC bases to train missile combat crews who are required to operate, maintain, and control the Atlas.

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munication of different psychological phenomena, among them emotional disorders; E. V. Appleton, electromagnetic means of communication. The introduction by Philippe Le Corbeiller is so good one wishes that it could have been much longer. Older teen-agers and adults.

A SENSE OF WONDER, edited by Dorothy Shuttlesworth. Doubleday & Company, Inc. ($3.50). Selections from the works of 19 eminent writers on nature, including William Beebe, Henry Beston, John Burroughs, Rachel Carson, Charles Darwin, Albert Einstein, W. H. Hudson, John Muir and Henry Thoreau. The material has been well chosen to show the responses of sensitive and perceptive observers to winter in the Antarctic, the kelp forests of the Pacific, auroras, shooting stars, the island of Madagascar, the discovery of the shape of the earth's orbit, the ways of the water spider, ocean waves, winter animals and so on.

THE CENTURY OF SCIENCE, by Watson Davis. Duell, Sloan and Pearce ($5.95). For more than 40 years Watson Davis has served science as an editor, reporter, publicizer and educator. Much is owed him by the scientific community and by those who when they were students were introduced to the subject by his *Science News Letter* and had their interest enlarged by other activities of his such as science fairs, science clubs and the annual Science Talent Search. In this book he gives a once-over-lightly to the main scientific advances of the 20th century: the atomic revolution, geography and geology, automation, aviation, rocketeering, electronics, genetics, biochemistry, medicine, psychology and psychiatry, new teaching methods and so forth. Superficial but journalistically competent. Teen-agers and up.

WANTED: AMATEUR SCIENTISTS, by Robert Froman. David McKay Company, Inc. ($3.25). Science needs amateurs, those who in their free time and for fun will be star watchers, telescope makers, number jugglers, botanists, bird watchers, butterfly collectors, shell gatherers, stone finders, skin divers, archaeological diggers, cave explorers, experimental gardeners and so on. The hobby not only gives personal satisfaction but also contributes usefully, as it has in the past, to the increase of scientific knowledge and the nourishment of the culture of science. This sensible and plain-spoken book gives explanations of the achievements of amateur scientists, describes opportunities and lists books and organizations that can help the beginner.

AEROSPACE GERIATRICS

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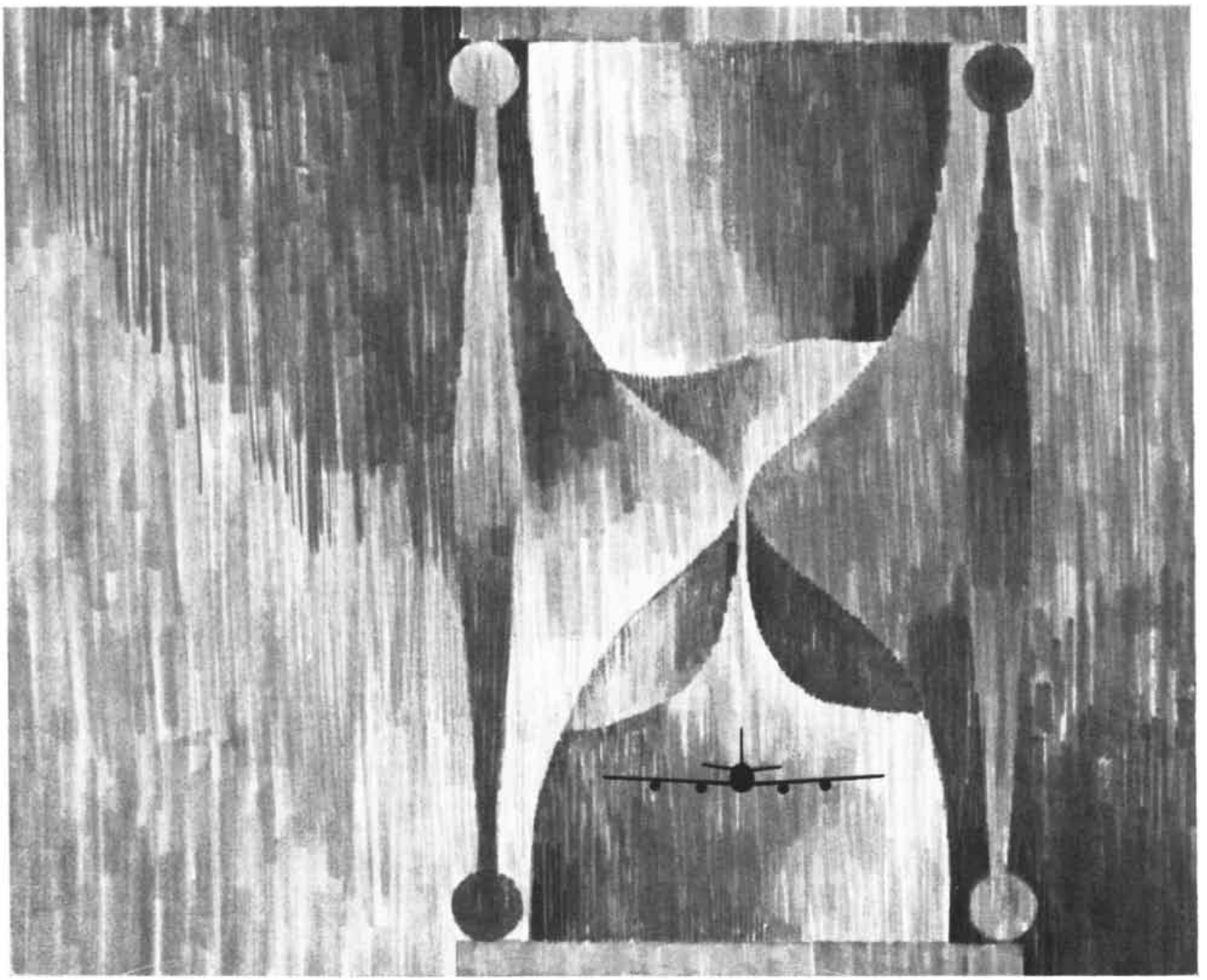
In aircraft parts, as in men, excessive stress accelerates the aging process. And stress aging per hour varies for each aircraft. Yet the present way of determining servicing schedules is based primarily on hours flown. □ Now Douglas researchers have developed a device which, when installed on an aircraft, provides a more positive method of determining check-up times for aircraft parts. □ Called a "Service Meter," and weighing less than 1½ pounds, the Douglas unit computes the accelerations encountered by its aircraft in relation both to number and severity. It allows servicing to be performed on the basis of the true *work age* of parts, and will be an important aid to maintenance procedures that keep aircraft young. □ Research like the foregoing has helped build the Douglas reputation for producing the world's most reliable aircraft.



The "Service Meter" is one result of research programs in 23 broad technological areas now under way at Douglas. Some relate to present programs like SATURN S-IVB, ZEUS, DELTA, DC-9 and SKYHAWK. Others are oriented on great aerospace developments of the future.

DOUGLAS

ANNUAL INDEX

The following index lists all the authors and articles that appeared in SCIENTIFIC AMERICAN *during 1963. Also indexed are "Mathematical Games," "The Amateur Scientist" and the principal book review in each issue.*

AUTHORS

ARTICLES

MATHEMATICAL GAMES

THE AMATEUR SCIENTIST

BOOKS

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THE WESTERN GREEKS: THE HISTORY OF SICILY AND SOUTH ITALY FROM THE FOUNDATION OF THE GREEK COLONIES

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