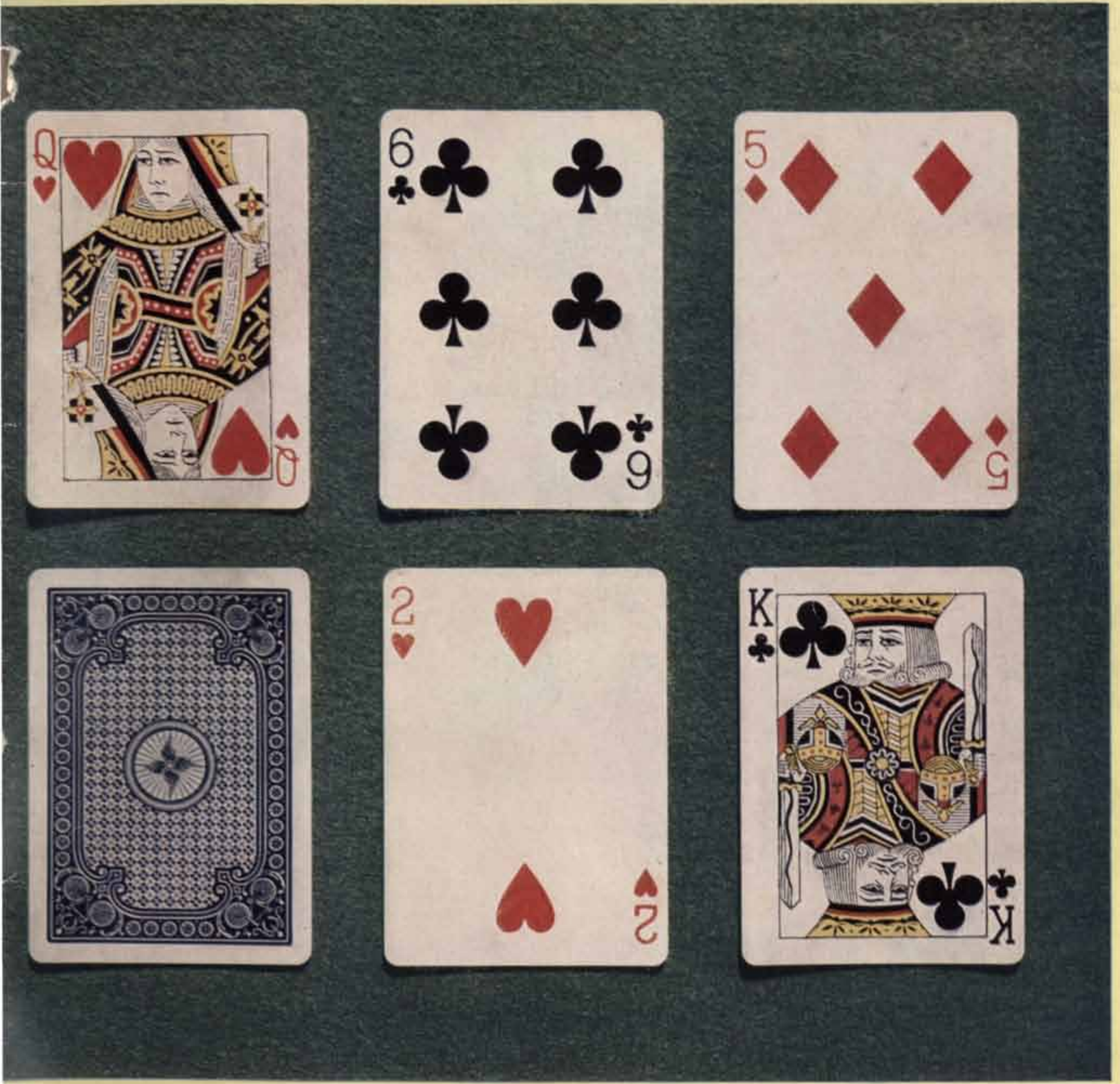
# SCIENTIFIC AMERICAN



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January 1951

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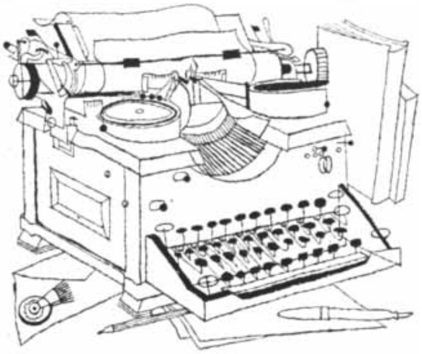

# LETTERS

Sirs:

In a so fundamental and rapidly growing field as cytoplasmic inheritance, it is inevitable that differences in emphasis and point of view will arise. "Partners of the Genes," the article by T. M. Sonneborn in your November issue, gives the impression that the plastids of plants are something different from mitochondria, the small bodies found in the cytoplasm of many kinds of cells. He states that "The plastid is the only visible, unquestionably normal cytoplasmic structure that has been shown beyond reasonable doubt to be self-duplicating, mutable and the basis for cytoplasmic inheritance of a trait. There is partial and more or less suggestive evidence, however, for a number of others." Sonneborn states that the chloroplasts arise from smaller colorless bodies known as leucoplasts. This is by no means the general case. It is true that the various plastid forms are interconvertible, and that the leucoplast is a colorless plastid. However, the work of a number of investigators, in particular Earl Newcomer of the University of Connecticut, has shown that plastids (including green plastids) arise from visible undifferentiated mitochondria.

Newcomer, in 1946, stated: "The results of this study show that there are no distinctions in morphology, structure, chemistry, function, staining behavior, or behavior during mitosis among the mitochondria in plants whereby one can separate them into categories of organelles among which there is no genetic relation."

Our own paper, to which Sonneborn refers, brings out the point that the enzymic deficiency which characterized the mutant mitochondria *also occurred in the plastids of the same cells.* Furthermore, in other cases mitochondrial mutants were found which were totally unable to mature as plastids, and others in which all stages of intermediacy with respect to plastid-forming ability were found. The figure of mutant plastids in Sonneborn's article illustrated slight plastid modification. A remarkably similar figure can be found in the August, 1943, issue of *Phytopathology,* where we, in addition, showed further mitochondrial modifications of the type described in this letter, some of them showing virus-like characteristics. These observations have provided additional evidence for the thesis that the mitochondria and plastids of higher plants are genetically linked, *i.e.,* that plastids can be considered mitochondrial elements in a state of differentiation. Thus mitochondria are visible basic elements of the cell, capable of self-duplication, mutation and modification, and the only elements, besides the nuclei, for which those properties have been demonstrated. Mitochondria in plants can differentiate into plastids, *e.g.,* chloroplasts (containing the green matter of higher plants), chromoplasts (red, yellow), or leucoplasts (colorless starch-formers).

These considerations provide a unifying view of cytoplasmic inheritance. The status of cytoplasmic factors such as kappa in Paramecium, sigma in Drosophila, kinetosomes, centrioles and blepharoplasts is uncertain, since their origins have not been fully established.

The mitochondria of plant and animal cells are fundamentally homologous structures, as shown by their morphology, chemistry, enzymology and reaction to vital dyes. The property of differentiation is not limited to plant mitochondria, because in animals we have evidence which we believe shows that they can develop, among other organelles, into melanin granules, causing dark skin or the dark pigmentation of some cancers (melanomas). In most cell types some of the mitochondria may remain undifferentiated. Although in the black cancers of mice it could not be established


**Scientific American,** January, 1951, Vol. 184, No. 1. Published monthly by Scientific American, Inc., 24 West 40th Street, New York 18, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer. Entered at the New York, N. Y., Post Office as second-class matter June 28, 1879, under act of March 3, 1879. Additional entry at Greenwich, Conn.

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that the melanin granules constituted a mitochondrial mutation, the authors were able to demonstrate that the granules represented modified mitochondria, the modification leading to the presence of specific enzyme systems which brings about the formation of dark brown pigment: melanin.

The authors could show that as a result of hereditary abnormalities of the mitochondria in certain plants, a cellular pathology highly similar to that occurring in certain virus diseases could be produced. These data, together with chemical considerations, led us to the hypothesis that some disease-causing mitochondria ultimately differentiate into viruses. We were able to demonstrate ribose nucleoprotein in plastids, which were shown to be free of virus contamination. Many plant viruses consist of or contain ribose nucleoprotein. It was also shown that through mutation mitochondria become modified so that there is a progressive reduction in chemical and enzymic complexity. We called attention to the fact that normal and mutant mitochondria can be shown to compete in the cytoplasm and that the observed conditions allowed the prediction that an intraplasmatic natural selection will occur. Extrapolating these actually observed trends would lead to the development of ribose nucleoprotein containing particles, mutable and with the ability to reproduce their properties. The end point of the derived agents, which are progressively reduced in size and chemical structure, would be the ribose nucleoprotein component: plant viruses. It was actually found that the greater the reduction in size and chemical complexity of the mutated mitochondrial derivatives, the greater their viruslike action. When one considers all agents known to cause diseases in plants, one sees that none of them even approaches the similarity to viruses as do the mitochondrial derivatives. There is no evidence that nuclear genes (presumably containing desoxyribose nucleoprotein) in plants ever "escape" to the cytoplasm and become the source of a line of viruslike entities. On the other hand, there is a basic similarity between viruses and mutated mitochondria in such fundamental properties as chemical structure, self-duplication, mutability, intracytoplasmic habitat, and the ability to produce *unique* cellular pathology.

The extent to which mitochondrial mutations may be responsible for many types of cancer and other animal diseases, as they have been proved to cause variegational diseases in plants, is the subject of our present investigations.

MARK W. WOODS

H. G. DU BUY

National Institutes of Health
Bethesda, Md.

# 50 AND 100 YEARS AGO

JANUARY 1901. "The year which has just drawn to a close must be written down as one of the least conspicuous in the last and most brilliant decade of a notable century. Not since we commenced to give our annual review has there occurred a year so barren of sensational developments. Among the many evidences of our growth and prosperity none is more significant than the figures of the Twelfth Census, which show that the population has grown to 76,295,220 in 1900, a gain of 21 per cent in a single decade. Undoubtedly the most important work in contemplation under the head of civil engineering is the proposed isthmian canal to connect the Atlantic and Pacific Oceans. In the electrical world progress has been made chiefly along familiar and well-established lines. Marconi's efforts have been directed more to synchronizing his messages and constructing a transmitter, the messages from which can be recorded only by the apparatus which has been tuned to receive them. The close of the year finds the United States Navy occupying the same relative position among the navies of the world that it did 12 months before, and indeed, if anything, our standing as the fourth in rank is somewhat strengthened. Peary is still in the far North engaged in establishing his line of communications, from the extreme outposts of which he will make his final dash for the Pole."

"E. Merritt and O. M. Steward have traced the connection between cathode rays and the particles discharged from negatively-charged bodies under the influence of ultraviolet light along lines resembling the famous investigations of Lenard. For simplicity the authors call the streams of particles discharged through the influence of ultraviolet light 'photoelectric rays,' and they then proceed to show that they are of essentially the same nature as cathode rays. This is the conclusion already arrived at by J. J. Thomson, who has even determined the ratio $e/m$ for these rays, and found it to lie between $5.8 \times 10^6$ and $8.5 \times 10^6$."

"To obtain some idea of the amount of energy involved in Becquerel rays, E. Rutherford and R. K. McKling have studied them in conjunction with Roentgen rays, and compared the thermal and electrical effects produced by the two kinds of radiation. The discharge producing the Roentgen rays had a frequency of 57 per second, and assuming that the duration of each impulse was $10^{-5}$ seconds, the bolometer readings indicated a maximum energy of 19.5 calories per second from each square centimeter. This is 560 times the heating effect of the sun's rays per square centimeter at the earth's surface. As the ions produced by some Becquerel rays are probably the same as those produced by Roentgen rays, the energy of the former may be deduced from that of the latter. In radium, whose energy is 100,000 times greater, the energy radiated per gram of the substance is not less than 3,000 calories per annum."

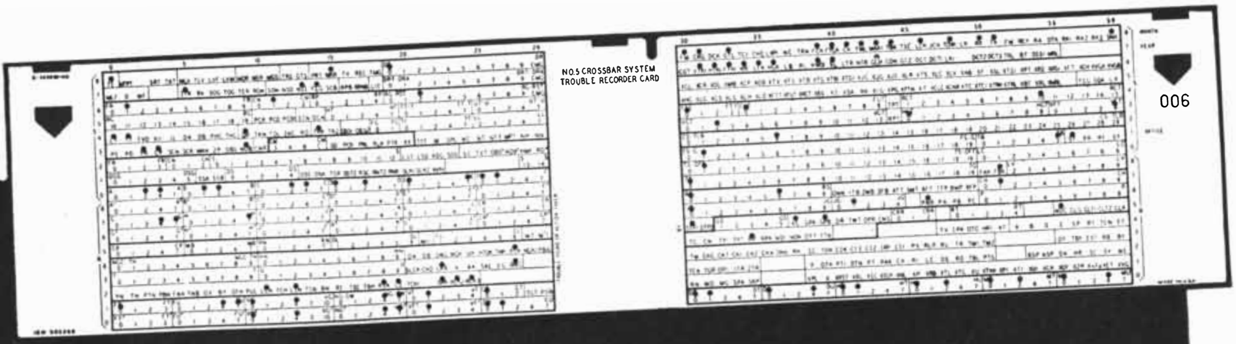
"The Pacific mail steamer *City of Peking* has been provided with an electrical steering device connected with the ship's compass. It is so arranged that the vessel cannot deviate from her course without ringing an alarm. The inventor is now working upon a contrivance by the use of which a steamer will steer automatically after her course has once been set."

JANUARY 1851. "We live in an age of wonders, and the last half-century has witnessed a succession of the most mighty events and the most astounding discoveries which have ever been made. If in 1800 there was no steamship in the world, where is the country now where they are not seen? If the steamboat has revolutionized communication by river and sea, the locomotive has done more to revolutionize travel by land. In 1800 there was not a single locomotive in the world. There cannot be less than 20,250 miles of railroad now in operation in Europe and America. Who, if he were told, 20 years ago, that the sunlight would be used for a limner's pencil, would have believed it? Among the discoveries of the last half-century the electric telegraph stands out in bold relief. It has given to man the power of transmitting his thoughts to his fellow man thousands of miles distant in a few seconds. The whole science of chemistry has been remodeled. In the hands of Davy, chemical compounds of what were supposed mere earthy crystals were resolved into metals in 1808. The animal chemistry of Liebig has been but recently given to the world. In astronomy the advancement has been equally rapid and wonderful. New and powerful telescopes have drawn the stars down to earth. The planet Neptune was recently discovered, even before a ray of its light had entered the human eye. And if the last half-century has given birth to so many grand discoveries and inventions, is there any reason to doubt that the future may more than outstrip the past? Hope is pointing her finger to the year 1900."

"Professor Agassiz is about to proceed to the South, intending to devote some time, in company with the officers of the Coast Survey, to a scientific examination of the Coast of Florida, with a particular view to the coal formations in that region."

"The Buffalo *Commercial Advertiser* publishes from reliable sources a detailed statement of the disasters on the Lakes during the past season, from which it appears that they involve the loss of 395 lives and $558,926. Ten steamboats, 21 sail craft, and one propeller craft have gone out of existence entirely. Of the lives lost, 250 resulted from the burning of the steamer *Griffith*, 65 from the explosion of the *Anthony Wayne*, and 38 from the collision of the steamer *Commerce*."

"Sculptured and painted blocks from the temple of Karnak, the finest in Egypt, have recently been dragged away to build a sugar factory. If these acts of the barbarian Turks are to be deprecated, how much more are the sacrilegious spoliations of European dilettanti to be condemned. Great indeed has been the liberty assumed by this class of men, to whatever country they may happen to belong, or whatever country they may happen to get access to. They seem to hold of antiquities what the poacher does of game. The King of Prussia has sent an agent, a Professor Lepsius of Berlin, three times to Egypt, a man who scrupled not to take away from Thebes three boatloads of plunder. Throughout all Egypt, the finest monuments bear the chisel and hammer marks of this learned desecrator. This destruction of these monuments is the more to be condemned, because wax or plaster of Paris molds of the characters could have been taken much easier."




# Another reason why your telephone gives so much for so little

*Studying punched card record of dial system operation. Each card (top) can report 1080 items*

In a large, modern dial telephone office, 2,000,000 switch contacts await the orders of your dial—and 10,000 of them may be needed to clear a path for your voice when you make a single telephone call. Within this maze of signal paths, faults—though infrequent—must be detected and fixed before they can impair telephone service.

The latest system developed by Bell Telephone Laboratories automatically detects its own faults, detours calls around them without delay—then makes out a "written" report on what happened.

The fault may be a broken wire, or a high resistance caused by specks of dirt on switch contacts. In one second, the trouble recorder punches out a card, noting in detail the circuits involved and the stage in the switching operation where the fault appeared.

Maintenance men examine the reports at intervals and learn what needs attention. Between times they go about their own duties in keeping service moving.

This is another example of how research at Bell Laboratories helps your telephone system operate at top efficiency, so the cost to you stays low.

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*WORKING CONTINUALLY TO KEEP YOUR TELEPHONE SERVICE BIG IN VALUE AND LOW IN COST.*

## THE COVER

The photograph on the cover illustrates a mathematical rule in the card game of Blackjack or Twenty-One (*see page 44*). In this game a dealer gives both the player and himself one card face up and another face down. The objective of the player is to possess a hand in which the cards add up to a total greater than that of the dealer's hand, but do not add up to more than 21. All face cards are valued as 10; aces, either 1 or 11. Both player and dealer may either stand pat on two cards or draw others. The mathematical rule applied by dealers in many gambling houses is always to draw with hands totaling 16 or less and always to stand pat with hands totaling 17 or more. In the three-card hand at the top of the photograph the dealer drew two cards adding up to 16. He then drew a third, bringing the total to 21. The player's hand is shown at the bottom. Playing cards copyrighted by The United States Playing Card Company.

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Cover by K. Chester

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SCIENTIFIC AMERICAN

Established 1845

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## ARTICLES



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SCIENTIFIC AMERICAN

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# HOW MAN CAME TO NORTH AMERICA

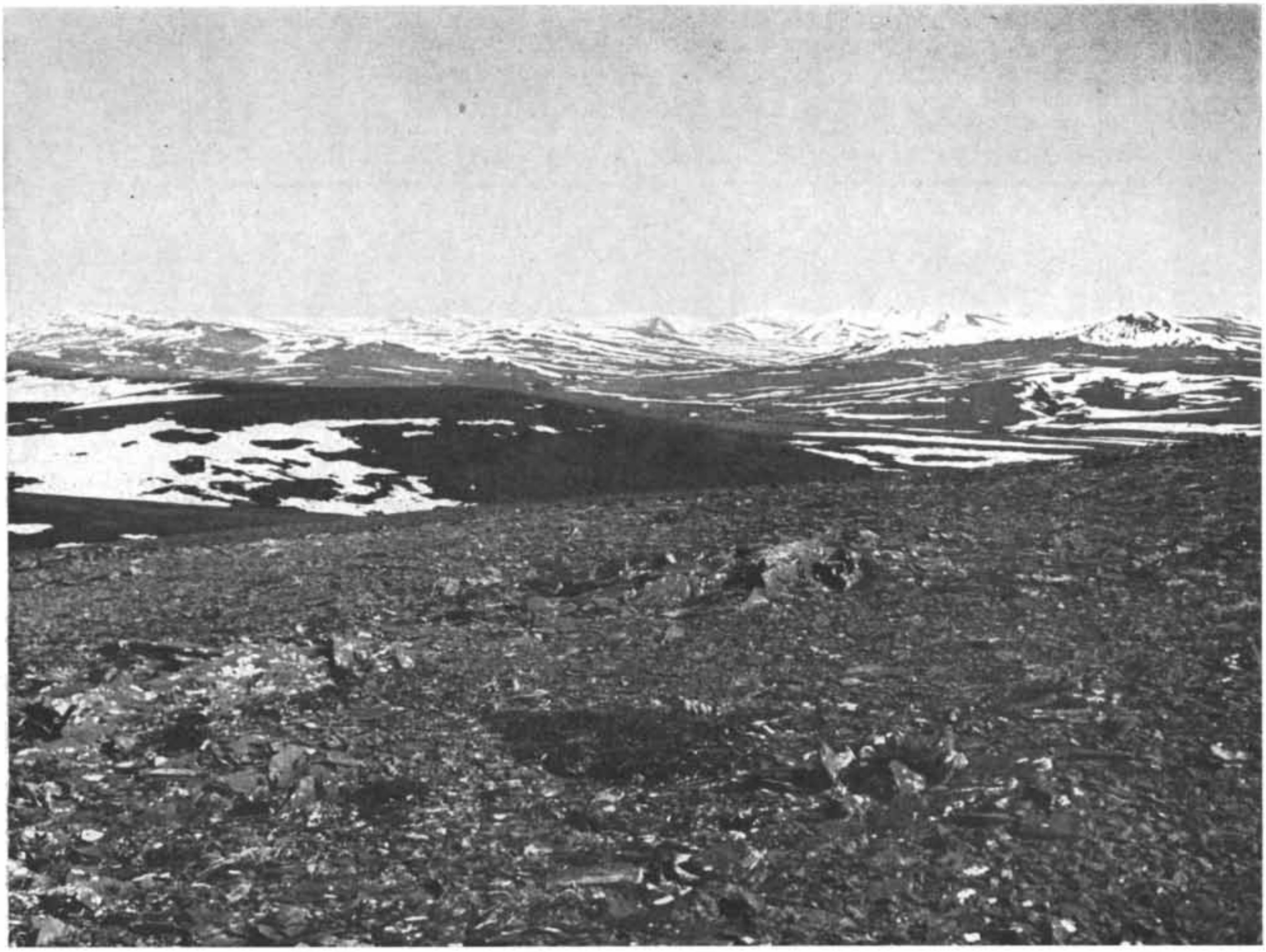
## It is assumed that he traveled from Asia, but exactly what route did he take? The first of two articles on the prehistoric Americans by two investigators of them

by Ralph Solecki

THE QUESTION of how and when man first arrived in North America has been one of the most keenly debated in archaeology. We are sure of only two things: that there were early men (Paleo-Indians) living on this continent at least 10,000 years before Columbus set eyes on it, and that they almost certainly had not come from Europe. Every sign points to the likelihood that the first human immigrants to North America came from Asia. The main question is by what route. Did they come by small boats across the broad Pacific? Very possibly a vagrant few negotiated the voyage at some time or other, but it seems improbable that the earliest men arrived that way. We are left, then, with Alaska, which is separated from the Asiatic mainland only by the 56 miles of the Bering Strait, as the most plausible gateway of man's first entry to North America.

The Alaska theory has been popular for many years, but until recently there was hardly a shred of real evidence one way or the other. One of the great anomalies was that although plenty of evidence of man's early presence had been found in the middle part of the continent (notably the 10,000-year-old stone spearheads unearthed at Folsom, N. M., and Yuma, Col.), not a sign of any human relic had appeared along his supposed route of entry through Alaska. Now investigators have begun a systematic attempt to retrace early man's steps through that territory, and the trail is growing warm. Studies of the rocks, fossils, topography, prehistoric climate and human traces in the region are unfolding the fascinating story of

**THE COASTAL PLAIN** of northern Alaska is flat and treeless. It was free of ice and much easier to travel than the mountainous region to the south. It was probably traversed by prehistoric hunters following their game.



**THE DE LONG MOUNTAINS** of the Brooks Range, northernmost of Alaska, lie south of the coastal plain. Through these mountains prehistoric Eskimos, and perhaps earlier men, found short cuts from the south.

the probable circumstances and conditions under which man first made the crossing from Asia to North America and began to populate the new continent.

One naturally starts by asking: Why did man leave Asia in the first place? We can be reasonably confident of the answer to that question: he followed his food. He apparently came to America in pursuit of herds of bison, caribou, moose and other grass-eating animals that deserted parts of northern Asia for greener pastures. It was not simply an adventurous spirit but the necessities of survival that led man over the hard route skirting the Arctic Circle to the new land.

That the game animals on which he depended had preceded him over this route is amply proved by their fossil remains. Paleontologists have found in Alaska fossils of the bison, musk ox, goat, moose, woolly mammoth, mastodon and many other animals that appear to have originated not in America but in Eurasia. Some of these fossils are 25,000 to 30,000 years old, showing that the animals had made the crossing well before man. Alaska must have been a lush animal habitat in those days; all over the territory there are abundant ancient remains of horse, deer, antelope, wolf, bear and beaver, as well as the newcomers from Asia.

HOW, the question remains, did the great migration of animals and men cross from Asia to Alaska? It is a question that we may never be able to answer conclusively and to our full satisfaction, but it does have answers, and some of them now appear to be very likely. Clearly the crossing would have been no serious problem for man himself. Even now on a clear day the shores of one continent are visible from the other across narrow Bering Strait, and two islands in the middle of the Strait—Big and Little Diomede—make it possible to cross the water in two easy 25-mile hops. Early man might have crossed over ice or in small skin boats. But even this may not have been necessary. There is every indication that during the Pleistocene Period, which ended about 25,000 years ago, Asia and Alaska were connected by a land bridge over which men and animals could have crossed dry-shod.

Fossil records clearly show that such a bridge existed at some time or times during the Pleistocene, and that it was glacier-free. Presumably the bridge was created by a lowering of the sea level as water was locked up in the glaciers on land. The Bering Strait is so shallow that a drop of only 120 feet in the sea level would raise its bottom above the water. But how did it happen that this area in the Far North was not covered by glaciers? Strange as it may seem, the glaciers which spread over practically the whole of Canada and most of the northern part of the U. S. actually spared most of Alaska; they were largely restricted to its mountain ranges. The only likely explanation is Alaska's low precipitation. In northern Alaska today the annual precipitation is only 5 to 10 inches. With so little rain and snowfall, the ice would not have covered the valleys.

The land bridge now submerged under the Bering Strait was probably once covered with a thick long grass like that found on the Alaska Peninsula today. It would have been an ideal fodder for grazing animals. After crossing the bridge they would have found a haven from the glaciers in Alaska's valleys.

Naturally the bridge worked both


**THE MACKENZIE RIVER VALLEY** runs south from the coastal plain. Because it was free of glacial ice earlier than the Rockies, the first immigrants could have followed the valley to the interior of North America.

ways: a few creatures of North America, notably the horse and the camel, probably migrated across it to Asia. But the paleontologist George Gaylord Simpson has pointed out that a narrow intercontinental land bridge of this sort is selective. It does not act as an open door but as a kind of filter, permitting some animals to pass and holding back others. In this case apparently the corridor drew animals from only one zone of North America, not from the continent as a whole; thus no animals that had come to North America from South America reached Asia.

Similarly some filtering mechanism seems to have operated in selecting the type of early man who came across the bridge to North America. The archaeological evidence indicates that the first Americans were nomadic hunters of grass-eating animals, and they evidently came in groups, seeking their prey cooperatively. The best present indications are that they came in the latter part of the Pleistocene and the early part of the Recent (*i.e.*, the latest) geological period, roughly between 10,000 and 20,000 years ago. There seems to be no doubt that man did not enter the New World *en masse* but in a series of pulsations continuing over a long time. Presumably he found in the New World a life not very different from that in the Old: the ecological conditions were much the same as those he was accustomed to and most of the animals were probably quite familiar. Only the map had changed a bit.

PIECING together the findings of investigators from various disciplines, we are beginning to discern the outlines of the probable conditions the first men encountered in Alaska, the kinds of plants and animals they dealt with and the probable routes of their migrations through the territory. Contrary to what has long been thought, the evidence indicates that the main route was not through southern Alaska but along the northern coast, over the very top of the continent.

It was not until 1947 that the first unmistakable proof of man's early presence in this region was discovered. In that year a U. S. Geological Survey party found a single stone spearhead on a bare, windswept ridge in the unglaciated northern foothills of the Brooks Range, Alaska's northernmost mountain range. This fluted stone point was definitely identified by Frank H. H. Roberts, Jr., the foremost authority on the Paleo-Indians, as the work of Folsom man, who had already been dated by the finds in New Mexico at some 10,000 years ago. Unfortunately this lone piece of chipped stone was the only human relic that could be found at the site of its discovery, but soon afterward more evidence turned up elsewhere in Alaska. At Cape Denbigh, on Norton Sound just south of the peninsula that is closest to Asia, J. Louis Giddings of the University of Alaska unearthed a number of fragments of Folsom and Yuma projectile points. He also dug up some more spectacular artifacts, the like of which had not previously been found anywhere in the New World. They were carving tools called burins, used to carve animal bones and antlers. Why none of these tools has been found with the Folsom and Yuma material farther south is not known, but it may be that the making of burins had become a lost art by the time early man reached the mid-continent.

Giddings uncovered his finds in frozen ground at a depth of seven feet at a

**FLINT OBJECTS** found in Alaska relate its prehistoric inhabitants to men in other parts of the world. At the left is a projectile point perhaps 10,000 years old. It resembles the Folsom points found much farther south. The other two objects are cores about 5,000 years old. They resemble the cores discovered in Asia and Europe.

stratified site. Just above these remains of early man was a sterile layer of clay, suggesting a long lapse in man's habitation of the area, and over the clay were several layers of successive Eskimo cultures.

Here, then, was conclusive evidence placing man in Alaska at least as early as 10,000 years ago. Evidently he had made his entry to North America through Alaska's northern lowlands, by-passing the glaciers that must still have been present. William A. Johnston of the Canadian Geological Survey believes that the most favorable route was over the low-level northern coastline of Alaska to the Mackenzie River and then down that valley (*see map on the preceding page*). This seems the most probable avenue of man's spread into the interior of the continent. The Rocky Mountains and their slopes along the west coast were covered with ice, and their river valley systems presumably were impassable until about 10,000 years ago. The route down the Yukon and the path of the present Alcan Highway are not easy to traverse (off the highway) even today. On the other hand, the Mackenzie Valley and a broad belt down through the continent east of the Rockies are believed to have been free of ice at an early stage, probably about 25,000 to 30,000 years ago.

Down this ice-free corridor the animals that had preceded man might have overrun the new continent in an incredibly short time, perhaps only a few hundred years. As the animals declined in number in Alaska, early man would have had to wander farther and farther afield to find herds of game. Gradually he would push his settlements southward toward their pastures. It is conservatively estimated that man would have reached the southernmost tip of South America in about 5,000 years if families of hunters expanded their range southward at the rate of only two miles per season. The evidence shows that 10,000 years ago early man was already deep in the interior of North America at various sites east of the Rockies.

NOW it is a strange and challenging fact that no samples of the Folsom implements found in North America have been unearthed in Asia. If they were brought to America by early man, they should appear somewhere in the Asiatic regions from which he came. It is entirely possible, of course, that the Folsom projectile points were developed in America from some different Asiatic prototype. But the challenge remains, and archaeologists hope that the trail of the Paleo-Indian will one day lead them to likely sites in northern Asia where they may hunt for the Folsom flints, or at least their prototypes.

If we skip several thousand years of prehistoric time, we *can* establish a connection between Asiatic and Alaskan tools. At several sites in Alaska there have been found flint cores about 5,000 years old. They are of the Middle Stone Age. They differ in general shape from the Folsom flint cores (*see photographs above*). With these cores were discovered peculiar long chips, or flakes, that had been struck from the cores. These flakes may have been inserted as side blades in hunters' spears, near the point ends. A gashing blow with a weapon of this kind might bring an animal down sooner than a mere stabbing wound.

N. C. Nelson of the American Museum of Natural History has noted that these Mesolithic cores and flakes bear a striking likeness to counterparts, probably the same age, which he found in Mongolia. Similar flint objects have also been dug up in Greenland and northern Japan. In fact, this particular method of flint workmanship appears to have been widely practiced in many parts of the world for a long time; similar cores and flakes or blades appear in Aztec Mexico and in the prehistoric mounds of the Ohio mound-builders.

The first finds of these Mongolian-type flint cores and flakes in Alaska were in the Yukon Basin: they were discovered in diggings on the campus of the University of Alaska at Fairbanks and later at Kluane Lake, near the Alaska Highway. In 1949 the writer, accompanying a party of U. S. Government geologists, unearthed other flints of the same type in northwestern Alaska near the ridge where the first Folsom projectile point in the territory had been found. Our party discovered some 200 sites with archaeological remains in this northern area, the supposed route of man's migration into North America. Two of these 200 sites yielded the Mongolian-type artifacts. Unfortunately none of the sites was stratified, so it is difficult to estimate the age of the finds. They were found apparently just where they were dropped, practically on bare rock; none was more than six or eight inches below the surface. There is little soil on these hills, and vegetation is very sparse. Moreover, due to the low precipitation erosion has been slight, which accounts for the fact that the artifacts have been displaced very little in the thousands of years they have lain there. In prehistoric times the area was mostly grassland, bearing herbage on which wandering herds of caribou, moose and bison fed.

All the sites of the finds in this area are on strategic bluffs or knobs which have a good view of the surrounding terrain, principally along the river valleys. Apparently they were lookout stations where the aborigines watched for game, and while keeping their vigil the hunters seem to have spent the time chipping flints to replenish their supply of weapons. It appears that the Eskimos, who came later, followed the same practice of keeping lookouts for game on the hills. Early white explorers who ventured inland in northern Alaska reported that they occasionally saw a whole encampment of hunters drop what they were doing and set off in pursuit of game when a lookout on a hilltop gave the signal that he had sighted a herd.

No stone axes or other large implements have been found among the remains of early man in Alaska. Evidently the Paleo-Indians did not use them. From this it may be deduced that they hunted mainly in the open rolling grasslands and had no need for heavy chopping tools.

DESPITE the plentiful indirect evidence of early man's presence in the form of his tools, not a single undisputed remnant of man himself has yet been brought to light. In all the excavations and field work so far conducted on this continent, no bones of ancient man have been found in association with these early artifacts. But archaeologists have not given up hope. Mindful of the discovery of the remains of the famous Berezovka mammoth in Siberia, they have not ruled out the possibility that somewhere in Arctic Alaska an early immigrant to North America may yet be found entombed in an ice wedge or in permanently frozen ground.

At any rate, from the evidence we have we can compose an outline of the probable course of events: During the Pleistocene, or Ice Age (really a series of four known general freezes and thaws beginning about a million years ago), so much water was locked up in the glaciers that it left a broad, ice-free land bridge between Asia and America. Over this bridge came a migration of animals which thrived and expanded in its new feeding zones—for a time at least. Much later, toward the waning of the glacial period about 20,000 years ago, came man, presumably attracted by the abundant game. Like the animals, man rapidly expanded his range over America. The initial migration route into the interior of the continent was probably over the northern, unglaciated part of Alaska and then down the Mackenzie Basin.

In only three years, the work in Alaska has turned up a wealth of information that compares favorably with the gleanings from a quarter-century of research on the Paleo-Indian elsewhere on the continent. The fruitful discoveries already made in Alaska suggest that it is a rich field for future work, and that it may one day yield much of the story of man's entry into this hemisphere.

*Ralph Solecki is an archaeologist at the Bureau of American Ethnology of the Smithsonian Institution.*


**FLINT CHIPS** (*center*) made by prehistoric man lie on the ground practically the way they were discarded. Strewn on the north side of hills, they were apparently struck off by hunters who were keeping watch for game.

**GREEN CHERT FLAKES** (*right*) were found buried just beneath the surface of the Arctic tundra. The flakes on the hills of northern Alaska are of many different ages. These appear to have been made by prehistoric Eskimos.

# The Human Body In Space

*Scientists and engineers have long considered the problems of flight to other planets. As the reality of space travel slowly draws closer, they particularly weigh its effects on man's earth-conditioned frame*

by Heinz Haber

THE GENERAL exploration of our planet has practically come to an end. By means of the airplane civilized man has filled in virtually all the blank spaces on the world's map, and today comfortable airliners fly regularly scheduled flights over wildernesses where courageous explorers perished of hunger, thirst, cold or exhaustion only a few decades ago.

From his conquered home-planet man has begun to look expectantly toward new worlds in the heavens. The Moon and the neighboring planets, Venus and Mars, irresistibly challenge his fancy with the same spell that the seven seas once cast over their explorers. Like the pioneers who first ventured to sea in sailing ships, we are preparing to launch our first frail craft in the vast ocean of space. Already unmanned rockets have risen hundreds of miles from the Earth, and they are going higher and faster every year. It is certain that in the not-too-distant future manned rockets will approach the limits of the terrestrial atmosphere. The next step then will be the launching of a rocket that will permanently circle the Earth outside the atmosphere—an artificial satellite. From this base the Moon will be an island just offshore; Venus and Mars will be nearby continents beckoning to a Columbus.

There is not much point in making predictions as to the timetable of the conquest of space. That will be determined largely by the rate of expenditure of means, manpower and effort. The expenditure required will of course be very high. Space flight is an undertaking which only a large, wealthy nation may dare to tackle. Success will depend on research and development in many fields: thermodynamics, the chemistry of combustion, metallurgy, electronics, aerodynamics, mechanical engineering, astronomy, meteorology, geophysics and so on.

We shall here confine ourselves to a problem that has so far received little scientific attention: namely, the human factor. How will the human explorer fare in his spaceship? What measures must be taken to enable men to survive in the alien environment of the void beyond our atmosphere? These questions open up a new field of science: what may be called space medicine. Space medicine will be an extension of aviation medicine, which developed with the airplane and has now become a large branch of study. In the case of space medicine we shall not be permitted, as in aviation medicine, to explore the problems as they arise. If the enterprise of space flight is to have any chance of success, we must solve the biological problems as completely as possible before we take off into space, in fact, even before our spaceship is designed.

FIRST of all we must reckon with the effects of rapid acceleration. The rocket engine, the only type of motor that could operate in the vacuum of space, works most efficiently at high rates of acceleration. Hence if the spaceship's fuel load is to be kept within reasonable bounds, it will have to accelerate as rapidly as possible. The space traveler will gain in weight in proportion to the acceleration of the ship during takeoff. The ship must accelerate in several stages, each lasting between one and two minutes. Toward the end of each period the crew would have to take an increase in body weight of about sixfold to tenfold. This grazes the limit of human tolerance, as measured in the centrifugal machines now used to test the effects of accelera-

**ACCELERATION exerts powerful effects on the human body. It is studied by space medicine because rockets operate most efficiently at**

tion on fliers. We can therefore conclude that young persons endowed with healthy circulation will be able to master the hazard of acceleration in a spaceship's ascent, provided they lie in a prone position.

After the ship has accumulated a sufficiently high velocity and left the Earth's atmosphere, its rocket engines will be shut off entirely. It will then travel on its momentum, without resistance in the emptiness of space. Now a new phenomenon will set in: the ship's occupants will lose all weight. There is a common misconception that the effect of gravity will be felt until the ship gets beyond the Earth's effective gravitational field. This is not true. The forces of inertia acting on the ship will balance the pull of the Earth, just as the centrifugal forces acting on the Moon keep it serenely on its course without danger of its being pulled to the Earth. As soon as the rocket motors stop, the spaceship and everything in it—the passengers, even the very air they breathe—will be devoid of weight.

In most discussions of space travel the consequences for the passengers of this weightlessness have been taken lightly. In fact weightlessness evokes a pleasant picture—to float freely in space under no stress at all seems a comfortable and even profitable arrangement. But it will not be as carefree as it seems. Most probably nature will make us pay for the free ride.

There is no experience on the Earth that can tell us what it will be like. True, the first instant of free fall in a dive from a diving board approximates the gravity-free state associated with ideal free fall, but it lasts only a moment. To imagine what complete weightlessness will mean we must resort to our general knowledge of physical and physiological principles rather than to experience.

It appears that we need not anticipate any serious difficulties in the functions of blood circulation and breathing. These are powered chiefly by the muscles of the heart and the elastic forces of the blood vessels, the midriff and the chest, which are independent of gravity. The weight of the blood plays some part in circulation, but not an indispensable part.

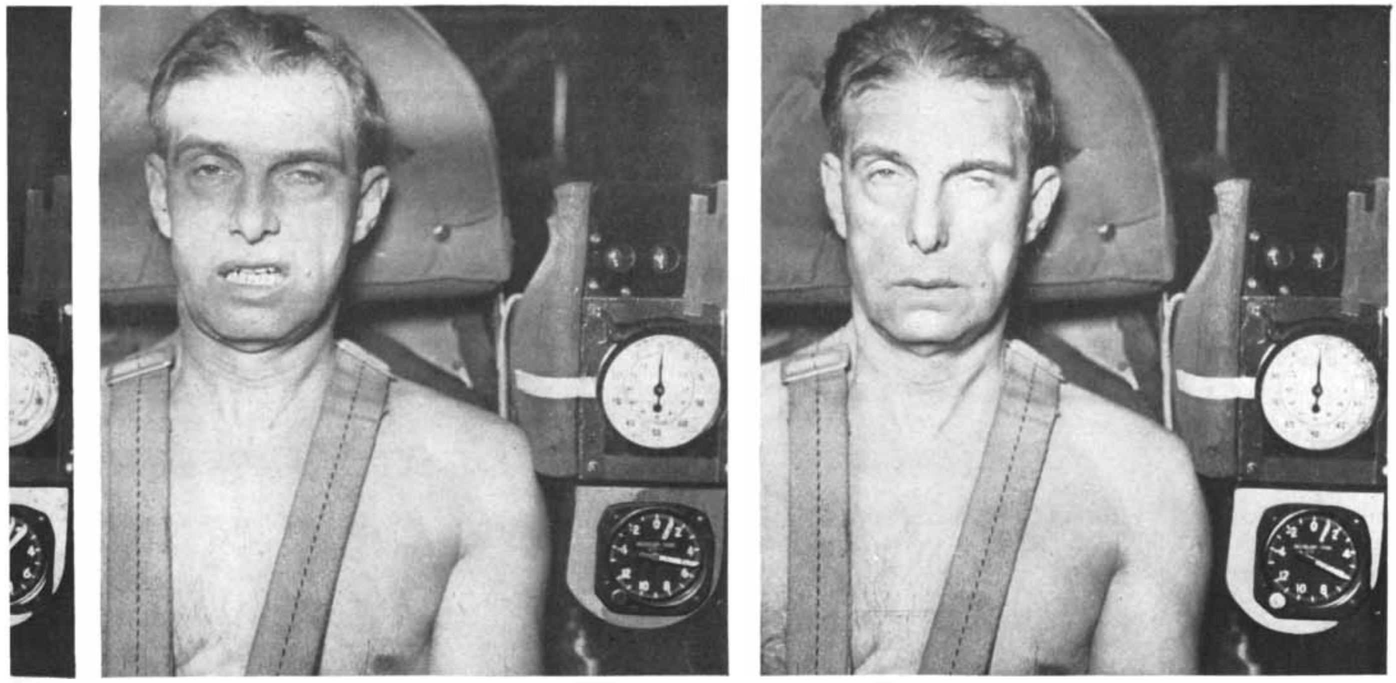
It is in the nervous system of man, his sense organs and his mind, that we can expect trouble when the body becomes weightless. The body possesses an intricate system of receptors which provide detailed information of all kinds of mechanical stimulation. Among these mechano-receptors are the receptor organs for rotatory and translatory motion in the inner ear, the receptors responsible for the pressure sense of the skin, the muscle spindles imbedded in all muscles that fix and move bodily masses, and the so-called Pacinian or Vater's corpuscles found throughout the connective tissues, especially near the muscles.

The last three receptors are chiefly responsible for man's special posture sense. They form a functional union controlling the perception of position and of active and passive movements of the body. Their stimulation is closely linked to a complicated reflex mechanism which serves to maintain equilibrium and to regulate bodily movements.

Now the lack of gravity would affect the posture sense and the power sense to a very different extent. The functioning of the posture sense would hardly be affected at all, since the tension of the connective tissue that provides the stimulation for its receptors is independent of weight or the lack of it. The end organs of this sense, in other words, give notice of the various positions of the limbs independently of outside forces. In contrast, the power sense, involving the muscles, is substantially affected by gravity. To move an arm, for example, the muscles normally must overcome not only the inertia of the arm but also its weight.

It is easy to see, therefore, that the lack of gravity would seriously disturb the harmony of the various sense mechanisms that control bodily movements. In a state of weightlessness the muscles would need to overcome only the body's inertia, but they would behave as if they also had to reckon with its weight. Hence the slightest effort by the space traveler to move his body would jerk him across the cabin. Man in space would therefore have to adapt his power sense to an entirely different pattern of forces.

Then there is the question of the body's orientation with respect to ob-



**high acceleration. The effects of acceleration are recreated in these photographs, which show a human subject being whirled in the great centrifuge of the Air Force Air Materiel Command at the Wright-Patterson Air Force Base. The increase of gravity is given on the dial at the lower right-hand corner of each photograph. In the first photograph the subject takes 2 g. In the second he takes 5 g. In the third he takes 6 g, "blacks out."**

jects around it. Two different mechanisms control this orientation: the eyes establish the position of the body relative to other objects; the mechano-receptors, stimulated by the weight of the body and its parts, register the direction of gravity. Ordinarily both of these perceptions match. But in the state of weightlessness they will be out of kilter; the eyes and the mechano-receptors will register entirely different pictures of the body's situation.

It is possible, however, that space travelers can be trained to orient themselves solely by means of the eyes. Experience in training aviators for blind flying indicates that man is capable of suppressing false information from his system of mechano-receptors. A pilot who flies through a solid overcast relies wholly on visual cues from his instruments. Through these alone he establishes orientation of his position and that of his plane in space. His mechano-receptors may give him the impression that he is flying level when he is actually ascending or descending; only his instruments can give him the correct picture.

In a weightless body at rest the mechano-receptors are inactive. They will be stimulated, however, by every movement of the body. During these movements the forces of inertia will lend weight to the body in proportion to the acceleration applied. While the mechano-receptors are thus placed under stimulations that vary greatly as to direction and size, the eyes will register the situation very differently. Here again is another factor causing dissociation of the various qualities of perception and sensation.

This dissociation may well produce a spatial counterpart of airsickness. Recent investigations have revealed that a disharmony of the perception and sensation complex can induce certain forms of seasickness. We must therefore reckon with the possibility that weightlessness will cause a kind of "space-sickness" that could incapacitate the crew of a spaceship.

CONSIDER still another factor. It is well known that the sensitivity of sense organs increases greatly as the strength of stimulation is reduced. For example, the eye, which barely registers the light from a flashlight in bright sunlight, is dazzled by the very same flashlight in a dark place. Prolonged darkness so enhances the sensitivity of the eye that the faintest glow becomes visible and an ordinary light, suddenly turned on, emits a painful glare.

Presumably the lack of gravity in a spaceship similarly will heighten the sensitivity of the gravity sense. The gravity-sense organs will react vehemently to the smallest forces acting on the body. Moreover, the slightest movement by the spaceship passenger is likely to make him a victim of curious deceptions. If he merely stretches his body or turns his head, he may be overwhelmed by the sensation that he is being lifted and jerked back and forth or that he is suddenly spinning around. A man liberated from the shackles of gravity would most probably be in a constant state of physiological and psychological tension.

Aside from his physiological difficulties, the weightless man would have to contend with the surrounding objects, which, being devoid of weight themselves, would play remarkably mean tricks. Loose objects, large and small, would float around aimlessly inside the cabin, and the passengers would have to keep a wary eye on them. This unremitting struggle with the weightless objects would add to the psychological stress on the travelers.

Possibly the perils of weightlessness might be avoided by some artificial substitute for gravity. For instance, the travelers' cabin might be rotated or might be suspended from the rocket at the end of a long cable and be swung around continuously. Centrifugal force would then restore the passengers' weight. Unfortunately, however, the so-called Coriolis forces which affect all bodies moving within a rotating system would introduce a new discomfort. A passenger would be all right so long as he was at rest, but whenever he moved a limb the Coriolis forces would pull it sideways; every voluntary movement would give the traveler the peculiar illusion that he was being moved haphazardly.

It has been suggested that the crew of a spaceship might be anchored to the floor by equipping them with iron shoes and magnetizing the floor. This, however, would probably add to the travelers' confusion, for while their shoes would be attracted to the floor, their nonmagnetic bodies would not. Moreover, the electronics engineer of the ship doubtless would object strongly to the havoc wreaked upon his intricate instruments by the floor's magnetic fields.

WHAT about air for breathing and the control of the cabin temperature? Our experience with submarines and sealed cabins in high-altitude airplanes indicates that the problem of supplying oxygen and ventilating the cabin in a spaceship will present no particular difficulties. But keeping the cabin at the proper temperature for its human passengers will raise entirely new problems.

Once the spaceship has left the Earth's atmosphere and the Earth's heat, its temperature will depend primarily on how much solar radiation it absorbs. The main problem will be to keep the ship cool enough. Its shell must be made of a material that will reflect most of the solar radiation. Only the very best reflectors, such as magnesium oxide, offer any possibility of keeping the ship at a reasonable temperature. The ship must also radiate away the heat it absorbs and the heat produced by its passengers and the many electrical and mechanical devices inside the craft. The difficulty is that at normal room temperature objects get rid of heat at an extremely low rate.

Another serious problem will be the protection of the passengers against ultraviolet radiation, which the sun sometimes emits in great extra bursts. The Earth's atmosphere filters out nearly all of this radiation, but in space the ultraviolet eruptions would hit the ship unimpeded. The harmful effects on the body of excessive ultraviolet radiation are well known. The metal walls of the spaceship would ward off ultraviolet rays, but no transparent material can remain transparent under massive ultraviolet irradiation. Hence much of the time the ship's windows will have to be kept covered; they can be unhooded only occasionally for necessary observations.

How great would be the hazard from cosmic rays? This is still a controversial question. The recent discovery of heavy primary particles in the upper atmosphere—particles ranging up to an atomic weight of 40 or more—suggests that the cosmic rays might indeed be dangerous. These particles crash into the atmosphere with energies millions or billions of times greater than those that can be produced in a laboratory. To keep them out entirely the spaceship would have to be encased in steel armor plate at least two inches thick. Such a weight of steel is entirely out of the question for a spaceship. Consequently we must resign ourselves to the fact that the passengers would inevitably be exposed to a certain amount of cosmic radiation, not only heavy primaries but powerful secondary particles and gamma rays.

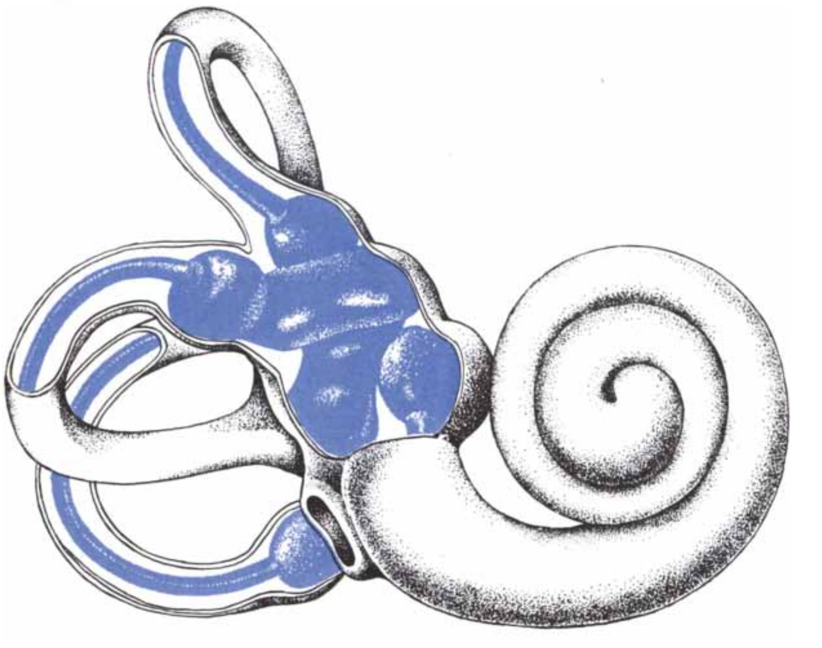
In view of this bleak picture one might better resolve to call off space flight and stay behind the stout shield of our planet's atmosphere. The danger is not, however, as great as may appear. Although the cosmic particles carry tremendous energies, their density in space is inconceivably low. It has been estimated that at an altitude of 80,000 feet an individual would absorb radiation at a rate only about 25 times greater than the permissible weekly dose. At this rate short trips into space would most probably be safe. Radiation effects might, however, become serious over the weeks and months of an extended trip.

THE spaceship would also run the gantlet of those other stray bullets in space: meteors. Even a meteor the size of a pinhead, flying at the meteoric speed of 20 to 60 miles per second, could easily puncture the steel hull of the ship. The vaporizing heat from the impact of a meteor would cause a minor explosion at the site of the hit. As it blasted a hole in the wall, the only shield between the passengers and the emptiness of space, the passengers would be subjected to a more or less explosive decompression, depending on the size of the hole. They would have something like 15 to 30 seconds to act before losing consciousness. The damage from a small meteor might possibly be checked by plugging the hole or by a system of air locks. But a hit by a meteor weighing an ounce or more would abruptly end the voyage. Meteors as large as this are believed to be so rare in space, however, that a spacecraft of the size now postulated might cruise for hundreds of years without meeting such a catastrophe. It is estimated that the ship would encounter tinier but still dangerous meteors about once a month.

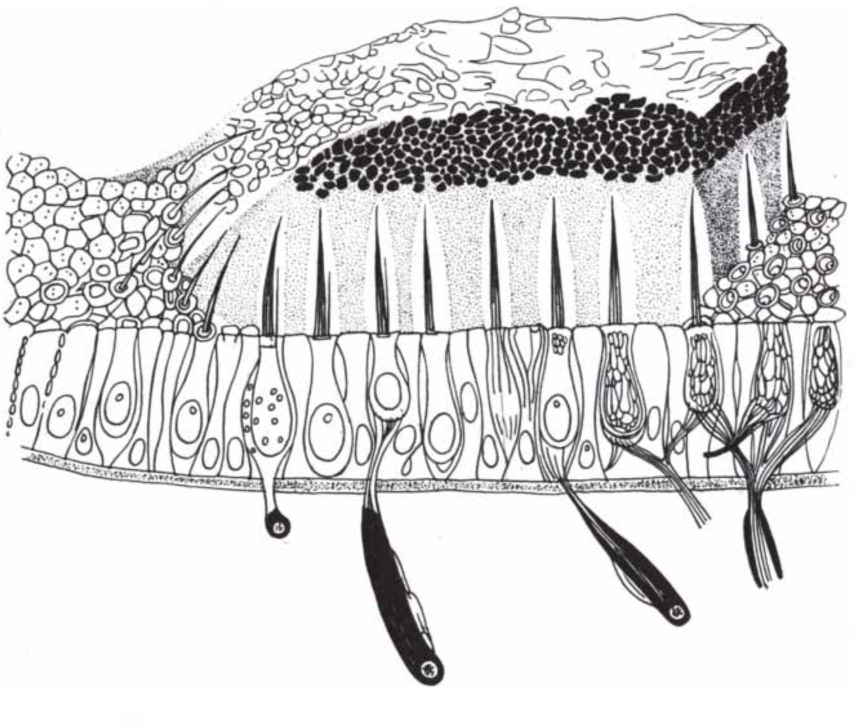
Is it too early to start worrying about the problems of man in space? Indeed it is not. Although the first space flight is not imminent, we are not so very far from the roof of our protecting atmosphere in experimental aviation. Man's newest aircraft, whipped upward by jet and rocket propulsion at breath-taking speeds, are constantly setting new altitude records. Their peak altitudes are a military secret, but one may assume that they fly at heights where the atmosphere is thinning out rapidly. At these highest altitudes, where the domain of space begins, fliers are already approaching the limits of the atmosphere that maintains a convenient climate, provides air for breathing, keeps the temperature within tolerable limits, filters the ultraviolet solar radiation, checks the cosmic rays, burns the meteors and provides the friction that preserves the effects of gravity. The V-2 rocket today routinely ascends to such heights.

In the not-too-distant future intercontinental airliners will probably travel in the thinnest layers of the atmosphere. Powered by rocket engines, the "ionocruiser" will shoot up rapidly until it is in the region of almost no air resistance. Then the engines will be shut off and the craft will fall in an elliptical curve toward its goal. The path of flight will be virtually that of a genuine celestial body, and during the period of coasting the gravity-free state will prevail. The flight of such a craft will closely approximate the conditions ultimately to be encountered in space.

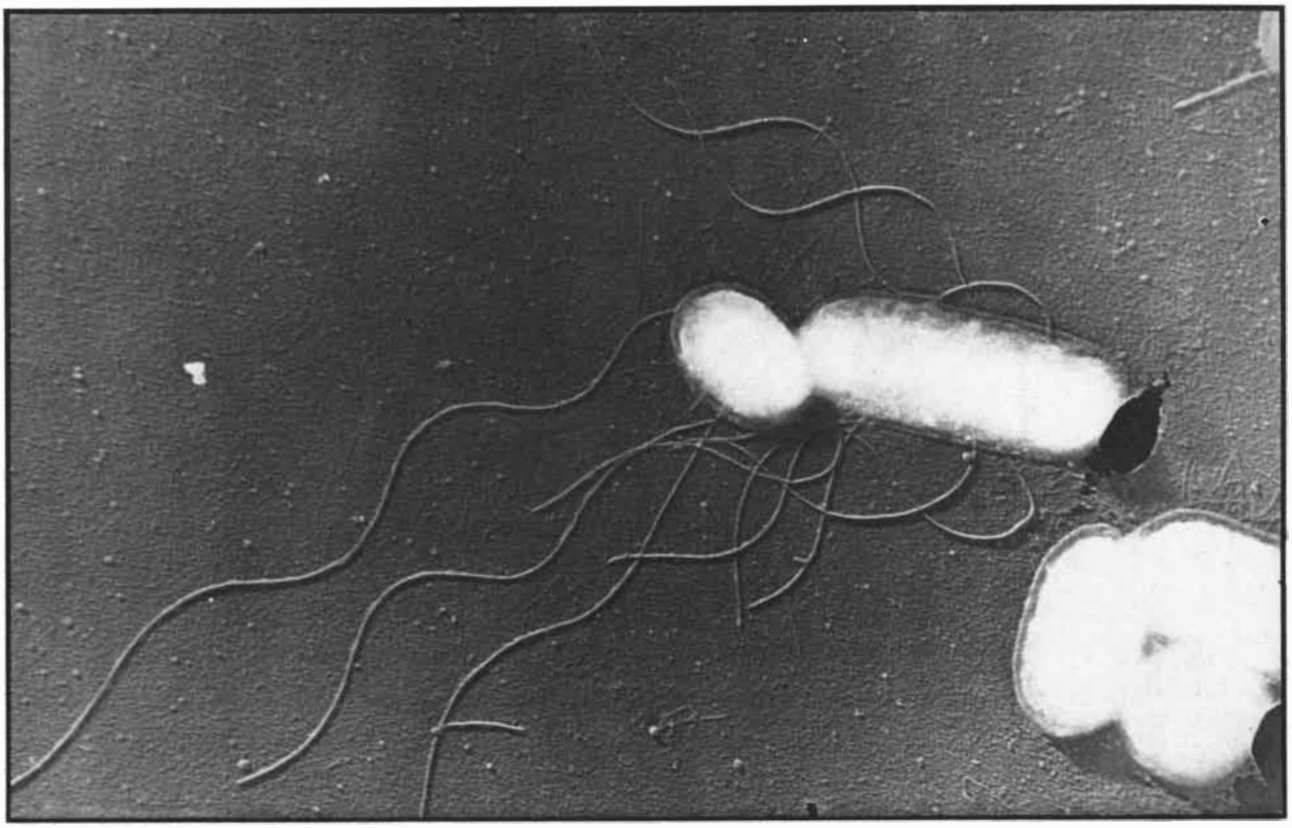
*Heinz Haber is a research scientist in the Department of Space Medicine of the U. S. Air Force School of Aviation Medicine.*



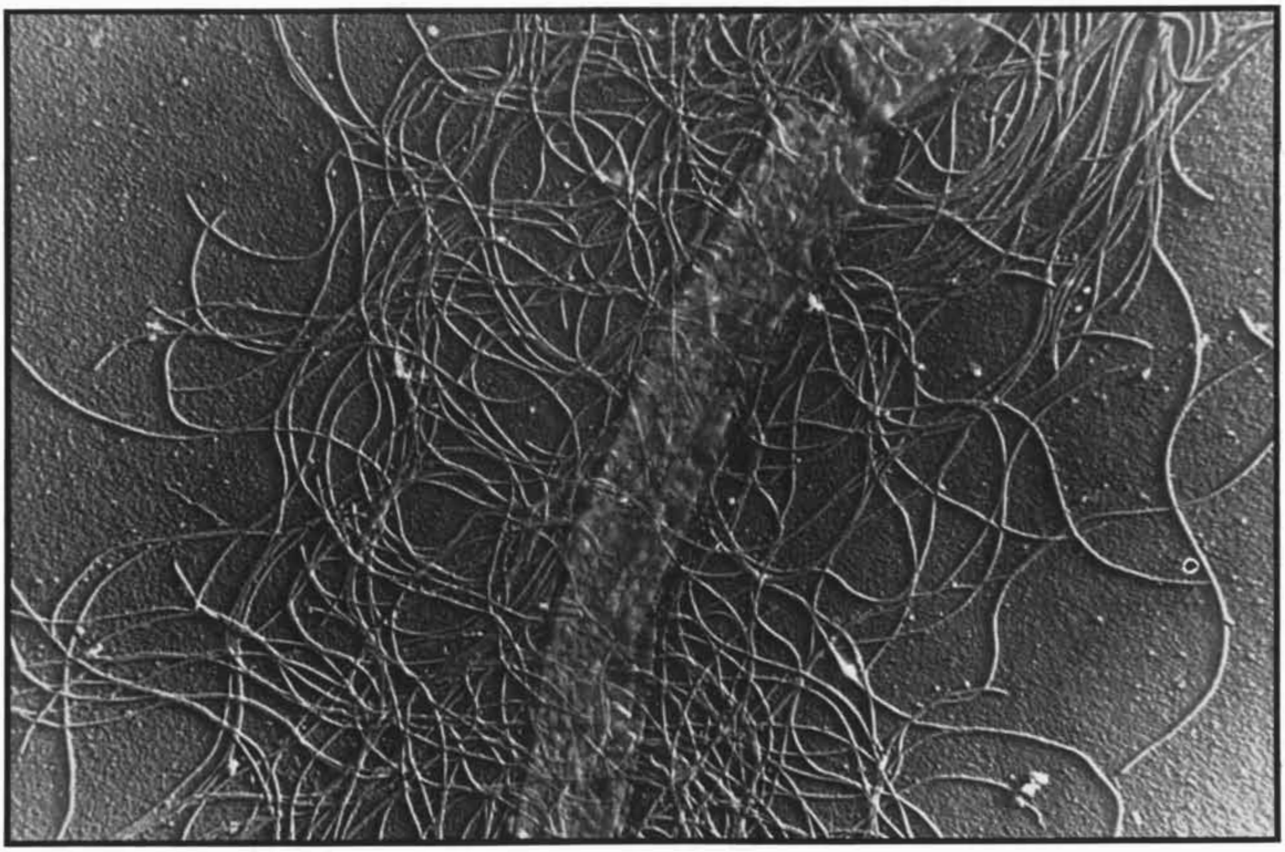
**VESTIBULE OF THE EAR,** the sensory organ that maintains the natural position of the head, contains one of the mechano-receptors that would be affected by the absence of gravity. This drawing shows the bony labyrinth of the ear. The cochlea is at right; the vestibule, at left. Within the vestibule is the membranous labyrinth (*indicated in blue*), which bears the receptors.



**MEMBRANE OF THE VESTIBULE** has regions sensitive to motion. In these regions tiny hairs project into a jelly that also contains relatively heavy particles of the mineral aragonite. When the head is moved, the inertia of the particles is communicated to the hairs. Nerve endings at the base of the hairs then convey impulses to the brain or a reflex mechanism.



**FLAGELLA** of *Proteus vulgaris* are revealed by an electron micrograph. The bacteria are the large white bodies; the flagella are the threadlike processes. This reproduction enlarges the bacteria 21,000 diameters.



**MANY FLAGELLA** stream from another form of *P. vulgaris*. In this form the bacteria are linked. One bacterium is in the center; another is at upper right. This reproduction enlarges the bacteria 21,000 diameters.

# FLAGELLA

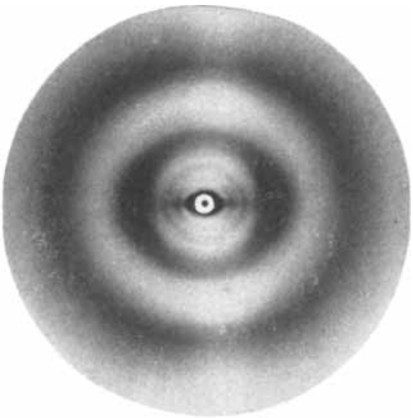
**The whiplike appendages of bacteria are among the smallest living structures. They behave like tiny muscles, so they are studied to reveal the basic properties of this and other contractile proteins**

**by W. T. Astbury**

WHEN we look into the world of small organisms under a microscope, we can see that many of these minute forms of life, including some bacteria, possess whiplike appendages by which they apparently propel themselves about. These flagella, as they are called, are extremely delicate. In bacteria they are too fine to be distinguished individually under the optical microscope but show up very beautifully in the electron microscope, though of course in this instrument they are not alive but dry and immobilized.

Bacterial flagella constitute some of the tiniest living structures we know. Considering that they are no thicker than large protein molecules, the problem of their motility is one of deep fascination. It is still a nice point whether swimming bacteria equipped with flagella are indeed always swimming by their flagella, but however that may be, it can hardly be denied that here is something quite fundamental as regards living movement. How do these small instruments work? A bacterium is a worthy object of study in any posture, but like Ko-Ko's tiger in *The Mikado*, "especially when lashing of its tail."

To try to get to the bottom of the nature of bacterial flagella an obviously desirable approach is to take X-ray diffraction photographs of them, for it is from X-ray analysis, which reveals atomic and molecular arrangements, that much of our present knowledge of the structure and properties of biological fibers derives. If only we could examine flagella by this technique and compare what we learned with the already available X-ray data on hairs, muscles, tendons, nerves and the like, surely something exciting might come out of it almost immediately. Only a few years ago this was no more than a dream, and then suddenly it became real. In 1944 appeared a paper by Sven Gard, a Stockholm bacteriologist, describing how to obtain preparations of bacterial flagella in fair yields and in a highly purified state. The method was quite simple: it consisted in shaking a suspension of bacteria in water until the flagella fell off their bodies—or perhaps it might be more precise to say until the bodies fell off their flagella, for the bodies sank to the bottom or at least could be readily sedimented in an ordinary centrifuge, while the flagella remained suspended in the liquid. The liquid skimmed off the top was effectively a *solution* of flagella which could be concentrated and generally dealt with in a high-speed ultracentrifuge.



**X-RAY DIFFRACTION** pattern of a thin film of ***P. vulgaris*** flagella shows that they have structural features characteristic of muscle and hair.

In this way it was shown that collections of detached bacterial flagella behave to all intents and purposes like long thin macromolecules. The prospect was opened up of examining them by all sorts of well-established techniques, by X-ray analysis in particular. Like other protein molecules they could be precipitated from solution by adding ammonium sulfate, for example, and then be dissolved again. It is an odd thought this—to be able to operate with solutions and precipitates of "tails"!

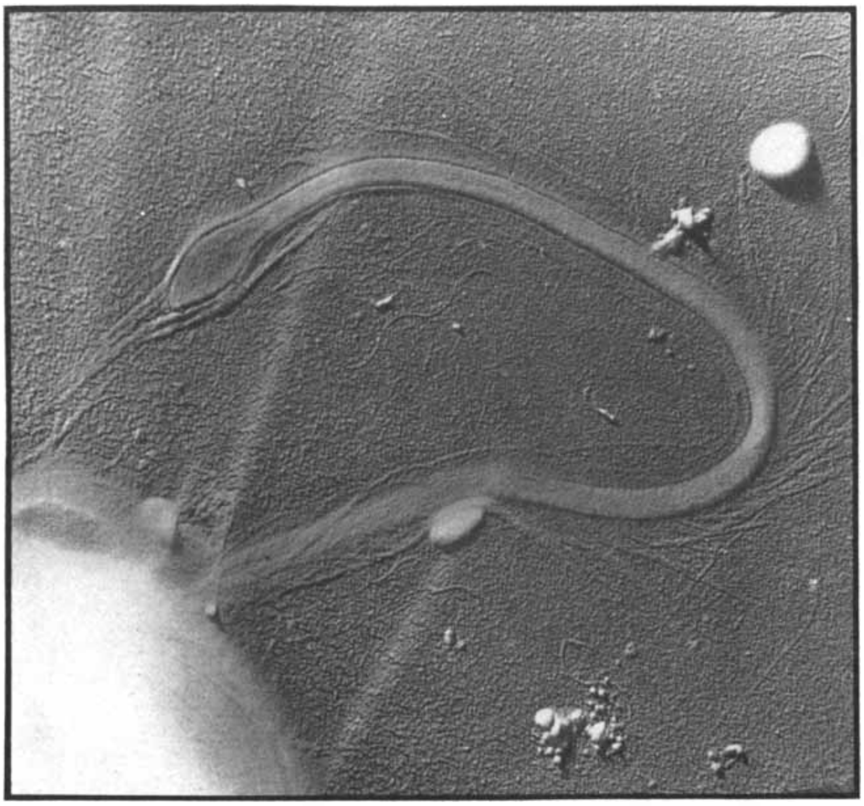
Following on Gard's work, the Swedish Natural Science Research Council decided to sponsor systematic chemical and physicochemical investigations centered in the Biochemical Institute of the Nobel prizewinner Arne Tiselius at Uppsala. Tiselius and one of his research students, Claes Weibull, had already made considerable progress in this scheme when it was arranged for Weibull to bring preparations to our laboratory at Leeds for X-ray study. The present article is written round some of the first results of this adventure.

X-ray analysis is a branch of optics, a mode of "vision" which uses the short electromagnetic waves called X-rays to examine details too small to be resolved by ordinary light. In principle and in general technique it is a shortwave counterpart of radar. We investigate the atomic and molecular arrangements of objects by sending X-rays at them and recording on a photographic film the waves that are scattered off, or diffracted. From this "diffraction diagram," a pattern of black spots, arcs and rings, we work back by physical argument and calculation to form a mental picture of what the objects must have been like to scatter the waves in such a way.

It would be asking too much of the X-ray analyst's capabilities at the moment to obtain a diffraction diagram of a single flagellum. What we are aiming at—a difficult enough task in any case—is photographs of many flagella drawn out straight and parallel to one another. Some progress has been made toward this goal, but for the present our X-ray evidence comes mostly from photographs of flagella lying flat in a thin film, which is the next best thing to examining them in bundles. If such a film is looked at in a direction parallel to its plane, the view is, crystallographically speaking, an approximation to that of a thin bundle of flagella.

It happens very often in scientific research, and in most other activities for that matter, that the success of a main

**SINGLE FLAGELLUM** of *Euglena gracilis* is shown by a photomicrograph. It is a much thicker and more complicated structure than a bacterial flagellum. This reproduction enlarges the microorganism 1,300 diameters.



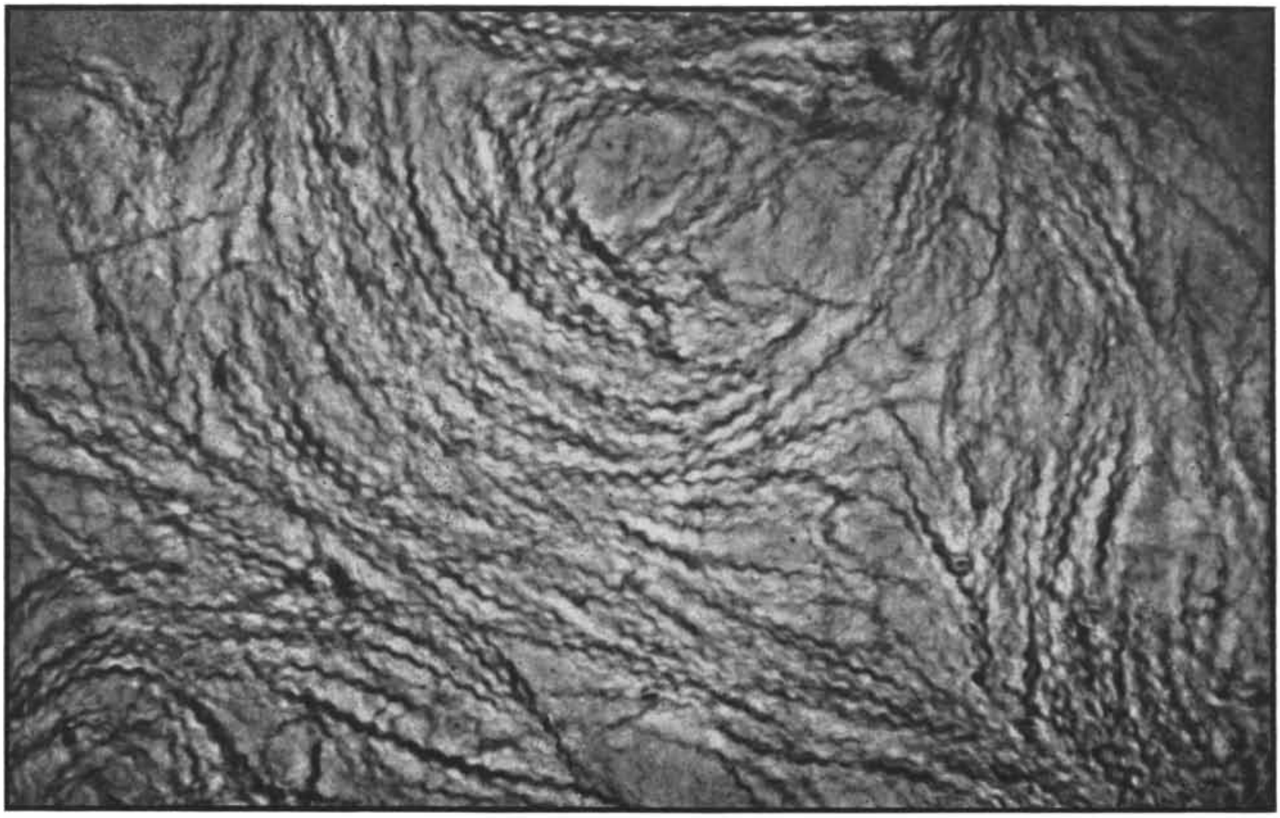
**FLAGELLAR STRUCTURE** of *E. gracilis* is shown by an electron micrograph. Within the loop of this large flagellum may be seen a single wavy bacterial flagellum. This reproduction enlarges the flagella 7,000 diameters.

plan depends in the last resort on some overlooked detail or some trick of manipulation, and the making of this film is rather a striking case in point. The film is formed easily enough by allowing a pool of viscous flagellar solution to dry on a glass slide. But how detach the delicate dried film from the slide without tearing it to pieces? The trick that solved this very real difficulty was to treat the glass slide with dichloro-dimethyl-silane, which makes the slide water-repellent and so makes it possible to lift off the film intact. Without this all the previous lengthy labor of preparing the pure flagella might well have been vitiated for the X-ray analyst.

AS YET only two kinds of bacterial flagella have been examined: those of the bacteria *Proteus vulgaris* and *Bacillus subtilis*. Although the X-ray diagrams are still imperfect, they are good enough to show that the two varieties of flagella are clearly similar in type. What is more—and this is the exciting discovery—they both show characteristic features that we have learned to associate with certain other fibrous protein structures, particularly hair and muscle.

We must now elaborate on this a little, for it is the essence of the whole affair—the dream that came true, in fact. It started more than 20 years ago with the X-ray interpretation of the molecular structure and properties of wool, hair and related keratinous tissues (so-called because they are all built from the fibrous protein keratin). All these tissues, including not only the many kinds of mammalian hairs but also horn, nails, hooves, spines, whalebone and so on, were found to give one and the same type of X-ray diagram when they were in their normal unstretched state. But when stretched they yielded quite a different type of diagram. This is in sharp contrast with the case of cellulose or natural silk fibers, which show no intrinsic change of pattern when stretched. There is a corresponding contrast in elastic behavior: if fibers of cellulose or silk are stretched by more than a few per cent, some of the elongation persists, whereas mammalian hairs, especially when moistened, are beautifully elastic. Wet hairs can easily be stretched by upwards of 50 per cent even at room temperature, and they contract precisely to their original length when let go.

Now fibers are of the nature of "molecular yarns"; they are constructed of long, flexible chain-molecules in much the same way as textile yarns are constructed from the visible fibers themselves. A yarn made from straight and inextensible fibers stretches only by the sliding of the fibers past one another. Similarly when cellulose and silk fibers are stretched, their practically inextensible chain-molecules simply slip past one another, leaving the molecules' shape



**PRECIPITATED FLAGELLA** form spirals. The pitch of each spiral is the same; it is characteristic of the bacterial species. These flagella were separated from *Bacillus subtilis* and precipitated with ammonium sulfate by Claes Weibull of Sweden's University of Uppsala. The reproduction enlarges the flagella 1,200 diameters.

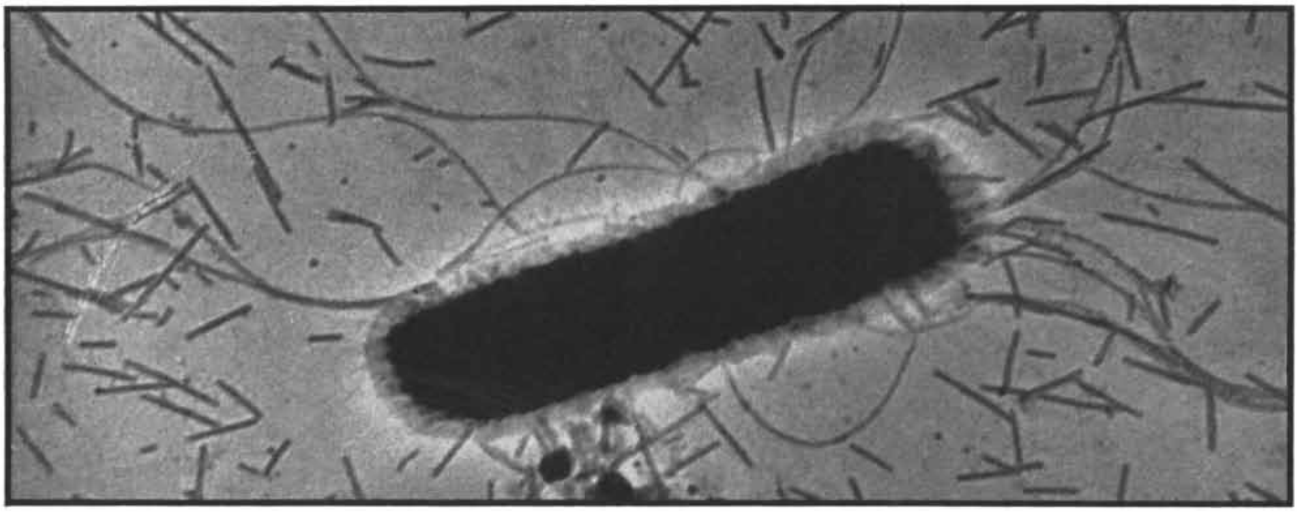
basically unchanged and consequently producing no fundamental change in the X-ray diagram. But consider a yarn constructed from finely kinked, springlike fibers with sufficient sideways interlocking to prevent slipping. In this case one can stretch the fibers themselves by pulling out the elastic kinks. This is the analogue of mammalian hairs: they are formed from molecules which are themselves elastic. Thus when the keratin molecules are pulled they take a different shape, thereby giving rise to a new X-ray diagram. On release such molecules tend to recover their natural shape and to give again their normal diagram. We can repeat this cycle of stretching and recovery, with corresponding changes in the X-ray diagram, as often as we please.

The unstretched form of the keratin molecule is called $\alpha$-keratin and the stretched form $\beta$-keratin. Like all proteins, keratin is composed of polypeptide chains. In keratin fibers the polypeptide chains run in the direction of the fiber axis, and their normal form is a long series of regular folds (the $\alpha$-folds) which we may picture on the molecular level as resembling, say, those of the conventional sea serpent. When we stretch a hair, the intramolecular folds—not to be confused with the visible waves or curls in hair, which are of a very different order of magnitude—are pulled out almost straight. When we let go, especially if the hair is wet, they go back again. Historically it was this interpretation of the elastic properties of keratin that revealed the potentialities of unfolding or reshaping in protein molecules as a class and gave a principal clue to the nature of living movement.

ALL this is impressive enough even if we look no further than the keratinous tissues, but it turned out to be only the foreshadowing of a much more comprehensive generalization. The $\alpha$-keratin type of X-ray diagram was found to be no exclusive prerogative of keratin; a surprising variety of structures share in it, epidermis and muscle in particular. It came in due course to be recognized as standing for one of the master plans in molecular biology—a plan which we now see includes in its scope even the minute flagella we are considering.

The family of fibrous proteins that conform to the $\alpha$-diagram is known as the keratin-myosin-epidermis-fibrinogen group, or k-m-e-f group for short. All the members of the family are constructed of polypeptide chains folded in the manner of keratin. They have the common property that the chains can both lengthen and shorten; they lengthen by unfolding, sometimes in response to simple pulling as when a hair is stretched, and shorten by falling into more pronounced folds than in the normal state. We need not go into the kinds of treatments by which these changes can be brought about; the important points are the standard molecular shape and the fact that the chain *is* capable of such changes. Note that we are not saying that the members of the k-m-e-f group are identical with one another—obviously they are not—but that they all derive from one scheme. The achievement of X-ray analysis is that it has penetrated the appearances bequeathed by evolutionary and developmental processes and uncovered this scheme. The k-m-e-f group is now seen for what it is: a beautiful illustration of what may be called the family history of molecules, lying at the foundations of the large-scale family history of classical biology.

Looking at the scheme in this larger context—and in the end that is how biologists of whatever complexion do look at their subject, consciously or unconsciously—it becomes difficult if not unjustifiable to think any longer of muscular activity as the unique and almost awesome problem it is sometimes supposed to be. The workings of a full-scale muscle are undeniably very complicated and we are still far from disentangling them, but all the same the trouble is probably more of detail than of



**TOBACCO-MOSAIC VIRUS and the flagella of *P. vulgaris* are shown in the same electron micrograph. The rod-shaped viruses are thicker than the flagella. This reproduction enlarges both structures 62,000 diameters.**

principle. If the X-ray findings mean anything, surely they are telling us that the contractility of muscle is only a special manifestation of properties characteristic in one form or another of all the members of the k-m-e-f group. It is not only the muscle protein *myosin* (in combination with *actin*) that has this power of contraction; they all have it, given the right stimulus. And it is the expression of a master plan working through the capacity of a certain pattern of polypeptide chain to fold and unfold. The epidermis, hairs and muscles are adaptations of one and the same idea. So also, it now appears, are bacterial flagella.

Whether we think of the flagella as primitive hairs or primitive muscles is of no great significance fundamentally, for they bear the stamp of both. The prime consideration is that they behave like *monomolecular* hairs or muscles. Their order of thickness, too, if we may judge by some of the features of X-ray diagrams of other members of the k-m-e-f group, fits in with this suggestion that they are single molecules. In the electron microscope we have directly compared the thickness of *Proteus* flagella with that of the rodlike monomolecular particles of tobacco-mosaic virus, and the flagella are definitely thinner. The comparison indicates that the flagella are roughly 120 Angstrom units thick, or about one two-millionth of an inch.

If we may change the metaphor and describe members of the k-m-e-f group as variations on a common theme, it is very tempting to surmise that bacterial flagella may represent the basic theme itself, or at any rate something closer to it than has ever been detected before. Most muscles, and even hairs, are colossal structures compared with bacterial flagella; but there has to be a beginning somewhere, and the thought is inevitable that perhaps in the flagella here it is. They are almost ridiculously small, true—they could hardly be smaller and still function—but that is the point. There is no room for complications; the motility mechanism must be in a form stripped down to its bare essentials.

IN WHAT sort of way might we suppose the bacterial flagella to operate? It is not too difficult, in the light of the foregoing arguments and others, to guess at a mechanism that could reasonably meet the requirements. To put it at its very simplest, imagine each flagellum to consist effectively of a long thin loop of protein chains running down one side and up the other. We have only to postulate that a state of folding or unfolding is transmitted along the chains to see how a rhythmic motion, consisting at least in bending, might take place. The propagation of a *change of state* is what is indicated.

A familiar illustration of such a phenomenon is the old experiment we do at school with a potful of supersaturated solution of Glauber's salt. When we drop a grain of crystal into the solution, crystallization spreads out rapidly from the grain as center, and before we know where we are the whole potful is solid. Something like that, we may fairly speculate, must happen along the structure of flagella, and presumably in response to a periodic stimulus arising somewhere in the body of the animal. There are signs in the electron micrographs that bacterial flagella are not merely outgrowths of the cell wall but emerge from the interior of the bacterium. At the internal end of each flagellum there seems to be a tiny knob. Possibly this knob is the "signal box" whence arises the impulse to a protein change of state—the supposed wave of chain-folding which, once started, travels on automatically, repeating itself over and over again.

Weibull has recently discovered that when the flagella of *Proteus* and *B. subtilis* are precipitated from solution by the addition of ammonium sulfate, they are in the form of what look like spirals; not arbitrary spirals, but spirals of a pitch that is constant and characteristic of the bacterium. It is as though the flagella, at the moment of being suddenly shaken off the bacterial bodies, were executing a spiral wave motion and died and were frozen in that attitude—a kind of molecular *rigor mortis*. Whether that is true or not, it is none the less impressive to observe, in electron micrographs of flagella against a background of rods of tobacco-mosaic virus, the obvious waviness of the flagella as contrasted with the stiffness of the virus rods (*see photograph above*). This is one of those quasi-elementary points that are really very profound. Here we have two species of long protein molecules of not very different thicknesses, yet one is stiff and the other flexible—more than flexible, it can apparently develop systematic movements peculiar to itself. Why is that? It will be a long time before we can know the full answer, but with this precious new finding that bacterial flagella may be classified with hairs and muscles the outlook is not without promise.

WE are now proceeding with similar experiments on more complex types of flagella, of which there are legion, and which are far removed from single macromolecules. They are "tails" that are more like tails, and their structure analysis will one day demand a great tome for which the present article can hardly form even the preface to the first chapter.

*W. T. Astbury is professor of biomolecular structure at the University of Leeds.*

Excerpts from a series of pupillography photographs taken on Kodak Infrared Film by Dr. Otto Lowenstein of Columbia University.

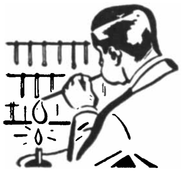
( A Quick Quiz on modern pH advancements )

# Do you know these important facts about BECKMAN pH CONTROL?

## Do you know...

### That Beckman pioneered modern glass electrode pH equipment?

Until Beckman pH instruments were developed, glass electrode pH equipment was a cumbersome, complicated laboratory curiosity. It was Beckman that pioneered today's simple, compact, highly accurate and completely dependable glass electrode pH equipment!



### That Beckman pioneered virtually every major development in modern glass electrode pH equipment?

Such far-reaching advancements as glass electrodes that can be used at temperatures as high as 130° C, and show negligible deviation even in high temperature-high pH ranges ... glass electrodes that can be used at temperatures as low as —20° C and will withstand repeated freezing ... glass electrodes so strong they can even be used as stirring rods—so abrasion-resistant they readily withstand long service in abrasive slurries ... these and other vital glass electrode advancements were *all* pioneered by Beckman. *Many of these advancements are still available exclusively in Beckman equipment!*

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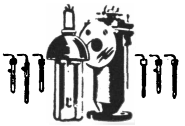
Included in the complete Beckman line are instruments specially designed to combine the high precision and wide versatility necessary for advanced research, medical and laboratory applications . . . others that combine maximum simplicity and high accuracy with complete portability for plant and field applications . . . still others that combine maximum simplicity and high accuracy with the plug-in convenience of full AC operation . . . plus *completely automatic* pH equipment for continuous pH indication, recording and control on large-scale processing applications.



### That Beckman also provides the industry's most complete line of modern glass electrodes?

Although glass electrode pH instruments are the most efficient pH equipment obtainable, no glass electrode pH instrument is better than the versatility, accuracy and dependability of the electrode assemblies available for use with it.

Beckman provides the industry's most complete line of glass electrodes for use with Beckman pH instruments—a type of electrode assembly to meet every industrial, research, laboratory and field requirement!

### That there are so many money-saving applications for Beckman pH control that you may be losing important profits unless you make a complete investigation of your operations?

There is pH wherever there's water, water solutions, moist pastes, sludges, slurries or other moisture-containing substances. And wherever there is pH, chances are the operation can be done better . . . with greater uniformity and less waste at lower overall cost . . . by Beckman-controlling the pH of the various processing operations.

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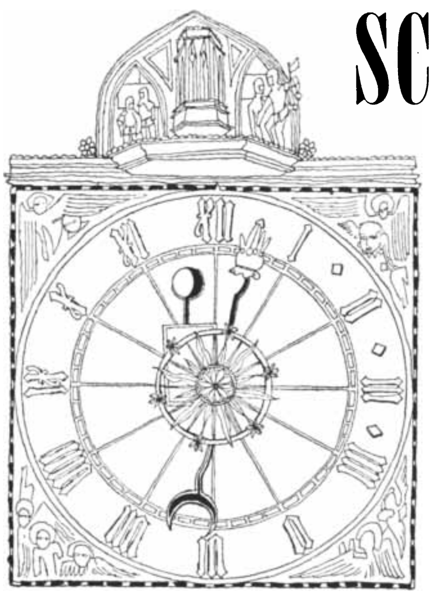
**pH Meters and Electrodes — Spectrophotometers — Radioactivity Meters — Special Instruments**

# SCIENCE AND THE CITIZEN



## TV and Education

SHALL part of the limited spectrum of channels for television be reserved for education? This question now confronts the Federal Communications Commission. In recent weeks it has held hearings which have spotlighted two strongly opposed points of view. Spokesmen for the nation's educators have urged that some channels be reserved for noncommercial educational use. Spokesmen for the broadcasting industry, opposing this request, have proposed instead that some of the time on commercial television stations be allotted to education.

Among the educational groups that have been represented at the hearings to press the educators' case are the National Education Association, the American Council on Education, the National Association of State Universities, the New York State Board of Regents and others. They contended that commercial bidding for television time is crowding educational programs off the air. Harriet H. Hester of the American Medical Association's Bureau of Health Education said: "Educators can't rely indefinitely on the charity of commercial stations."

John Crosby, radio and television columnist of the New York *Herald Tribune,* noted that the current battle for channels between educators and commercial broadcasters is the same as was fought during the early days of radio. This time, however, the issue is greater, both because the number of channels for television is much smaller than for radio and because television is a more effective medium of education.

At present there is only one television station in the U. S. devoted to education —WOI-TV, owned and operated by Iowa State College in Ames, Iowa. The City of New York, which has long operated a municipal radio station, has asked the FCC for a waveband on which to conduct a city television station, to be placed at the disposal of the Board of Education and local colleges and universities.

Thus far science and education have been given relatively little time on commercial television stations. One of the best science programs, a weekly 15-minute show conducted on a national network by Roy K. Marshall, professor of astronomy at the University of North Carolina, was recently dropped. Marshall has now been given a sponsored local program (10 minutes minus commercials) on WNBT in New York at 6:15 five evenings a week. Also on the air are the unsponsored "Johns Hopkins Science Review," a half-hour program on the Dumont network at 8:30 p.m. Tuesdays, and "Watch the World," a half-hour show on the NBC network at 5:30 Sunday afternoons, which features a five-minute lecture by Marshall and semi-educational telecasts on such topics as "a tour of Chinatown" and "how a mink coat is made."

## Casualty

EUGENE GARDNER, nuclear physicist of the University of California and co-discoverer of the first artificial mesons, died of beryllium poisoning on November 26 at Vallejo, Calif. He was 37 years old and a casualty of the atomic bomb project.

Gardner inhaled beryllium dust while working at the Manhattan Project's radiation laboratory in Berkeley in 1942. The symptoms of berylliosis, similar to those of pneumonia, were not detected until 1945. Since then Gardner had been hospitalized for varying periods. He did his most important work in 1948, during his illness. He was one of the group who bombarded graphite with alpha particles to produce the first man-made mesons in the University of California's 184-inch cyclotron (SCIENTIFIC AMERICAN; June, 1948). In the last six months of his life Gardner kept a microscope near his oxygen tent, so he could study meson photographs whenever he was permitted out of bed.

## Lopo, Hypo, Gleep and Zeep

A MAJOR release of heretofore secret data on nuclear reactors has been announced by the governments of the U. S., the United Kingdom and Canada. For the first time certain detailed information on the design, construction and operation of reactors is now available. The release is restricted to low-power reactors, useful for research but not for power or weapons production. It will facilitate the training of reactor engineers and technicians by letting instructors use specific data from actual experiments. Authorized institutions will also be permitted to build their own low-power reactors with fissionable materials loaned by the government.

During the next few months virtually complete information will be released on the design and operation of the world's first nuclear reactor, constructed from uranium and graphite at the University of Chicago in 1942; a modified version of this reactor now located at the Argonne National Laboratory; a uranium and heavy water reactor at Argonne; the two homogeneous "water boiler" reactors called "Lopo" and "Hypo," at the Los Alamos Scientific Laboratory; the British low-energy reactor known as "Gleep," at Harwell, England, and the Canadian "zero-energy" pile called "Zeep," at Chalk River.

The first release of information revealed a few quantitative facts on uranium nuclear reactions, some of them surprising to laymen. It was disclosed that an appreciable proportion of atoms of fissionable uranium 235 do not fission when they capture a slow neutron. Instead they form relatively stable atoms of U-236 which decay by radioactivity. For every 545 fissions there are 100 such stable captures.

The number of free neutrons released when a U-235 atom fissions was officially announced to be between 2.4 and 2.6.

The most interesting reactor described by the Atomic Energy Commission is Hypo, the high-power water boiler. The smallest of all the controlled reactors, its critical mass of fuel is about 1.8 pounds of U-235. This is in the form of a uranyl nitrate solution in water, with about one part of fissionable U-235 to six parts of non-fissionable U-238. The solution is known to the Los Alamos scientists as "soup." The soup is in a one-foot spherical container of stainless steel. Around this is a thick reflector, or "tamper," of beryllium oxide and graphite, and this in turn is surrounded by a heavy shield which includes four inches of lead, $\frac{1}{32}$-inch of cadmium and five feet of poured concrete.

Hypo has a peak power of about six kilowatts, representing a flux of about 300 billion neutrons per square centimeter per second at the center of the reactor. It is cooled by water circulating in a coil inside the sphere. A flux of slow neutrons of the order of one billion neutrons per square centimeter is available in the graphite tamper surrounding the reactor. Under normal conditions Hypo is self-regulating. As the temperature increases the volume of the solution expands and the reactivity per unit volume declines, automatically slowing down the reaction. If the reaction should become overheated, cadmium control rods would automatically drop into the solution to absorb neutrons and stop it.

### *AEC in Carolina*

THE $260-million plant for production of tritium for the hydrogen bomb project will be built on the Savannah River in South Carolina at a site 20 miles southeast of Augusta, Ga. The site, a 250,000-acre tract, was selected by E. I. duPont de Nemours & Co., which will build and operate the project. Construction will start early in 1951.

The Savannah River will supply the necessary water for cooling and serve as a discharge basin for wastes. Drainage in this area will minimize radioactive contamination of ground water. Ample nearby electrical power is available from the Tennessee Valley Authority. The site is accessible to Augusta and to Aiken, S. C., so the AEC will not need to establish a new community, as at Oak Ridge and Los Alamos.

President Truman gave further impetus to the atomic weapons program last month by asking Congress for an additional $1,050 million for the AEC, as part of the general arms appropriation of $17,850 million.

### *Synthetic Gasoline*

FOR several years the U. S. Bureau of Mines, looking ahead to a decline in the nation's petroleum resources, has been plugging away at pilot plant tests of the production of synthetic gasoline from coal. Last month it announced that it was at last producing gasoline "in practical quantities" and at a reasonable cost by the so-called hydrogenation process. Its demonstration plant in Louisiana, Mo., 100 miles north of St. Louis, is currently yielding about 9,000 gallons of gasoline a day. Leslie L. Hirst, director of the plant, said the production cost was close to that of gasoline from natural petroleum. The hydrogenation process, which treats coal with hydrogen under high temperature and pressure, can make Diesel oil, paint solvents, wood preservatives and other chemicals as well as gasoline.

The Bureau is also making progress in its tests of the Fischer-Tropsch process for converting coal into gasoline; it expects this process to be in production by next spring.

### *Oceans from the Interior?*

A NEW theory of how the Earth acquired its oceans and atmosphere has been proposed by William W. Rubey of the U. S. Geological Survey, retiring president of the Geological Society of America. At the Society's recent annual meeting he suggested, with supporting arguments, that the volatile elements of the seas and air may have come from the interior of the Earth, leaking to the surface as gases.

The classical idea has been that the Earth has had oceans and atmosphere from the beginning, when it cooled from a molten mass. But the recent evidences in favor of the view that the Earth began as a cool, solid body have raised objections to that theory.

Rubey himself came to his hypothesis through a different approach. Studying the saltiness of the sea, he found a puzzling fact about the geochemical composition of the Earth's surface: certain volatile components of the air and oceans—water, carbon dioxide, chlorine and nitrogen—are much too abundant to be accounted for as the products of the surface weathering of rocks. Consequently he began to examine the possibility that these "distillable spirits" of the Earth's solid matter had arisen from interior rock. He found that granite rocks hold in solution more than enough volatile material to account for the oceans and atmosphere. As the rocks cool, they give up some of this material, which may escape to the surface in volcanoes or hot springs.

Rubey further discovered that the relative amounts of the "excess" volatiles in the oceans and atmosphere correspond closely to their proportions in volcanic gases and hot springs. Assuming that the discharge of water from hot springs in the U. S. is typical for that all over the Earth, in the two billion years of the Earth's existence hot springs alone could have yielded over 100 times as much water as exists in the present oceans, according to Rubey's calculations.

His theory suggests that the oceans are still growing, but so slowly that no change would be perceptible. The same process that releases water also brings about a progressive lowering of the ocean bottoms, so that despite their constantly increasing volume the oceans' surface level has remained about the same throughout geological history.

Meanwhile, the discovery of a huge new mountain range 1,000 miles long under the waters of the Central Pacific has been announced by a joint expedition of the University of California and the U. S. Navy. Its head, Roger Revelle of the Scripps Institution of Oceanography, reported that the range is 100 miles wide, with peaks up to 14,000 feet high, and extends from Wake Island to Necker Islet near the Hawaiians.

### *Recipe for Cloud Chamber*

A CLOUD chamber simple enough to make at home has been designed by four physicists at the Brookhaven

National Laboratory. The contraption actually has advantages as a research tool over the elaborate machines built for physics laboratories. Conventional Wilson cloud chambers permit observation of particle trails for only a fraction of a second at a time. The new device allows continuous observation of the tracks.

The home-made cloud chamber can be constructed with cheap and readily available materials. You start by filling a flat round container with dry ice. Cover this with a metal disk 5 to 17 inches in diameter with a black velvet cloth on top. On this place a glass cylinder, open at both ends and slightly smaller in diameter than the disk. Then cover the cylinder with a second metal disk, with a piece of alcohol-soaked felt attached to the bottom of it. Finally, place a tray of water on top of the whole thing.

The alcohol vapor emitted by the soaked felt in the cylinder is cooled as it approaches the bottom disk, chilled by the dry ice. Below a certain level the vapor becomes cool enough to produce supersaturation. When a charged particle enters the supersaturated zone near the bottom, the vapor condenses along the track of the atoms and molecules it ionizes, forming a visible trail. You can see the tracks against the black velvet background by shining a flashlight on it. Since a zone of supersaturation is always present, due to the continuous diffusion of vapor from the felt pad, the tracks of cosmic-ray particles are constantly visible, whereas in a Wilson cloud chamber they are seen only momentarily when the chamber is expanded suddenly to produce supersaturation.

The original suggestion for this type of chamber was made in 1939 by Alexander Langsdorf, Jr., then at the California Institute of Technology and now at Argonne National Laboratory, Chicago.

## *How to Lose Your Appetite*

THE old superstition that alcohol with food improves the appetite has been dealt a blow by a group of investigators at the Permanente Foundation in Oakland, Calif. They insist, on the basis of certain experiments, that the alcohol in one small glass of wine is enough to convert appetite into satiety.

Their method of investigation was to test the effects of drinking on the acuity of the senses of smell and taste. They administered 150 cubic centimeters of a weak ethyl alcohol solution by mouth to each of six subjects. After drinking, the subjects suffered as great a loss of ability to smell freshly ground coffee and to taste sugar as after eating a normal lunch. They also reported a sharp decrease in the desire for food. One of the subjects was a habitual drinker, and he responded less sensitively; it took a double dose of alcohol to kill his appetite.

The investigators suggested that alcohol may produce this effect "either by depressing the ability to recall and associate certain experiences of the past, or by interfering with perception of certain sensory stimuli necessary for creating or maintaining the composite sensation of appetite."

## *Color Photographs Without Dyes*

A METHOD of producing natural color photographs from ordinary black-and-white images has been described in *Science* by Robert D. Bensley of the University of Chicago. The colors are provided during development by finely divided silver.

Bensley, an anatomist, discovered the technique accidentally. He was trying to produce very fine-grained positives from black-and-white negatives by substituting in them practically grainless silver chloride. "The result was most astonishing. Instead of the fine-grained positive that was expected, the plate flashed up in a number of colors." By further experiments he worked out a method whereby black-and-white images can be processed into permanent, natural colors. For full color the process requires two negatives taken with different filters, and a rather complicated development. How the colors are produced remains to be explained; Bensley thinks they may be determined by the size of the silver particles.

## *Human Bites*

HUMAN teeth are not as effective weapons as the fangs of a wolf or wildcat, but they are dangerous enough. So report George F. Crikelair and Gaylord S. Bates of the Wayne University College of Medicine in *The American Journal of Surgery*.

"About 80 per cent of all human bite lacerations involve the fingers and hands," they write, "while the remaining 20 per cent are scattered over the rest of the body." The two surgeons confined their study to 46 cases of bites of the head and neck. Of the victims, 33 were adults bitten in fights, 6 were children bitten accidentally at play and 2 were persons injured during sexual attack. "The cheeks and lower lip were involved most frequently. There was loss of tissue in one of the cheek bites and in seven of the lower lip bites."

Despite the possible loss of tissue, Crikelair and Bates find bites of the head and neck less dangerous than bites of the hand. For anatomical reasons, bites of the hand are much more likely to become dangerously infected. The surgeons advocate treating human bites of the face and neck in much the same way as other wounds. The average hospitalization of their 46 patients was 5.78 days. Most of the wounds healed without serious permanent disfigurement and there were no fatalities.

# What GENERAL ELECTRIC People Are Saying

T. M. BERRY

*General Engineering & Consulting Laboratory*

CONTOUR FOLLOWER: The optical contour-follower control is an automatic curve-following device. It has several unique features which make it ideally suited for use as a machine-tool control for the purpose of reproducing, in metal, a shape designated on a line drawing.

A number of machine-tool controls of the template-follower type are in general use for machining duplicates from a metal master pattern. The optical contour follower is used in making the master pattern itself.

In many cases thousands of duplicates are made from a single metal master, and only a few masters are required. The amount of time and labor involved in making these few accurate masters is relatively unimportant. Developmental manufacturing, however, requires that a master be duplicated only a relatively few times and that a much larger number of masters be made. In this case the time and labor involved in making a master are very important. It was for the purpose of reducing this time and labor that the optical contour follower was developed . . .

*"G.E. Review"*
*June, 1950.*

★

J. P. DITCHMAN

*Lamp Department*

PLANT LIGHT: The advent of new artificial light sources stimulates the efforts of plant physiologists and other scientists to solve the fundamental riddle of how plants grow. Carbon arc incandescent lamps, sodium lamps, mercury lamps, and many combinations of these have been used in growth chambers where light, humidity, temperature, and air are controlled to grow plants entirely under artificial conditions. Today laboratories are being equipped with combinations of fluorescent and incandescent lamps for this purpose. . .

There are many laboratories in agricultural colleges equipped with rooms for growing plants entirely under artificial conditions, trying to develop methods independent of natural conditions. These research objectives, it is said, could lead (if successful) to political and economic consequences which could rival those of the atomic bomb. If we could maintain food production under ground, we could provide a hedge against some of the spectacular devastation feared in an atomic war.

*Illuminating Engineering Society*
*Pasadena, California*
*August 21, 1950*

★

H. A. LIEBHAFSKY
A. E. NEWKIRK

*Research Laboratory*

CORROSION STUDIES: The annual cost of corrosion is so great that it is desirable to explore every promising technique for the investigation of corrosion processes. Among the most feared of these processes is pitting, which, being a form of localized attack, is well suited to investigation by methods such as radiography that depend upon the absorption of x rays.

To illustrate the value of these methods, the pitting of three kinds of stainless steel in ferric chloride solution at room temperature has been studied. Radiographs have been obtained that show how pitting varies with the kind of steel and with the degree of cold deformation. Furthermore, it has been possible to demonstrate that the direction of attack can be profoundly influenced by gravitational forces and by the occurrence of crevices. While the radiographs largely confirm past experience, they provide much detailed evidence that might escape visual observation . . .

Finally, it has been possible to measure the rate of pit growth on specimens continuously immersed—an important fact, because removal of the specimen from ferric chloride solution can stop altogether the growth of particular pits. The technique employed could be used to measure in favorable cases the rate of pitting in closed systems.

*National Academy of Sciences*
*Schenectady, New York*
*October 10, 1950*

★

J. P. RUTHERFOORD

*Apparatus Department*

STREET LIGHTING: Kansas City, working with the Kansas City Power & Light Company, has almost completed a postwar relighting program. By using modern, efficient, highly effective equipment, the total number of luminaires on Kansas City streets has been reduced from approximately 15,000 under the old system to about 13,500 under the new system.

The total effective lumens, however, have been increased from approximately 11,500,000 under the old system to approximately 49,000,000 under the new system. In spite of this tremendous increase in effective lumens on the street, the annual street lighting bill to the city has increased from $552,000 per year to only $626,000 per year.

If you evaluate that in terms of lumens on the street, the people of Kansas City were paying approximately $47.53 per 1000 lumens under the old system and are presently paying only $12.80 per 1000 effective lumens under the new system.

*Rotary Club*
*Weymouth, Mass.*
*July 24, 1950*

*You can put your confidence in—*

**GENERAL ELECTRIC**

# THE ECONOMICS OF ATOMIC POWER

## An account of the first thorough inquiry into the potential usefulness of nuclear fuels in various industries and many parts of the world

by Sam H. Schurr

IN the present state of international tension any analysis of the peaceful possibilities of atomic power admittedly must take a long view. No one can close his eyes to the fact that the political and military aspects of atomic energy will dominate all other aspects for some time to come.

The Cowles Commission study of the economics of atomic power, which this article summarizes, in the main excluded political questions and assumed a state of affairs in which the development of atomic power could proceed without artificial hindrances. The complexity of the subject demands this approach. Science often finds it must separate the variables in a problem and consider them independently if it is to handle the problem at all. This is certainly the situation in the complex field of atomic energy.

Attempts to depict the future of the "atomic age" have tended to run to two poles. At one extreme enthusiasts have pictured a world in which nuclear energy will drive our cars and round-the-world airplanes, blast aside mountains and break up icecaps, heat our homes and kill our germs, power our railroads and run our factories, control our weather and transport us to the moon. At the other, pessimists have asserted that atomic power will never be practical except for a very limited kind of use. Our study attempted to make a realistic appraisal of the economic feasibility of the use of atomic power on the basis of the present estimated range of costs and present concepts of nuclear technology. We therefore left out of account problematic future developments (*e.g.*, the possibility that nuclear energy might be converted directly into electricity) and restricted our analysis to a single type of plant—a heat-and-electricity generating station in which the conventional furnace would be replaced by a nuclear-fission reactor.

Now in such a plant we are dealing with something that is partly new but not altogether so. It differs in some fundamental respects from a conventional power plant, but it also has many points of similarity, and the latter give us some known yardsticks for cost comparisons.

One important difference, of course, is in the energy content per pound of fuel. In a conventional plant a pound of coal can be transformed into about one kilowatt-hour of electric power. In a fission-powered plant a pound of atomic fuel would yield about 2.5 million kilowatt-hours of electric power. Assuming that natural uranium (or thorium) could be completely converted into nuclear fuel, of which there seems to be a good chance, this means that a pound of uranium would be the equivalent of approximately 2.5 million pounds, or 1,250 tons, of bituminous coal. Hence in comparison with coal uranium would be a practically weightless fuel. The cost per unit of energy of transporting atomic fuel would be negligible. The economic importance of this fact is clear: the use of nuclear fuel would tend to equalize the cost of fuel throughout the world.

It follows also that in terms of energy content nuclear fuel is likely to be cheaper than coal. In 1943 relatively pure uranium obtained from good-grade ores cost about $20 per pound. An equivalent amount of coal at $6 per ton, the average price paid by utilities in 1949, would cost $7,500. Nuclear fuel would be considerably cheaper even if low-grade uranium ores were used. For example, even if the cost of pure uranium increased 100-fold, to $2,000 per pound, it would still be only about one fourth as costly as coal per kilowatt-hour of energy yield.

The two hypotheses just stated—that nuclear fuel might be available everywhere in the world at about the same cost, and that this might be a very low cost—determined the fundamental orientation of the Cowles Commission study. Our analysis was concerned mainly with the possible economic effects of ubiquitous, low-cost power.

### Cost of Atomic Power

But fuel is only one element in the cost and availability of power. The construction and operating costs of the plant in which the fuel is burned must also be taken into account. Since it is not yet possible to calculate those costs with any definiteness, we considered a range of cost possibilities, as estimated by various authorities who have considered the problem. We made the costs from these different sources as comparable with each other and with the cost of power from conventional sources, in terms of certain common cost elements, as the data permitted. We chose the price levels of 1946 as the basis for the comparison. Although the general price level has risen considerably since then, the relation between the prices of the materials needed in atomic and conventional power plants has not changed substantially, so the comparison is still valid.

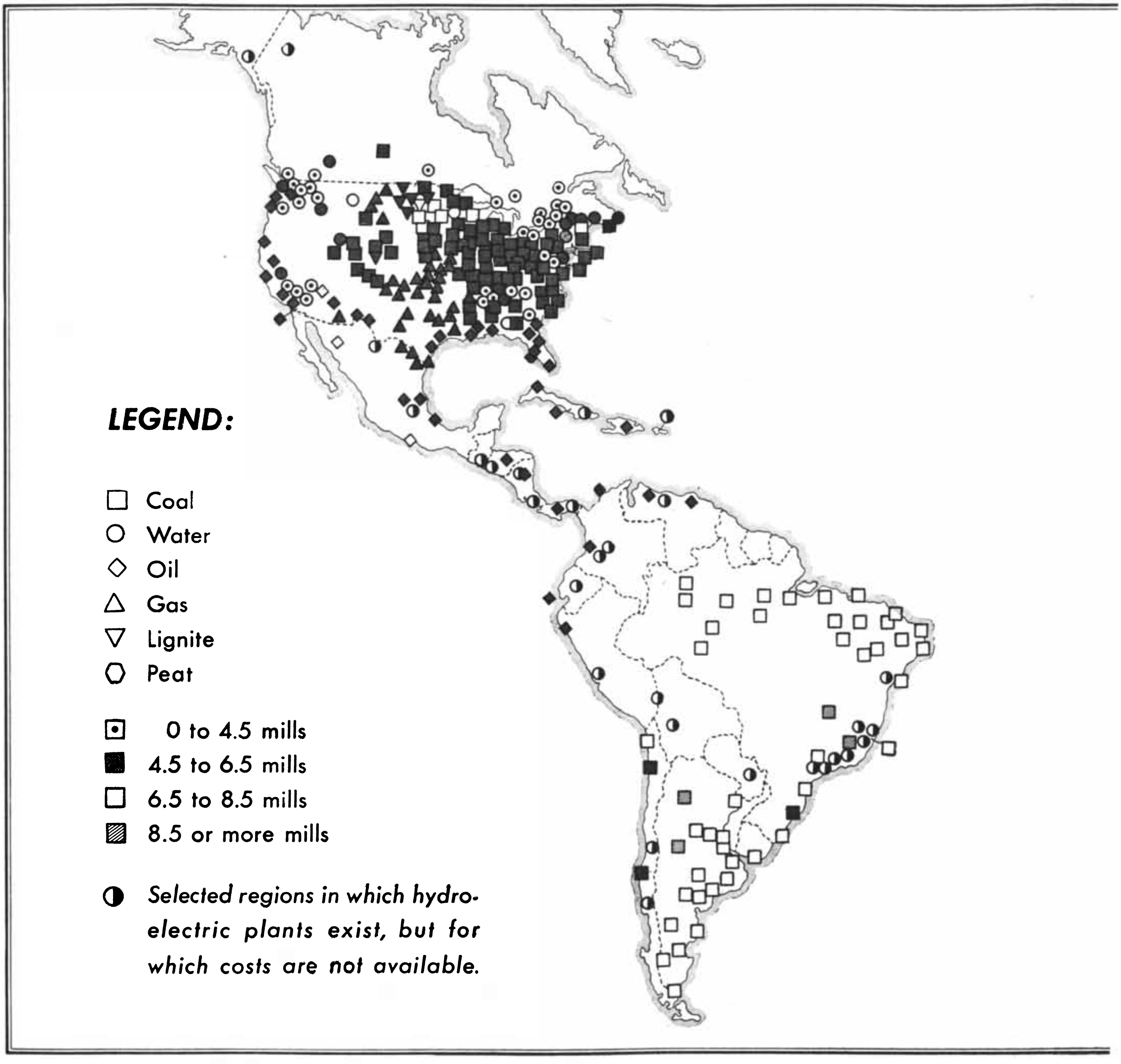
The hypothetical atomic power plant chosen for analysis is a central electricity-generating station with a capacity of 75,000 kilowatts operating at 50 per cent of capacity—a reasonable average level of operation for such a plant. On this basis three estimates of the possible cost of producing atomic electricity were arrived at: low, intermediate and high. The minimum, below which the cost cannot possibly fall, is 4 to 4.5 mills per kilowatt-hour. The intermediate figure is 6.5 to 7 mills per kilowatt-hour. The highest estimated figure for the cost of atomic power is about 10 mills per kilowatt-hour.

It must be emphasized that these figures are only rough estimates. We can be reasonably sure, however, that the minimum will not fall below 4 mills. We know that the atomic power plant will require certain equipment, such as turbines and the like, that a conventional generating plant uses, and these would represent a considerable proportion of the total cost of the plant. The 4-mills minimum is based on the assumption that the capital investment per kilowatt in a nuclear-powered plant would be no higher than that in a coal-fueled plant.

The firm minimum estimate is a very useful figure because it tells us the utmost that may be expected of atomic power. It thereby enables us to determine where it would *not* be economical to use it even under the most favorable circumstances and also indicates the nature of changes that might take place.

We have evaluated these estimates in terms of an approximate time scale. The highest figure we take to represent the cost in the first commercial plants producing atomic power. The intermediate cost figures we consider to represent an approximation of the level of costs which might prevail in plants built, say, 5 to 10 years after the first commercial installations. These plants would incorporate the improvements based on the lessons learned in constructing and operating the earliest plants, but would still fall short of the most efficient designs that might ultimately be achieved after many years of experience. The lowest figure represents the minimum cost at which atomic electricity could ever be produced by techniques considered likely at the present time.

Now how do these figures compare with the cost of generating electricity in conventional coal-burning plants? For this comparison we used prewar prices

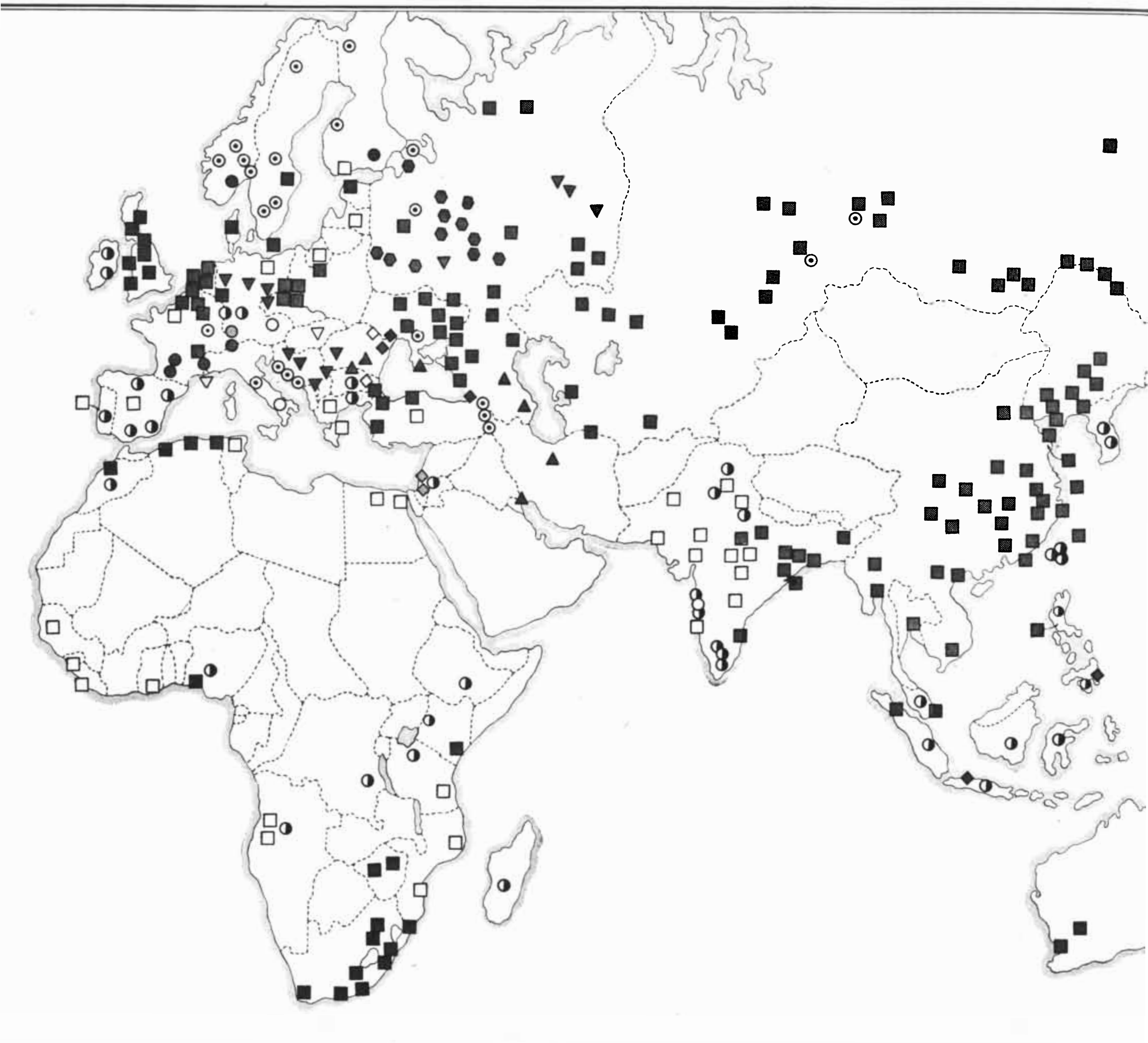



**COST OF GENERATING ELECTRICITY** is estimated for selected points in the Western Hemisphere. These costs for ordinary fuels are basis for evaluating atomic power in various areas. Map is continued on next page.

of coal, which of course were considerably lower than they are today, because they were the only satisfactory figures available on a world-wide basis. We estimated what generating costs would be in a large coal-burning plant (75,000 to 100,000 kilowatts) of the most modern design operating at 50 per cent of capacity. Assuming that the plant was located close to an exceptionally low-cost mine that produced coal at the low price of $1.50 per ton, it could generate power at 4.5 mills per kilowatt-hour. In the prewar decade coal was mined at this price in some sections of the U. S., Great Britain, the U.S.S.R., Manchuria, China, India and South Africa. But this was unusual. The average cost of coal at the mine in the U. S. as a whole was about $2 per ton. At that price the cost of generating electricity in a modern plant near the mine would be between 4.5 and 5 mills per kilowatt-hour. The typical cost in plants at the mine mouth around the world would be about 5 to 5.5 mills.

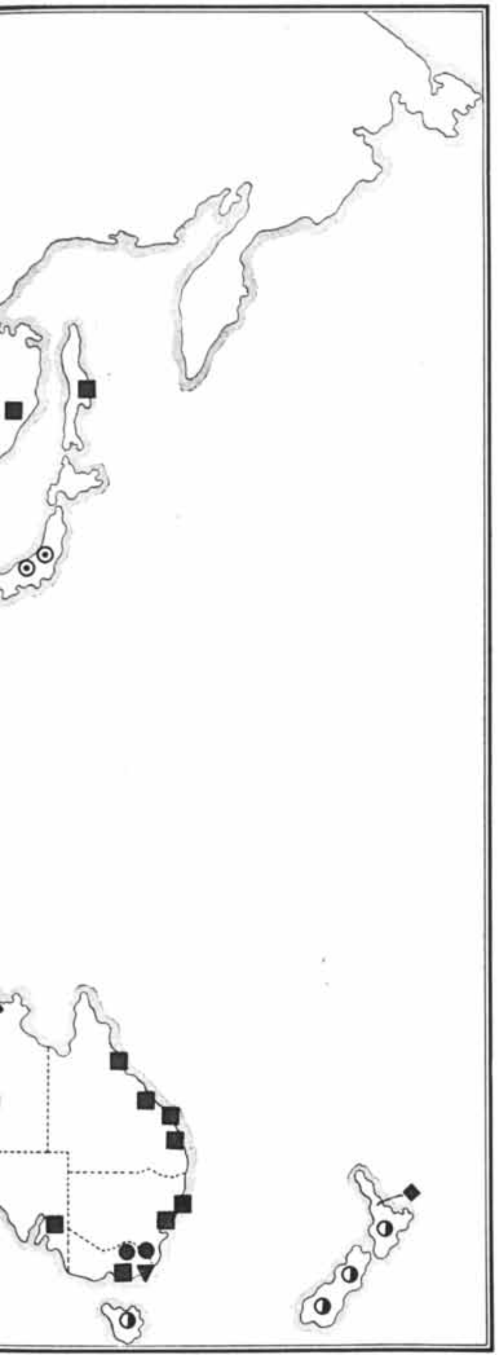
Of course the cost rises as the distance of the plant from the mine increases. In the U. S. in 1937 the average freight charge for delivering coal to plants was $2.17 per net ton—more than the mining cost itself. A representative railroad freight charge for a haul of 500 miles was $4.13 per ton. Reckoning in this transportation cost, a power plant 500 miles from the mine would produce electricity at 6.5 mills per kilowatt-hour.

Shipping coal by water is of course much less expensive per ton-mile than by railroad, but the cost generally is still considerable because of the long distances involved. For instance, the coal shipping charges in 1937 from Great Britain to various ports in Brazil and Argentina ranged from $3.20 to $3.60 per ton. The price of British coal at these



**COST OF GENERATING ELECTRICITY** is estimated for selected points in the Eastern Hemisphere. In the cases where electricity is generated by burning fuel, cost is estimated on the basis of a 100,000-kilowatt plant ports ranged from $7.80 to $8.20 per ton, and at many cities far from the coast it was $10.50 or more. At these prices it would cost about 7 mills per kilowatt-hour to produce electricity in a model plant in a port city of Brazil or Argentina and more than 8 mills in an inland city of those countries.

It is clear, then, that in comparison with electricity produced in coal-burning plants at the mine mouth (at 1937 coal prices) atomic power would be competitive only if available at a cost near the minimum estimate. But at a distance of 500 rail miles from the mine in the U. S., atomic energy could compete with coal if it could produce electricity at the estimated intermediate cost. And in Brazil and Argentina electricity costs based on British coal approach the highest cost estimates of atomic power. In other words, the economic feasibility of atomic power, and its effects, will depend primarily on geography.



of the latest design. Hydroelectric costs are based on existing plants.

A major part of our research was devoted to analyzing the possible effects of low-cost atomic power on individual industries. These industries were aluminum, chlorine and caustic soda, phosphate fertilizer, cement, brick, flat glass, iron and steel, railroad transportation and residential heating. All of them are, or could become, important consumers of energy.

In analyzing each industry we asked three major questions: 1) Would atomic power bring about an important reduction in its production costs? 2) Would it encourage the introduction of new production techniques? 3) Would it change the industry's present geographical pattern?

Our findings on these questions vary considerably from industry to industry, but certain significant generalizations are possible. The most significant is that in the U. S. atomic power probably will not have important effects on the industries studied unless it can be made available at a cost near the estimated minimum. Even at this low cost for power, production costs in the industries concerned would not be greatly reduced. But in several cases, assuming that atomic power does become available at the minimum estimated cost, the savings might be enough to encourage changes in production processes or relocation of factories.

### Iron and Steel

The possible effects can best be illustrated by considering a particular industry. Let us take iron and steel. Iron ore smelting today is completely dependent on coal in the form of coke. In smelting coal acts both as a source of heat and as a chemical agent. Energy is also required in the later stages of steel manufacture, such as steel refining and rolling. Obviously it is highly advantageous, to obtain the greatest fuel economy, to carry on all these operations at the same place. Consequently the pattern has been to combine coke ovens, blast furnaces, steel furnaces and rolling mills in one group of works at a single site. Coal has thus had a powerful influence in dictating the geographical concentration of the iron and steel industry in the U. S.

Atomic power might alter the pattern in one or both of the following ways: 1) it might replace coke as a blast furnace fuel, thereby releasing the entire operation from its fundamental dependence on coal, since the other processes could operate on other fuels; 2) it might simply separate the steel furnace and rolling mill from the blast furnace, with important effects on those later operations.

We have noted that in the blast furnace coke serves as a chemical reducing agent as well as fuel. But there is on the horizon another reducing technique which might be economically feasible in the U. S. This method would use hydrogen as the reducing agent rather than carbon; it would reduce iron ore to sponge iron. The process, just emerging from the laboratory, is considered promising by the research metallurgists who have experimented with it.

Atomic electricity could be used to produce hydrogen by the electrolysis of water. How would the two reduction methods compare in cost? Obviously only an extremely rough comparison can be made, since the hydrogen method has not yet been tried commercially. Our calculations indicate that the hydrogen method could not compete with the coke blast furnace in present steel centers, which are built close to coal. But if we consider new plants free to locate anywhere, the hydrogen process becomes a possibility. Since no transportation costs to speak of are involved in the use of atomic fuel, the plants could be placed near iron ore. We find that if atomic power could be made available near the estimated minimum cost, reducing plants located in the iron ore region of northern Minnesota might be able to deliver iron to the Chicago-Gary market at a lower cost than the steel plants in that area, and could almost match the cost of iron in the Pittsburgh region.

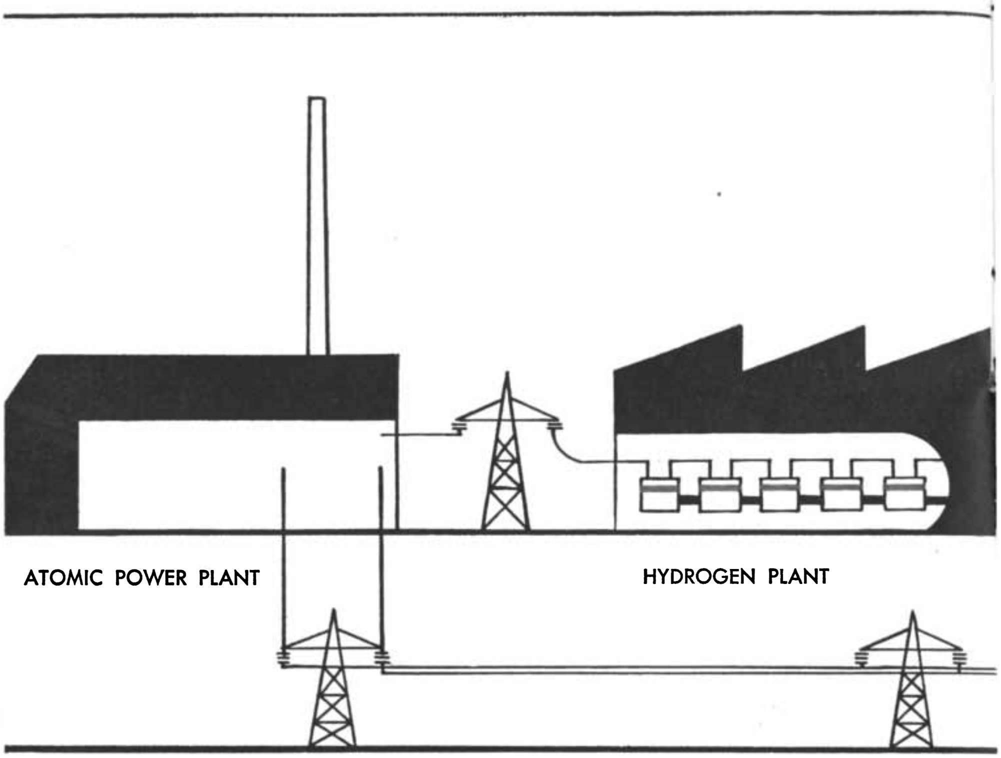
This particular result rests on assumptions which may prove invalid, particularly with respect to the relative costs of transporting iron ore and sponge iron. It at least raises the possibility, however, that in new plants to be built in the future the hydrogen reduction process might be brought within economic reach.

If the hydrogen process based on atomic electricity should be adopted, it might have major effects on the location and size of steel-producing facilities. The use of by-product gases from the coal would no longer be of great importance, for the hydrogen reduction process would not yield anything like the volume of hot gases exhausted by the coke oven and blast furnace. This change would weaken one of the most important factors which has historically made for the integration of all operations from the coke oven through the rolling mill. On the basis of the hydrogen process, the iron might be reduced at the ore site and the later stages of steel production might be placed near the market for steel products. Furthermore, it appears possible that the hydrogen method could exploit ore resources of about one-tenth the size needed for economic investment in a blast furnace. In time, therefore, the iron-reduction industry might be decentralized, with hydrogen sponge-iron plants developing in various regions, based on local reserves of iron ore.

The other way in which atomic power might affect the steel industry would be the wider employment of processes which enable individual steel plants to operate without depending on the blast furnace or iron ore. For example, atomic power might encourage the electric smelting of steel scrap at new centers. With electrically smelted scrap instead of iron ore as the raw material, a steel plant would not need to be near either iron ore or coal; it could be located wherever abundant scrap supplies existed. Moreover, this development would be assisted by the new process of continuous casting, recently developed experimentally by the Republic Steel Corporation, whereby molten steel is converted to finished shapes in one step, eliminating the making of ingots and billets.

All this might make it possible to build large-scale steel plants in steel-consuming centers, such as New York, Boston and St. Louis, where they are not practical at the present time. The transportation savings derived from producing the steel in the place where it is to be used might well make the utilization of atomic power for scrap smelting worth-while. Steel production by this method would of course be limited by the amount of scrap available, which in the near future is not likely to exceed 30 to 40 million tons a year.

So much for iron and steel. The analysis of the other industries showed that changes in production processes or geographical location or both might also occur there, always assuming that atomic power could be made available at a cost near the estimated minimum. Atomic power might, for example, free aluminum production from its ties to cheap hydroelectric power and permit the establishment of aluminum plants in bauxite regions such as Dutch Guiana or in important markets like New York. It might stimulate process changes in the manufacture of phosphate fertilizer, cement and so on.




**HYDROGEN REDUCTION OF IRON ORE is one process that might benefit from a ubiquitous source of cheap electric power. The power could be**

### House Heating

As for residential heating, although there are a great many ifs, it appears that atomic furnaces warrant serious consideration. Space heating is the largest consumer of energy in the U. S.; in 1945 it took almost 20 per cent of our total national energy supply. We considered the economic feasibility of heating houses from district stations where the heat would be produced by nuclear reactors and piped directly (without conversion into electricity) to homes. Experiments in the direct use of heat from a reactor for space heating are already being carried on at the Harwell reactor station in England.

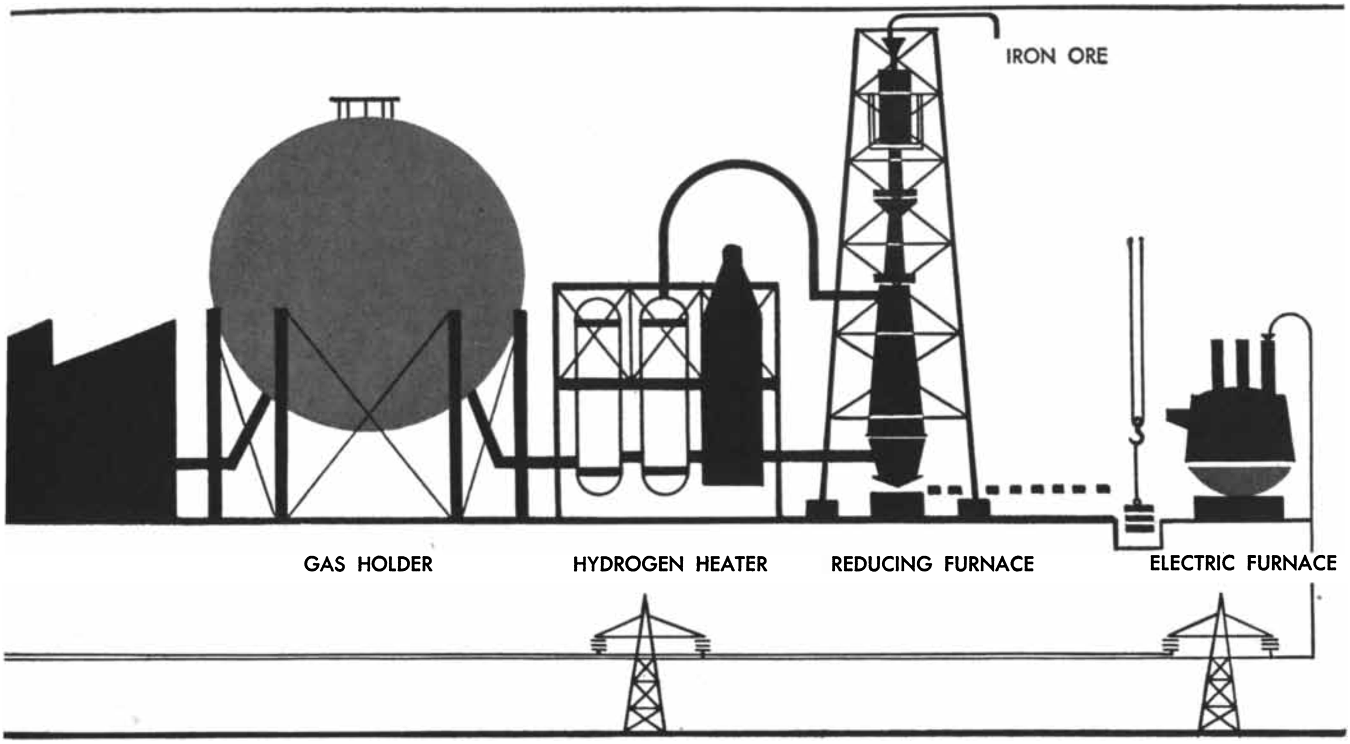
The most important variables affecting the cost of residential district heating are population density and climate. In general, a combination of high population density and cold winters would be required to bring district heating into competition with conventional methods. Our analysis shows that these conditions exist in New York, Chicago, Boston, Buffalo, Milwaukee, Newark and a few other cities, all of which have cold winters and an average population density of more than 13,000 persons per square mile. Not all areas of these cities meet the necessary requirements for economical district heating, but large parts of them undoubtedly do.

The conclusion from our analysis is that atomic furnaces might well compete with conventional heating in these areas. It would not reduce the cost much, if at all, but its convenience (lack of smoke, emancipation of individual householders from their furnaces, and so on) might turn the scale. If so, atomic heating might be applicable for some 10 per cent of the nation's population.

In summary, our findings suggest that in the U. S. the total cost savings from atomic power would be very small, but important changes in the structure of the economy might occur. Process changes might greatly increase the demand for power, and at the same time the availability of atomic power might reduce the market for conventional fuels. These process changes might also give rise to new industrial activities designed to meet the needs for novel types of industrial equipment, new and untried engineering skills, and so on. Atomic power would be a great stimulus to regional economic development. It would have especially important effects in regions where human resources have been under-utilized in the past. The establishment of new industries in such regions would set in motion a chain reaction leading to higher per capita income in the area, primarily as a result of the more effective employment of local labor. In this case the increased mobility of the fuel resource might serve, in effect, as a partial substitute for the lack of mobility of the workers who have remained in the region despite the scarcity of local opportunities for employment.

### International Aspects

Let us turn now to the possible effects of atomic power in other countries. The U. S. is rich in conventional fuels. It seems obvious that in countries where such fuels are scarce the impact of atomic power could be much greater. But we must begin by noting an important reservation. At the present time electric power, the most likely form in which atomic energy will be made avail-




**used to evolve hydrogen from water by electrolysis. The hydrogen could then be used to reduce the ore. Such an ore-reducing plant has already been designed by the New York engineering firm of H. A. Brassert & Co.**

able, accounts for only a small part of any nation's total energy consumption. For example, in the U. S. no more than about 15 per cent of the total energy consumed is electricity; the rest is heat and mechanical forms of energy. If atomic power could satisfy only this fraction of a nation's total energy requirements, its importance would be severely limited. Consequently the usefulness of atomic power to countries lacking other fuels will depend on their developing process changes that will enable them to make greater use of electricity. It will be much more important to them than it is to the U. S. to find new ways to use atomic energy in the production of steel, fertilizers and construction materials like cement and brick, in railroad transportation and in the heating of homes. Assuming that they do so, however, the possibilities of atomic power may be very large indeed, for countries that have very limited supplies of conventional fuels would have a different approach to the cost of atomic power from that of the U. S., which can compare its cost closely with that of plentiful other fuels.

What are these energy-poor countries? Argentina and Brazil are prime examples: they have negligible resources of fuel, and many of their important population centers are far from potential water power. Then there are countries like Denmark and those of North Africa, which lack not only fuel but water power. Another class is represented by Hungary, which has some fuel resources but of low grade and costly to mine. Again there are countries like Italy, Austria and Switzerland which have water power but have already developed a large part of this potential and will find it increasingly difficult and expensive to expand their energy supplies further. Finally there are countries like Great Britain which have had plenty of fuel in the past but may find it increasingly difficult to mine adequate supplies in the future.

Fuel-short countries can, of course, import fuel from countries that possess sufficient supplies; Brazil and Argentina have imported coal from Great Britain across thousands of miles of ocean. But the difficulty of acquiring foreign exchange may impose limitations on a country's ability to pay for very large amounts of fuel from abroad. Consider Brazil, for example. That country's population before World War II was about 45 million. Its total consumption of coal was about 2.5 million tons a year. On the other hand, Great Britain, with a population of about 48 million, only a little larger than Brazil's, consumed about 200 million tons of coal per year. If Brazil were to consume only one fourth as much coal per capita as the British did before the war, it would need to import approximately 45 million tons annually—some 30 times as much as it actually imported in 1939. At $8 per ton, the approximate prewar price, this level of imports would cost about $360 millions, which is about $50 millions more than the total value of Brazil's imports of all commodities in 1939. Such a volume of coal imports could not be financed without a radical change in Brazil's foreign trade position.

Now if atomic fuel, instead of coal, oil or water power, becomes the basis of power, the picture changes radically. The international distribution of uranium and thorium is probably quite different from that of other energy resources. Brazil, which is deficient in mineral fuels, has extensive resources of thorium. So has India, a nation with poorly distributed resources of conventional fuels.

Even more important is the fact that it will be immensely cheaper to import uranium or thorium than coal or oil. As we have seen, a pound of uranium would be equivalent in energy to 1,250 tons of coal. On that basis it would cost Brazil only $1 million to import uranium with energy equivalent to $360 million worth of coal.

This saving in the cost of fuel would not necessarily be the net saving for atomic power, since the saving of foreign exchange would also depend on how much of the plant facilities for nuclear reactors could be produced within the country. An underdeveloped country, for example, probably would have to import most of the special equipment required, perhaps for decades. Our analysis shows that despite this, the so-called backward countries might achieve substantial savings in foreign exchange by using nuclear fuel instead of coal. For an advanced country such as Great Britain the advantage would be much greater, because Britain could be expected to build and equip its own atomic energy plants.

### Investment

In considering the possibilities for development of atomic power in backward countries we must give considerable weight to the capital investment required. It seems altogether probable that the investment for the construction of an atomic power plant will be substantially higher than for a conventional coal-burning plant. Since the backward areas generally have a shortage of capital, and hence have relatively high interest rates, this would be a serious drawback. But our analysis suggests that in some regions of the world the over-all investment for an industrial system based on atomic power might be no greater, and perhaps smaller, than for one based on conventional fuels. A coal-based economy would require an enormous investment in coal mines, coal-carrying railroads and so on. Hydroelectric power also demands a large capital investment.

We reached the general conclusion that in countries poor in conventional energy resources the foreign exchange advantages might weigh heavily in favor of atomic power, while in backward countries that have ample conventional sources of energy the scarcity of capital and consequent high interest rates might favor ordinary power. In this connection the history of hydroelectric power development may be significant. Despite the fact that hydroelectric projects require a heavier investment than plants using mineral fuels, even underdeveloped regions have frequently found it worth-while to build them. A major reason offered for this decision is the saving achieved in foreign exchange which would otherwise have to be spent for importing fuel.

When it comes to individual industries, there are some substantial differences in the prospects of atomic power in the U. S. and in other countries. For example, we found that in the U. S. the use of nuclear energy for powering railroads is very unlikely. In the first place a nuclear engine for locomotives seems impractical. In view of the shielding required for the reactor, it appears improbable that the locomotive could be made small enough to travel on present tracks or clear present tunnels, bridges, railroad terminals and so on. Moreover, it may be uneconomic to build a reactor engine with the relatively small power output that a locomotive uses.

Consequently if atomic power is used by railroads at all, it will probably be applied to electrification of the roads from central power stations. In the U. S. the average density of traffic in most regions is not sufficient to justify general electrification even at the minimum estimated cost of atomic power. A further obstacle is that if atomic power were produced at this cost, it would probably replace coal for many other uses, which in turn would reduce coal shipments and perhaps cut rail traffic below the minimum necessary to justify electrification. On the whole, the most likely trend in the U. S. is toward the use of Diesel oil rather than coal or nuclear energy for railroads.

On the other hand, some of the countries that lack mineral fuels may very well find the use of atomic power for railroads preferable to importing fuel. They might find it to their advantage to electrify their main lines and use coal or oil for subsidiary ones. In Switzerland more than 80 per cent of the rail traffic before the war was carried on electrified lines, based on water power, and in Sweden 40 per cent of the railroad mileage was electrified; in Italy, 10 per cent.

There are similar national differences in the possibilities for the use of atomic power in steelmaking. Great Britain, whose coking coal reserves are limited, probably would apply atomic power to its steel industry before the U. S. In less developed countries, which today produce little or no steel, the possibilities would be even more attractive. As these countries industrialize, they will need great amounts of steel for factories, machines, railroads and so forth. To countries such as India and Brazil, which possess vast iron-ore reserves but comparatively little coking coal, the hydrogen reduction process based on atomic electricity may seem the best answer to the problem of building a large-scale steel industry. On the whole it is reasonable to believe that the new metallurgy opened up by atomic power might provide one of the most promising methods for expanding steel output in underdeveloped areas.

### Backward Areas

Our study gave some attention to the problem of the role that atomic power might play in the general industrialization of backward areas. It is clear at once that the availability of energy is not itself the decisive factor. The most important requirement is capital, and the scarcity of capital in those parts of the world is probably a more serious obstacle to future industrialization than a shortage of energy. But virtually all the important underdeveloped areas are proposing and undertaking planned industrialization. If atomic power becomes feasible and available to them, thereby removing at least the energy limitation, it is likely to play an extremely important part in their industrialization.

Which countries would it help most? Surprising as it may seem, China is one of the least likely to find any advantage in atomic power. It has abundant coal, well distributed throughout the country. Its iron ore resources are comparatively small. However, ubiquitous atomic power might enable it to substitute light metals for iron and steel and thus facilitate industrialization; atomic power might also help it to develop local industries in the remote interior.

Japan is perhaps a more promising region for atomic development. It has considerable hydroelectric power, but it is already pressing upon the limits of its energy resources, and atomic reactors would provide a very welcome new source of power.

India has some coal and large possibilities for hydroelectric development, but the latter are likely to be expensive in that country, and atomic power at the lower estimated costs might be competitive. India also suffers from a shortage of coking coal, so the hydrogen reduction process for iron might favor atomic power. The area of the world to which atomic power might hold out the most promise is South America. That continent is almost entirely lacking in coal, and its water power is relatively inaccessible. On the other hand, it has many of the other requirements for industrialization—with the important exception of capital.

As might be expected, one of the most striking aspects that emerges from an analysis of the possibility of ubiquitous, low-cost power is the great influence it is likely to have in promoting regional development. For the backward countries, starting from scratch, atomic power may make it possible to choose whether to concentrate their future industries in a few areas or disperse them widely, placing them in close contact with agriculture. The larger underdeveloped countries may well decide to begin modestly by building regional economies in which local industries will process local agricultural products for consumption and manufacture the tools, machinery and fertilizer needed by agriculture. This approach has influenced many of the plans for industrialization and for "valley authorities" in those countries.

The development of industry in close proximity to agriculture might reduce population migrations, provide off-season factory work for farmers and farm labor, ease the transition of the displaced handicraft worker to the new economy, facilitate the mechanization of farming and accelerate the acculturation of the predominantly agricultural population to an industrialized society.

*Sam H. Schurr is co-author, with Jacob Marschak, of the Cowles Commission report:* Economic Aspects of Atomic Power.

# pH

## It is a measure of acidity and alkalinity that is indispensable in research and industry. Its real meaning is nonetheless little appreciated

by Duncan A. MacInnes

ABOUT 20 years ago, in a talk on pH before the New York section of the American Chemical Society, the author introduced the subject as follows. Primitive man knew when he was hot and when he was cold, but it took civilization and a considerable advance of science to give us a quantitative measure of these qualities in the form of the temperature scale. Qualitative ideas of acidity and alkalinity likewise have been around for a long time, but it is only in the last 40 years that they have been put into measurable form by the pH scale. There were representatives of the press present. Someone collapsed the two ideas into one, and the Associated Press broadcast the information that I had invented a "pH thermometer." My next few days were hectic. Inquiries about this supposed instrument arrived from far and near. I had to write many letters saying that the glass-electrode method of measuring pH, about which I had really talked, was still in the development stage, and though it was very promising it still required costly apparatus and skilled experimentation. Years passed before I stopped getting letters asking about the pH thermometer.

The experience demonstrated that the subject of pH was important in the lives of many people, and that an apparently easier method of determining pH values was exciting news to them. In the past few years many difficulties have been surmounted, and the utilization of pH measurements in research and in the control of industrial processes has gone ahead by leaps and bounds. Unfortunately an appreciation of the fundamental significance of pH measurements has not made similar progress.

Although the ideas of acidity and alkalinity are not new, they are singularly difficult to define in terms of common experience. Acids have a sour taste and turn litmus red. Solutions of alkalies have a smooth feel between the fingers, a bitter taste and turn litmus blue. The modern theory of acids and alkalies is largely descended from the 19th-century Swedish chemist Svante Arrhenius. According to his theory the strength of an acid is due to hydrogen ions ($H^+$) and that of an alkali to hydroxyl ions ($OH^-$). Arrhenius decided that a .1 "normal" hydrochloric acid (a solution containing a tenth the molecular weight in grams per liter of hydrochloric acid) is 91 per cent broken up into ions. On this basis the hydrogen-ion concentration in the solution is .091. Acetic acid at the same concentration is only 1.3 per cent dissociated; its hydrogen-ion concentration is therefore .0013. The hydrogen-ion concentration of pure water is on the order of .0000001. In alkaline solutions the hydrogen-ion concentration is still lower.

Figures with many zeros to the right of the decimal point or the corresponding negative exponents are awkward to deal with and think about. In 1909 the Danish biochemist Sven P. L. Sörensen suggested a relation to meet the difficulty. The relation was: $pH = -\log (H^+)$. This simply means that we take the logarithm of the hydrogen-ion concentration and add a minus sign so that the resulting number will normally have a positive value. Thus .1 normal hydrochloric acid has a pH of 1.04; .1 normal acetic acid has a pH of 2.89 and water has a pH of 7. A .1 normal solution of the alkali sodium hydroxide has a hydrogen-ion concentration of .00000000000011 and a pH of 12.9! Obviously pH values are more compact and more useful.

THE solutions of our common experience cover a considerable range of pH values. Lemon juice has a pH of 2.3; vinegar, 3.1; orange juice, 3.3; sour milk, 4.4; milk, 6.6; 1 per cent baking soda, 8.2; 1 per cent washing soda, 10.7; and 1 per cent lye, 13. The interior of the human body can tolerate pH values of about 3 to 8; the exterior, a somewhat greater range. In this respect, at least, the pH scale is analogous to the temperature scale: the human body can endure only a relatively narrow range of values.

Naturally the usefulness of the pH scale depends upon finding a convenient method for determining pH values. A standard method long employed uses a simple electric battery or, more properly, galvanic cell. Such a cell consists of two electrodes with one or more conducting solutions between them, and it is capable of yielding electrical energy. The principle of the cell's use in obtaining pH values is illustrated in the schematic drawing at the top of the opposite page. One electrode is a platinum plate covered with finely divided platinum and with a stream of hydrogen bubbles passing over or near it. It is placed in a vessel containing a solution of unknown pH. The other electrode is a layer of calomel floating on mercury. Between the second electrode and the solution of unknown pH is a very strong solution of potassium chloride; the two solutions make contact at a "liquid junction."

How do we ascertain the pH of the unknown solution? The pH influences the cell's electrical potential, which we can measure. Unhappily that is only part of the answer. Even if we make a number of simplifying assumptions, we must use a rather complicated relation to join pH and potential. Let us call the potential E and the hydrogen-ion concentration $H^+$. We must also assume that the temperature is 25 degrees C. and use a constant $E_0$, which we need not explain here. The relation is $E = E_0 - .059 \log (H^+)$. This involves the unwieldy usage that caused Sörensen to devise his relation $pH = -\log (H^+)$. By substituting and rearranging the terms we get $pH = (E - E_0)/.059$. Thus at 25 degrees C. the pH of the unknown solution is the potential of the cell minus the constant divided by .059.

NOW the argument so far is part of the "classical" theory of electrolytic dissociation. For several decades this theory served science remarkably well. A whole system of physical chemistry was built upon it, and its ideas reached deep into several branches of biology. Nonetheless difficulties have outmoded it for precise interpretations of pH.

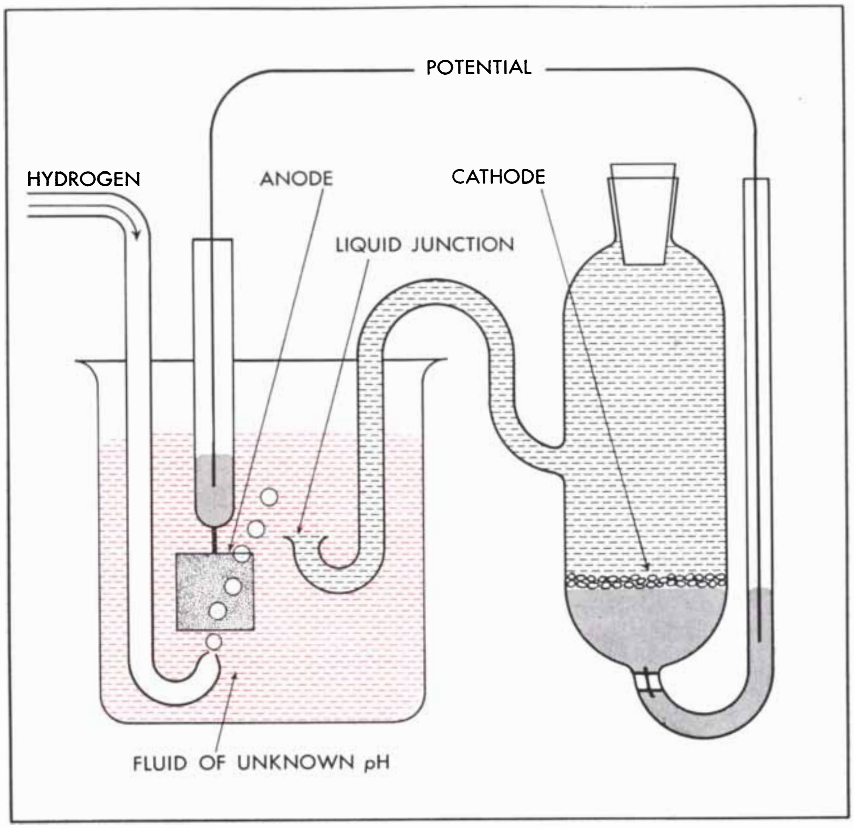
Two of the difficulties are concealed in the relation $E = E_0 - .059 \log (H^+)$ for the potential of our galvanic cell. One of them is the assumption that a change in the hydrogen-ion concentration affects the potential only at the platinum plate. There an electrochemical reaction causes one hydrogen molecule ($H_2$) to dissociate into two charged hydrogen atoms or protons ($H^+$) and two electrons ($e^-$); the reaction is written $H_2 = 2H^+ - 2e^-$. (Actually the protons immediately seize a water molecule and form the more complex ion ($H_3O$.) It is impossible, however, to change the solution in the vessel without also affecting the conditions at the liquid junction, which has a potential of its own. The liquid junction is carefully chosen so that its theoretical potential is very small, and the changes in its potential when the hydrogen-ion concentration is varied are still smaller. Nonetheless *one* change in the hydrogen-ion concentration of the unknown solution has caused *two* changes of potential in the cell, one at the plate and one at the liquid junction. The dilemma persists no matter how many experiments are made: the number of variables exceeds the number of measurements. This of course complicates the interpretation of pH measurements.

The second difficulty concealed in the relation $E = E_0 - .059 \log (H^+)$ is the assumption that the hydrogen ion is a "normal" substance, *i.e.*, that its effect upon its surroundings is proportional to its concentration. This, however, is not the case. In dilute solutions the activity of an ion is progressively less than one might expect as its concentration is increased. The phenomenon is due to the effect of ions upon one another. The theory of interionic attraction developed by Peter J. W. Debye, now of Cornell University, and the German physicist Erich Hückel is one of the most exciting advances in chemistry during the past 25 years.

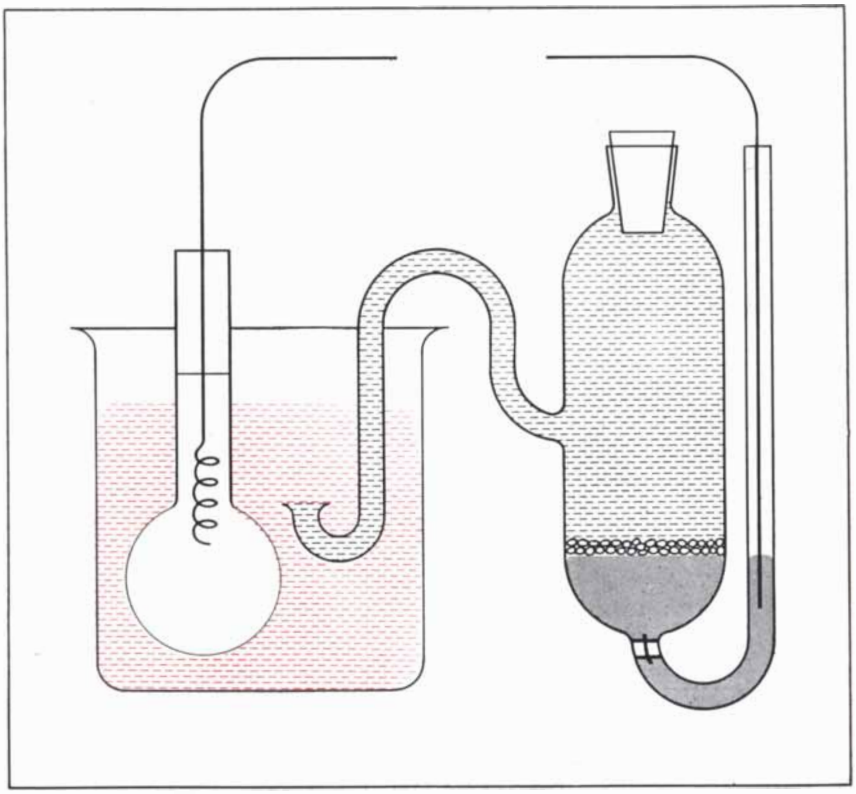
As a result of these difficulties it is best to assume that there is no simple relation between hydrogen-ion concentrations and pH values. This fact diminishes the usefulness of pH measurements only slightly. An analogy is that one does not need to know the whole theory of thermometry in order to make good use of a thermometer. As a matter of fact precision thermometry has problems which resemble those of pH measurement.

Until recently pH measurements were greatly restricted by some annoying peculiarities of the platinum electrode immersed in a stream of hydrogen bubbles. It is essential that only the reaction $H_2 = 2H^+ + 2e^-$ take place on the surface of the electrode; other reactions will make the measurement incorrect. Unfortunately many other reactions can occur, especially because the finely divided platinum with which the electrode is covered may be an excellent catalyst. In some early attempts at pH measurement made on soap solutions the author found that the potential steadily mounted, the sensitivity of the readings decreased and the electrode became covered with a white deposit. The fatty acids of the soap were evidently being hydrogenated, as is done deliberately in the manufacture of some shortenings.

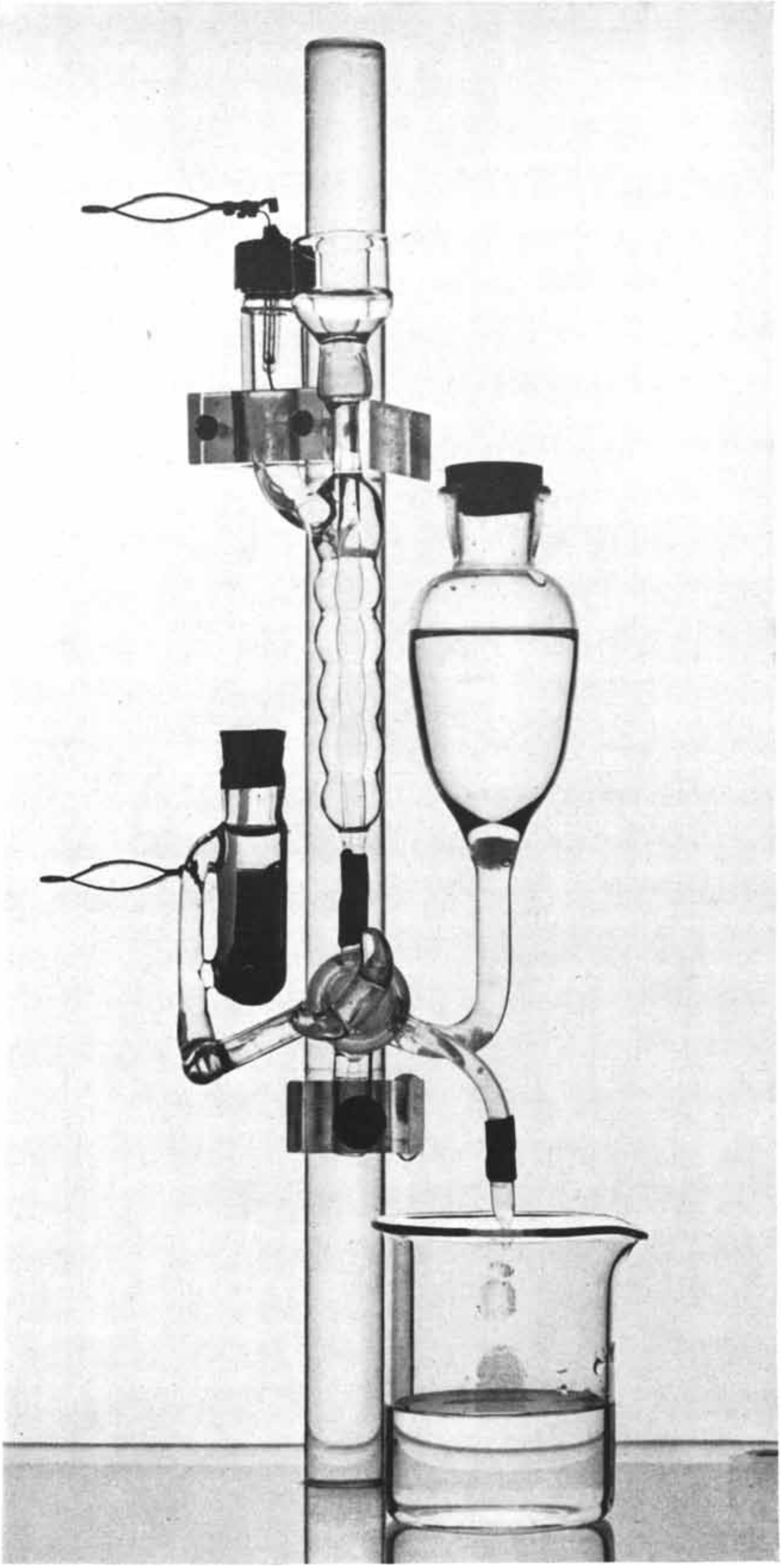
A difficulty of another kind arises in the determination of the pH of blood plasma. Here the pH is largely controlled by dissolved carbon dioxide, and this can be driven off by the stream of hydrogen bubbles. Although many important




**GALVANIC CELL** consisting of two electrodes and two solutions is used to measure pH. Anode is platinum plate; cathode, layer of calomel. When very strong acid solutions surround plate, anode and cathode switch places.



**GLASS ELECTRODE** extends the utility of the cell at the top of the page. In that arrangement the electrochemical action at the platinum electrode may also involve reactions which interfere with pH measurement.



**ACTUAL APPARATUS for measuring pH corresponds to arrangement at bottom of preceding page. Solution of unknown pH is poured into small funnel at top center. The pH-sensitive glass is narrow tube in center. In valve below it is the liquid junction. Calomel electrode is in vessel at left.**

applications of pH measurement were first accomplished with the hydrogen electrode, its use has been limited. Its technique is complicated and its pitfalls, resulting in inaccurate measurements, are many. Still the hydrogen-electrode cell remains the standard to which all other methods are referred.

AN entirely different and widely used method of determining pH values involves the use of "indicators": substances that change color when the acidity or alkalinity of a solution is altered. Litmus dyes are among the most familiar of these. In solutions with pH values below about 7 these vegetables dyes are red; in solutions above 7 they are blue. There are many such indicators, and they are most useful in making rough pH determinations. Among their deficiencies, however, is the fact that their colors are affected by salts and other substances.

The really widespread use of pH measurements in research and industry has come with the glass electrode, which gets around the difficulties inherent in the hydrogen electrode and indicators. The glass electrode goes back to an experiment performed by the German chemists Fritz Haber and Z. Klemensiewitz in 1909. In their experiment the metal electrode with its stream of hydrogen bubbles was replaced by a bulb of soft glass containing an acid and a platinum wire. When they placed this electrode in solutions of various pH values, they discovered that the potentials of their galvanic cell resembled those utilizing hydrogen electrodes.

These observations were rapidly falling into oblivion when they were rescued by the U. S. chemist Walter H. Hughes. He showed that the glass electrode could be used as a convenient method of measuring pH values. With this new method it was found possible to obtain the pH values of fluids that could not possibly be examined by the hydrogen electrode or indicators: whole blood, strong oxidizing and reducing agents, plant extracts and so forth. However, there were difficulties in the application of the glass electrode. The glasses used for the bulbs had very high electrical resistances, making it difficult to measure potentials even with the most sensitive instruments. In addition the response of the electrode to changes in pH depended markedly upon the composition of the glass.

At the Rockefeller Institute the author and Malcolm Dole made a trial-and-error investigation of these difficulties. We found that most modern glasses were quite useless and that commercial soft glasses were not much better. But a glass with a low melting point, made of soda, lime and silica, yielded accurate pH values for acid solutions through the neutral point to fairly alkaline solutions, *i.e.*, from pH 1 to about pH 10. Recently some of the instrument companies have produced glasses which are claimed to measure pH values accurately above 10, but precise information on these materials has not yet made its appearance in print.

THERE is an old story to the effect that a college graduate, wishing to impress a prospective employer with his erudition, remarked that a certain manufacturer had improved his product by "regulating his Ph.D." Actually the young man hit upon a real association. If a Ph.D. gets into a laboratory or an industry, it is likely that he will soon be making pH measurements. The devices for making pH determinations, once found only in a few academic laboratories, are now familiar artifacts of our civilization. A more or less complete bibliography of pH applications would fill a very large book.

The application of pH measurements often involves the concepts protein and proton, both derived from the Greek word meaning primary. Let us consider proteins first. Proteins occur in all living matter. They are of particular interest in connection with pH measurement because they have both acid and alkaline properties. At most pH values, proteins are highly charged ions. This is indicated by the phenomenon of electrophoresis. When an electric current is passed through a protein solution, the protein ions move toward the positive pole if the pH is low, and toward the negative pole if the pH is high. At an intermediate pH, called the isoelectric point, the ions remain stationary. The pH value of this point depends on the nature of the protein. It is particularly noteworthy that the electric charge of a protein may change within a short pH range. Thus it is not surprising that in the study of proteins and related substances pH is one of the more important variables that must be considered. Since these substances are essential constituents of all living matter, pH must be measured or controlled in a large proportion of biological researches.

The importance of pH in human physiology is illustrated by the fact that the value for blood rarely goes far from 7.4, the normal variation being between 7.3 and 7.5. The variation compatible with life is between about 7 and 7.8. Many of the enzymes which catalyze the chemical reactions of the body are also sensitive to alterations of pH.

Directly and indirectly, the influence of pH values on bacterial growth has been the subject of a vast amount of investigation. Most bacteria have ranges of pH in which they can reproduce, and optimum values at which their growth is a maximum. The activity of their metabolic products, such as toxins and enzymes, may be influenced by relatively small changes of pH. Many bacteria produce acids, and as they multiply there is a trend toward lower pH values. The result is that the rate of increase in these bacterial populations declines and in some cases stops. If the culture is maintained at an optimum pH, the population and the acid production both increase. By adding alkali to cultures of *Lactobacillus acidophilus* with an automatic device based upon the glass electrode, L. G. Longsworth of the Rockefeller Institute was able to increase their population 4 times and their acid production 12 times.

In view of these examples it is not surprising that pH is of great importance to many industries. This is especially true, as might be expected, in processes where fermentation is involved, such as the making of bread, beer, wine, cheese and even leather. Since the textile industries deal mostly with animal and plant products, it follows that they must make pH measurements in such processes as wool scouring, fulling and dyeing. And these are only a few of the many applications.

Another region in which pH measurements and control are of great interest is the soil. Everyone is familiar with the fact that certain crops will not grow in soils that are too acid, and that in many cases pulverized limestone can be used to correct the condition. The relation of the pH of soils to the nature of the vegetation that is present or can be grown is one of extreme complexity, because most of the effects of pH are indirect. Its values determine the solubility, and thus the availability, of some of the necessary mineral constituents of the plants. Soil bacteria and parasites are likewise sensitive to variations of pH. In spite of this complexity the pH values of soils must be considered in order to grow crops and to understand the natural distribution of plant life.

THERE remains the fundamental question as to why pH values are so important in so many ways. This brings us to the concept of the proton. This positively-charged particle is one of the fundamental constituents of matter. Many of the properties of metals are explained on the assumption that negatively-charged electrons can move with relative freedom through a positively-charged framework. In very rough analogy, quite a number of the characteristics of biological materials are in all probability due to the presence of protons that can shift readily from one site to another. From this point of view the utility of pH measurements is that they are rough measures of the chemical energies of these reactive protons which move about in living matter, taking part in the complex tasks of building and adjustment of the many structures and substances involved in the life processes.

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# RED DOG, BLACKJACK AND POKER

## Three card games are considered in the context of a modern mathematical theory. Warning: the theory does not provide a blueprint for winning

by Richard Bellman and David Blackwell

EVERYONE knows that the best way to win at poker is to be lucky. Nevertheless, after a few disastrous sessions in which three kings encounter three aces head on, a straight yields ungracefully to a flush and a king-high bust loses to an ace-high bust, even an unanalytical player is apt to examine his conscience and meditate on his sins.

It is easy and relatively inexpensive to discover that it is exceedingly unprofitable to persist in drawing to inside straights, to raise on two pair against a one-card draw or to indulge in the optimism of drawing two cards to a flush. On the other hand, undue pessimism is also a drawback. A little study of elementary probabilities discloses that a four-card straight open at both ends is not a bad investment, that a four-flush is even better and that a four-card straight flush should keep one in almost any pot.

All this is fairly rudimentary. The situation becomes delicate when a player who has drawn one card plunks down a stack of blue chips and radiates confidence. There seem to be only two alternatives: one calls—and stares at an ace-two-three-four-five straight; or one folds—and the next player calls with two pair and rakes in the chips.

At this point one usually shrugs philosophically and consoles oneself with the thought that bluffing is a fine art, and that one is either born with this ability or not. The prevalent feeling is that a successful poker player must combine the steely nerves of a Western frontier marshal with the analytic ability of a cinema psychiatrist.

Is this necessarily true? Or can bluffing be stripped of its metaphysical cloak and exposed to the cold logic of mathematics? The modern mathematical theory of games inaugurated by John von Neumann permits us to answer "yes."

Before we take up the complicated game of poker, with its fine interplay of conflicting strategies, let us consider first some simpler games in which the possibilities are more limited and which are therefore better suited to illustrate the fundamental concepts of the theory.

The coin-matching game is a good place to begin. Suppose that we are compelled, in all fairness, to match coins with our youngster on Sunday morning to determine who gets to read Li'l Abner first. It is clear that we may just as well toss our coin and let chance determine whether we show heads or tails. Let us, however, analyze this game in detail, for it indicates the procedure to be followed in more complicated games.

WE MUST first of all agree upon what is meant by a good method of play. In general, in any game of chance moves we cannot ensure a win on any particular play, even if the odds are highly in our favor. For example, if we draw a ball from an urn containing 100 white balls and one black ball, it is extremely probable that at any one draw we shall pull out a white ball; nonetheless we cannot guarantee it. Consequently in such a game we must relinquish any hope of winning every time and look instead for long-term results. In other words, we decide to ignore momentary fluctuations and be guided only by the over-all average effect.

In a coin-matching game where each person flips his own coin, heads and tails are likely to occur in very nearly equal numbers over a large number of tosses. In the long run the number of wins will be approximately equal to the number of losses and neither player will gain much. In the terms of elementary probability theory this is expressed as follows: Let A win if the coins match, B otherwise. There are four possible outcomes: heads-heads, heads-tails, tails-heads and tails-tails. Each occurs one quarter of the time. One half of the time—hh and tt—A wins; one half of the time—ht and th—B wins. The over-all gain for either is zero, and the game is fair.

Suppose that we alter the game slightly and insist that A still toss his coin but allow B to choose heads or tails as he sees fit. Is it still a fair game? Interestingly enough the answer is "yes." We have here a manifestation of a very important, albeit paradoxical, quality of a large number of games; namely, that one player can inform his opponent of his over-all strategy without yielding the slightest advantage. This result may be proved mathematically for a large class of games; the principle is stated in von Neumann's famous fundamental minimax theorem. In the game here in question, the application of this axiom is clear enough: B gets no advantage from knowing that A tosses heads and tails at random, nor A from knowing that B chooses his move each time. Though the applicability of the minimax principle is not often so clear in advance as in the coin-tossing game, there are many popular games to which the theorem applies. (Poker, however, is not among them.)

Suppose, in the coin-tossing game, we allow A as well as B to choose heads or tails as he sees fit. Then B, to make sure that A does not obtain an advantage, must himself play heads and tails with equal frequency. Thus each player can choose a fixed method—namely, displaying heads and tails equally—which will ensure him a net gain of zero. In game theory this plan of combining different moves is called a mixed strategy; a pure strategy would consist in playing heads or tails all the time. Pure strategies are easier to find and to play, and hence it is desirable to have criteria that tell in advance when a game has a good pure strategy. Unfortunately many of the most interesting and important games escape any known criteria.

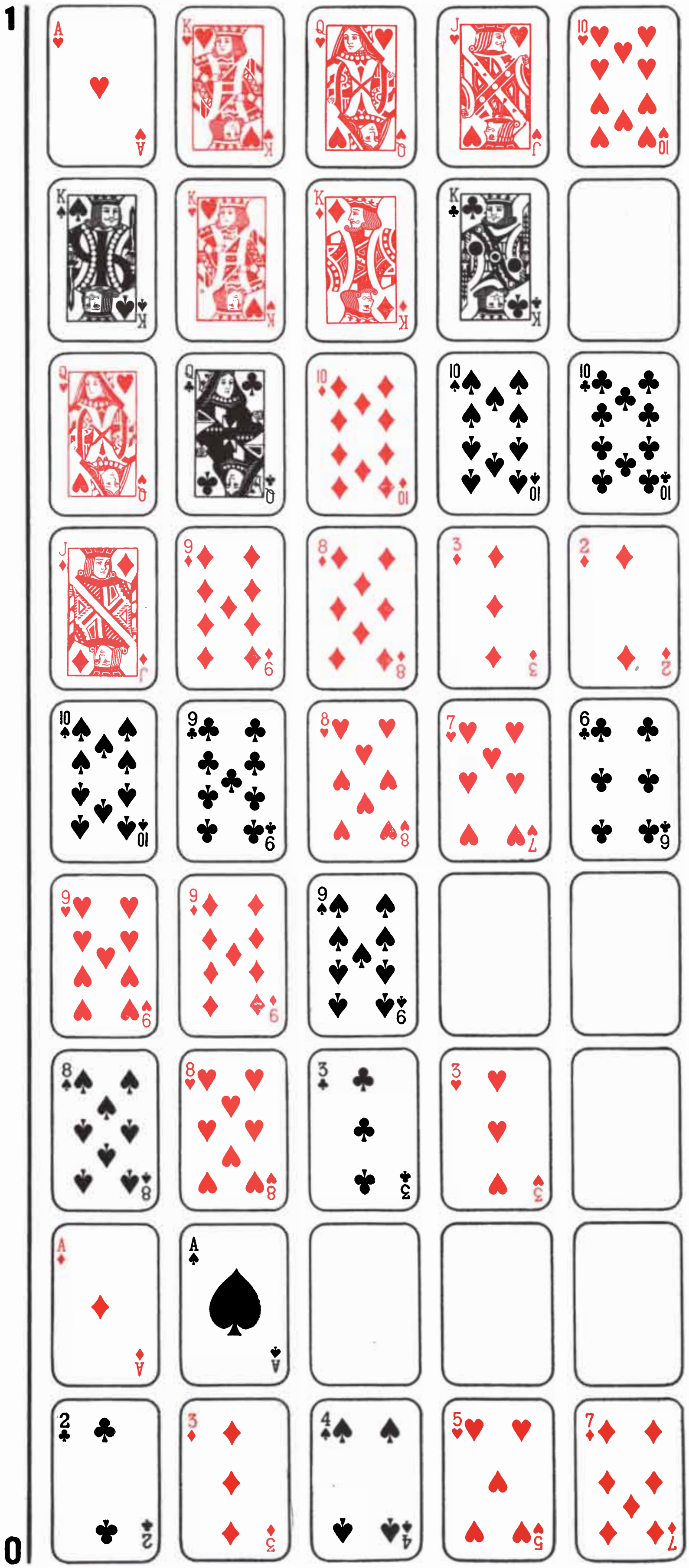
Now a mixed strategy usually requires that the moves be mixed in a random fashion. Suppose that the player's plan is to take one action one third of the time and another two thirds of the time, the two to be mixed in a random way. A simple, practical method of doing this is to let the position of the second-hand on a watch determine the play. The player makes the play he has decided to use one third of the time if the second-hand on his watch is in the 20-to-40-second interval; otherwise he makes the other play. If, as in a card game, there is a considerable interval between successive decisions, this method should lead to a random mixture of policies in the correct proportions.

LET US now turn from coin-tossing to the more complex strategies of card games. Since we are interested not so much in the fine points of the game but rather in analyzing the basic structure of good play, we begin by making a number of simplifying assumptions. In the first place, we consider only two-person games. A start has been made on the theory of games with three or more players, but it cannot be said that any satisfactory explanation of the actual play in such games exists at present.

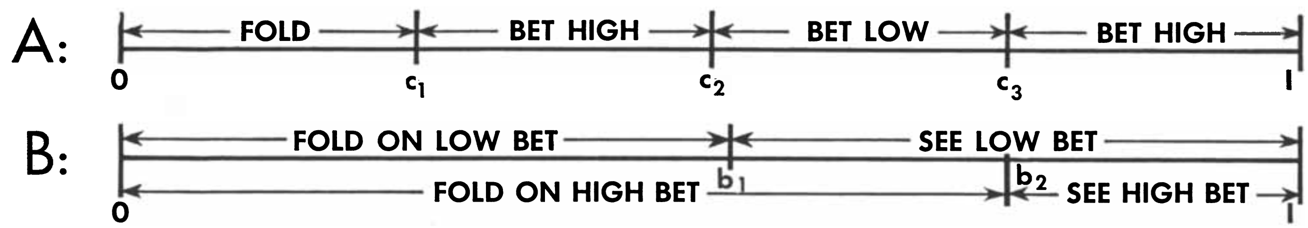
We begin by ranging the possible hands in order of value. In poker, for example, there are several million ranks of hands, running from the lowest bust to a royal flush. Dividing the rank of a hand by the total number of possible hands, we may represent each hand as a point in the interval 0 to 1. The various possible hands do not occur with equal probability; for example, two pair occur very much more frequently than four of a kind. However, as a first simplification we assume that all hands are equally probable. Now we assume that any hand can be represented by a number in the interval 0 to 1. Thus the poorest possible hand is designated as 0, a hand halfway up the scale as $\frac{1}{2}$, and the best hand as 1. If $x$ is the number representing a particular hand, then the ratio of worse to better hands is $x/(1-x)$, so that if $x=\frac{1}{3}$, there are twice as many superior hands as inferior hands.

Now in adopting this mode of analysis we have shifted from algebra, used for evaluating coin-tossing strategies, to integral calculus, a tool for handling the relations between variables in an interval. The mathematical advantage lies in the fact that calculus is simpler than algebra, integrals easier to handle than sums.

For simplicity's sake we shall start with the devilish little game called Red Dog, a sort of unilateral poker game whose solution sheds considerable light on what to expect in the solution of a




**POKER HANDS are first ranked on a scale running from 0 to 1. The highest hand is a royal flush (*top*); the lowest, a 7-high bust (*bottom*). Between them are millions of possible hands, here illustrated by the other general orders of value: four of a kind, full house, flush, straight, three of a kind, two pair and one pair.**




**TACTICS** of a simplified poker game are plotted by ranking hands in interval between 0 and 1. Player A can fold, bet low or bet high. Player B can fold or see. Intervals indicate hand values that dictate the player's choice.

poker game. One version of the game is as follows: Each player is dealt four closed cards from a bridge deck, and each antes one unit into the pot before play begins. The player on the left of the dealer plays first. He has the privilege of passing or of wagering that he can beat the next card turned up by the dealer from the deck with one of the four cards in his hand *in the same suit*. He can wager any amount up to the total in the pot. If he loses, he contributes this amount to the pot. Each player in turn has the same opportunity. Whenever the pot falls below a certain level, each player antes. Two features of poker that are illustrated by this game are the random hand furnished by the deal and the choice of the size of the bet.

For our analysis we take a simplified version of Red Dog, in which there are only two players, B and D, and each player is dealt only one card. B is the person capable of initiating betting, D the dealer. D deals one card to B and one to himself. Before the betting begins, each player antes one chip. B has the choice of folding, in which case D wins the ante, or of betting any amount between one chip and a fixed maximum. If B bets, D must cover his bet. Then the player with the higher card wins.

What is the best method of play for B, where, as usual, we mean the method that maximizes his expectation? It is intuitively clear, and may easily be shown rigorously, that there is no advantage in bluffing on B's part. Consequently B bets strictly on the value of his hand; the better his hand, the greater the size of his bet. This implies that B does not bet at all on any hand below a certain value. Thus his general strategy is to choose a hand value below which he will fold and to bet on all hands at or above this level, the size of his bet depending upon the strength of his hand.

Now it can be shown by a simple mathematical argument that if we assume that all hands are equally probable, B's best strategy is to fold when his hand ranks in the lowest quarter of all the possible hands, to bet the minimum of one chip if his hand ranks between $\frac{1}{4}$ and $\frac{1}{2}$, and to bet the maximum on all hands ranking above $\frac{1}{2}$, or the average. In other words: Never play hands that are too bad; bet a minimum on fair hands; bet the limit on good hands.

INVETERATE poker players will perhaps recognize a similarity between these mathematically derived dicta and the canons of experience in poker. The principal feature missing is bluffing. The interesting feature of the solution is that B's strategy is pure. What he does is indicated solely by the value of his hand. He does not play hunches, or watch for nervous twitches or signs of weakness in his opponent.

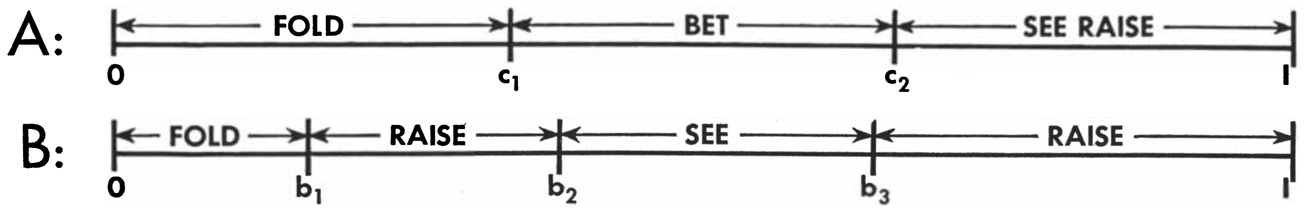
This is perhaps a good place to insert a word concerning the difference between playing a game with an inanimate opponent, as is done in various types of experimental work, and playing against a thinking adversary. It is possible to lay traps for an animate player by pretending to deviate from the best strategy, thus inviting him to deviate from his safe strategy to take advantage of your lapse. This type of play adds immeasurably to the zest of the game, but it is quite risky and must fail against a player who refuses to be tempted by the prospect of easy riches. It is well to remember that confidence men number their victims principally among those who want to make a quick dollar.

Better known and more complicated than Red Dog is the card game called Blackjack, or Twenty-One. The object is to draw cards to get a higher number of pips (a face card counting as 10) than the dealer without going over 21. The dealer must call all bets of the players, but has some countering strategies: the privilege of sticking, *i.e.*, seeing with the cards he has already dealt to himself, or of drawing additional cards. Many of the gambling houses have deduced on the basis of experience that the dealer can use a pure strategy: namely, always draw another card on 16 or below, and always stick on 17 or above. Observe that this strategy on the part of the dealer is an automatic answer to any possible bluffing on the part of the other players. A player with a three in the hole and a face card showing will lose unless he draws again, for his strong-looking hand will not tempt the dealer to overdraw.

It is not difficult to analyze the game of Blackjack mathematically by game theory, but the arithmetical labor involved would demand a Hercules. For example, one simple situation involves the computation of 512 numbers before the analysis can even begin. At that rate we prefer to allow Blackjack to retain its mystery.

We are now ready to consider poker itself. Since the actual game involving more than two players is at present beyond the reach of mathematical analysis, we shall examine only two-person games. It turns out that two-person poker, even in a simplified form, contains all the interesting features of the actual game.

We analyze three simplified versions. The first illustrates the basic structure of play; the second allows the first player to vary his bets; the third allows the second player to raise. In all three we reach the astonishing conclusion that to get the best results both players must use pure strategies! In other words, each player knows exactly what the other does with a given hand. However, since the hands themselves are concealed, this information is of no value. (It should be said that at this stage we can give no general theorem which proves that every




**STRATEGY** of a somewhat less simplified poker game is plotted on the same scale. Player A can fold, make a bet of a certain size or see a raise. Player B can fold, make a raise of the same fixed amount or see the bet.

two-person poker game, regardless of how many bets, raises and draws are allowed, has a solution involving pure strategies for both players. We believe this to be true, however, and we have a mathematical technique which enables us to find a solution of this type whenever one exists. The mathematical presentation will be published in another place.)

In the first game A and B receive cards x and y, respectively, where all values of x and y are equally probable; that is, one hand occurs as often as any other. Each player antes one chip before play begins. A is then allowed two choices: he may fold, in which case B wins the ante, or he may bet a certain fixed amount, a.

Now it is obvious that the play of each player will hinge on the size of a, the bet A is permitted to make. The mathematical analysis shows that the best play for each player will be determined by two separate formulas which establish the critical values for the respective hands. A gauges his play by the formula $(a/a+2)^2$. If, for example, the size of his bet is 2, then the critical value is $(2/2+2)^2=\frac{1}{4}$. This means that if the hand A receives ranks in the lowest fourth of all possible hands, he will fold; if his hand ranks above that value, he will bet. B, on the other hand, determines his play by the formula $a/a+2$. If A bets 2, the critical value for B is $2/2+2=\frac{1}{2}$. Consequently B will fold if his hand ranks in the lower half of all possible hands, and will see A's bet if his hand ranks in the upper half. The reason why B's minimum hand for betting is higher than A's is clear: A, in making a bet, has already announced that his hand ranks in the upper three quarters of the possible hands, and B's hand must be at a certain point in this upper interval to have an even chance of winning.

IN THE second game we allow A three choices instead of two: he may fold, bet low or bet high. B again can fold or call. The best strategy for each is shown in the diagram at the top of page 46. The critical hand values for A's betting are represented by $c_1$, $c_2$ and $c_3$; these again are determined by a certain formula based on the size of A's low and high bets. A folds if his hand is poorer than $c_1$, bets high if the value of his hand is between $c_1$ and $c_2$, bets low if it is between $c_2$ and $c_3$ and bets high if it is better than $c_3$. B now has two critical values, $b_1$ and $b_2$, which depend on whether A bets low or high. B always folds if the value of his hand is below $b_1$; he sees a low bet whenever his hand ranks $b_1$ or better and sees a high bet when his hand is $b_2$ or better.

It can be seen that A's high bet in the interval $c_1$ to $c_2$ is definitely a bluff, since A would always lose if B saw this bet. Similarly A's low bet in the interval $c_2$ to $b_1$ is also a bluff. Notice that B apparently makes no attempt to catch A bluffing; over the long run, however, the bluffs are automatically taken care of by the choice of $b_1$ and $b_2$. On the other hand, A's bluffing is an essential part of his game, designed to force B to cover enough of his low and high bets.

As mentioned above, the critical hand values are determined by the sizes of the bets. The following figures give some idea of the relative values: When A's low bet is 1 and his high bet is 2, then $c_1=\frac{1}{12}$; $c_2=\frac{1}{6}$; $c_3=\frac{5}{6}$; $b_1=\frac{1}{3}$ and $b_2=\frac{1}{2}$. When A's low bet is 2 and his high bet 4, then $c_1=\frac{17}{72}$; $c_2=\frac{7}{24}$; $c_3=\frac{11}{12}$; $b_1=\frac{1}{2}$ and $b_2=\frac{2}{3}$. The moral from these figures is that as the stakes rise, both players play more conservatively: they bluff less frequently and fold more often.

The methods used to obtain the foregoing solution can determine the best play for a game in which each player is allowed any number of different bets.

WE have said that both players can announce their pattern of play before the start of the game without suffering any loss thereby. The statement that both players use pure strategies seems at first sight to run counter to the known (heuristic) theory of bluffing. The resolution of the paradox lies in the fact that the players allow the game, which furnishes the random cards, to do the bluffing. If the cards are dealt at random, any further randomization through the use of mixed strategies by the players is superfluous.

In the third game we introduce another essential feature of poker: the raise. We allow A only one bet of a certain size, a. Now B, besides folding or seeing A's bet, is permitted to raise by the same amount. A may then see the raise or fold. The best play for each is given by the diagram at the bottom of page 46. B will raise when the value of his hand lies in the interval $b_1$ to $b_2$ and also when it is higher than $b_3$; A will see the raise only if his hand is better than $c_2$. Again the critical hand values are determined by the size of the bet, a. If $a=1$, then $b_1=\frac{42}{243}$; $b_2=\frac{31}{81}$; $b_3=\frac{61}{81}$; $c_1=\frac{1}{3}$, and $c_2=\frac{41}{81}$. If $a=5$, then $b_1=\frac{4}{7}$; $b_2=\frac{3}{4}$; $b_3=\frac{31}{34}$; $c_1=\frac{5}{7}$, and $c_2=\frac{14}{17}$. For the case $a=5$ these values are approximate and accurate to within one per cent.

In conclusion, we confess that although we have given some general principles which are applicable, we have not furnished any blueprint for winning at poker. But after all you wouldn't want to win all the time—or would you?

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# An Explanation of Twins

*From the standpoint of the biologist single births are just as remarkable as multiple births, but the latter provide a clue to the processes responsible for both*

by Gunnar Dahlberg

THE birth of twins is apt to cause excitement because our wonder and curiosity are aroused by the uncommon. If twin births were the rule and single births the exception, we would be incredulous over the birth of merely one child—just as, things being as they are, we would be amazed at the birth of a single kitten or a single puppy. Actually the birth of twins is no more wonderful than the fact that in the overwhelming majority of cases the female of our species bears but a single child. From a scientific point of view the latter phenomenon is as challenging and exciting as the former; both are part of one and the same problem.

We do not know what causes twins to be born. The explanations offered by scientists are still only hypotheses. I shall present here my own theory, based on physiological observations and on certain more or less probable assumptions.

We know that twins occur about once in 80 human births; triplets once in 80 times 80, or 6,400, and quadruplets once in 80 times 80 times 80, or 512,000. Of the birth of quintuplets only about 30 instances have been recorded in all history. There are three fully substantiated cases of the birth of sextuplets. One is vouched for by a missionary in Africa who visited the Negro tribal village where rumor said the event had taken place. When he arrived at the mother's hut, he found only five infants; the natives said the sixth was dead and already buried. He offered a small payment if he could see it. A woman went to a corner of the hut and upturned a basket; out of it rolled the dead sixth. The missionary photographed the sextuplets together. No case of septuplets has ever been authenticated, but in the small German town of Hammel an der Weser stands a tombstone said to be in memory of a woman who died in labor while bearing seven; on the tombstone are depicted the mother and seven fetuses representing the birth.

The mortality of twins and other multiple births is well known to be higher than that of single children; they are often born prematurely, and even those at full term are generally more feeble at birth. The famous Dionne quintuplets are the largest multiple birth known to have survived.

It is estimated that about 20 per cent of the women in a population have a propensity for twins. A woman who has borne twins once has one chance in 17 of bearing twins again. As women grow older, the likelihood of twins rises: for a pregnant woman of 40 the probability of a twin birth is three to four times as high as for a woman of 20. Twin births vary with populations, probably in part because of racial differences. They are more common in Northern Europe than in Southern Europe.

NOW what are the biological clues to the origin of twins? As almost everyone knows, there are two kinds: those that come from a single egg, commonly known as identical twins, and those that spring from two separate eggs which are discharged and fertilized at the same time. Two-egg twins, apart from the fact that they are of the same age, are no more alike than any other brothers or sisters. As often as not they are of different sexes. Twins that develop from the same egg, on the other hand, are as alike as the left and right half of an individual's body. They are always of the same sex and often very difficult to distinguish from one another. About one pair of twins in four is of this single-egg type.

Suppose we start with the simple hypothesis that twins arise from a tendency of some eggs to double, *i.e.*, divide into two normal eggs. This would certainly seem to be true of all one-egg twins: the egg from which they come doubles *after fertilization* to produce two complete individuals. The doubling process could also account for some two-egg twins. An occasional egg may have so strong a tendency to double that it divides even before fertilization. In that case both eggs can be fertilized separately and two embryos can develop simultaneously. This hypothesis, which I first formulated in 1926, seems to be supported by certain statistical facts. If the assumption is correct, a mother whose eggs have a disposition to double might at different times bear two-egg twins and one-egg twins. A study I made of a number of mothers in Sweden who had borne more than one set of twins, and later studies by others, indicate that such mothers do indeed tend to have both kinds of twins.

This theory of a doubling tendency can account for the various degrees of separation observed in human and animal births. If the doubling takes place before fertilization, we have a pair of two-egg twins. If it occurs after fertilization, the result is a pair of one-egg twins. If the tendency to double is less pronounced or occurs very late, the twins may be more or less joined together, as Siamese twins are. It is well known that great variations in the degree of conjunction of twins are actually observed.

But it seems that doubling of the egg cannot account for all twin births. The reasoning behind this conclusion is as follows: The probability of one-egg twin births, which clearly arise from egg-doubling, remains fairly constant throughout a woman's childbearing life. This suggests that the egg-doubling tendency does not vary with increasing age. On the other hand, the frequency of two-egg twin births goes up rapidly with women's age, reaching a maximum at approximately 37 years. We must therefore find some explanation other than egg-doubling for some of the two-egg twin births, particularly those that occur at the later ages.

THE explanation may well lie in the fact that the ovaries sometimes discharge two eggs at once, instead of the usual one. The ovaries contain somewhere between 100,000 and 400,000 eggs. Of these about 400 ultimately mature. Normally only a single egg matures at a time; it is then discharged during the short monthly ovulation period from its Graafian follicle into the Fallopian tubes, where it becomes available for fertilization. But it is known that occasionally two eggs may be discharged simultaneously from separate Graafian follicles.

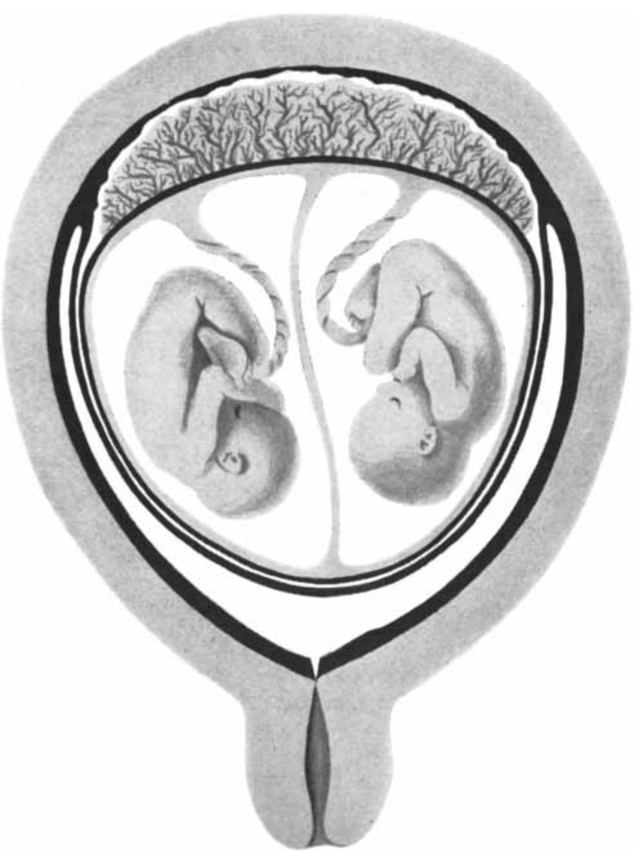
Why, one may ask, does this happen? There is no valid reason, as I have already suggested, for posing the question in that form. We really ought to ask why as a rule only one egg is discharged at a time. Taken by itself the rule is just as mystifying as its exceptions, and we cannot explain these exceptions until we understand the normal mechanism.

We may be able to get a clearer picture of the situation by considering an analogy. Suppose that a large number of sheep are penned in a fold and once a month a single sheep leaves the fold. Now there are two possible explanations. It is conceivable that regularly each month, one and only one, sheep is moved to seek escape, while the rest have no such impulse. If this possibility seems absurd, we must accept the alternative explanation: namely, that once a month a gate is opened and many sheep try to get out but only one succeeds, the gate closing as soon as it escapes.

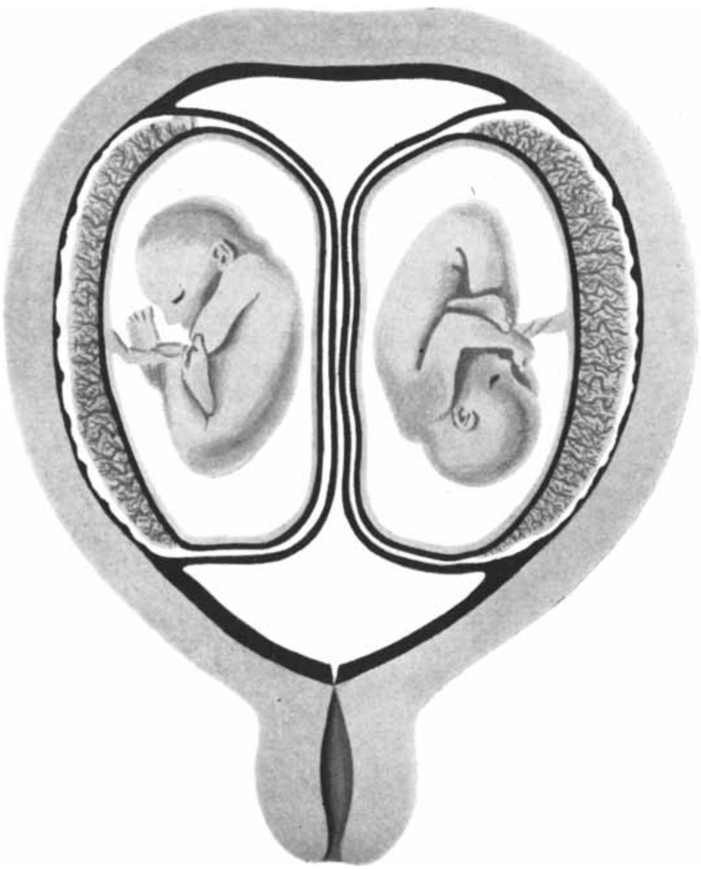
Evidently this is the case in the ovary. It is extremely improbable that the individual eggs are predestined to mature in a certain order and at the rate of precisely one each month. It is much more likely that the eggs strive to mature in crowds. This being so, there must be some kind of valve mechanism that lets through only one egg of the crowd. This mechanism cannot be controlled by the nervous system, for no nerves pass from the ovaries to the Graafian follicles. Furthermore, the mechanism must be such that it acts on both ovaries at the same time. The possibility nearest at hand is that some chemical substance plays a role in the development of the eggs. In a given group of developing eggs the one that wins the race to maturity must cause some substance to be excreted into the blood which prevents the remaining eggs from developing fully. Sometimes, however, two eggs may finish in a dead heat and cross the critical boundary simultaneously. Then we get a pair of twins.

THUS FAR we have analyzed the problem strictly by the process of logic. Students of the natural sciences, however, possess a healthy disbelief in bare logic. They like to see logical deductions verified by experiment. In this case the problem is to demonstrate that a fully developed egg possesses some substance which inhibits ovulation of the other eggs. This substance should be found in the liquid which fills the Graafian follicle that holds the egg.

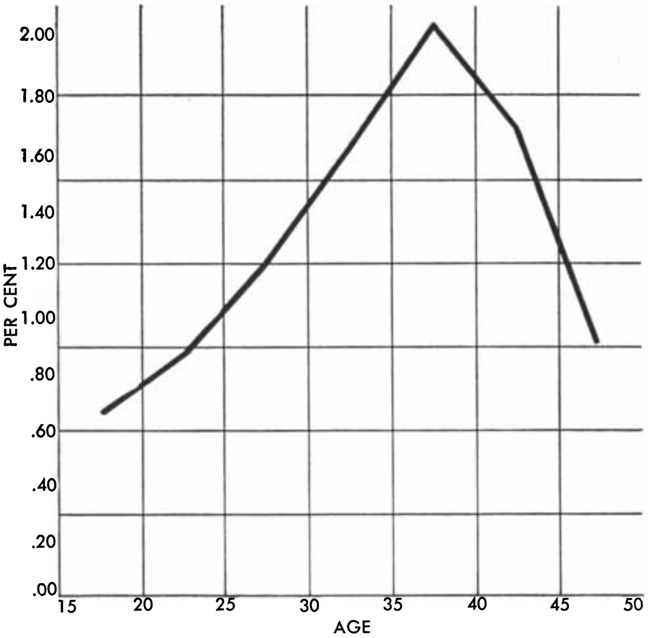
My first efforts to find such a substance were frustrated by certain technical difficulties. But the discovery of the Zondek-Aschheim pregnancy test in the 1930s provided a ready means of investigating the question. In this test urine from a woman believed to be pregnant is injected into an immature female mouse. If the woman is actually pregnant, the eggs in the mouse's ovary develop. This is because a pregnant woman's urine contains a pituitary hormone that stimulates ovulation. Now if the liquid in Graafian follicles contains a substance that inhibits ovulation, then the addition of small quantities of the liquid should cancel the ovulation-stimulating effect of a pregnant woman's



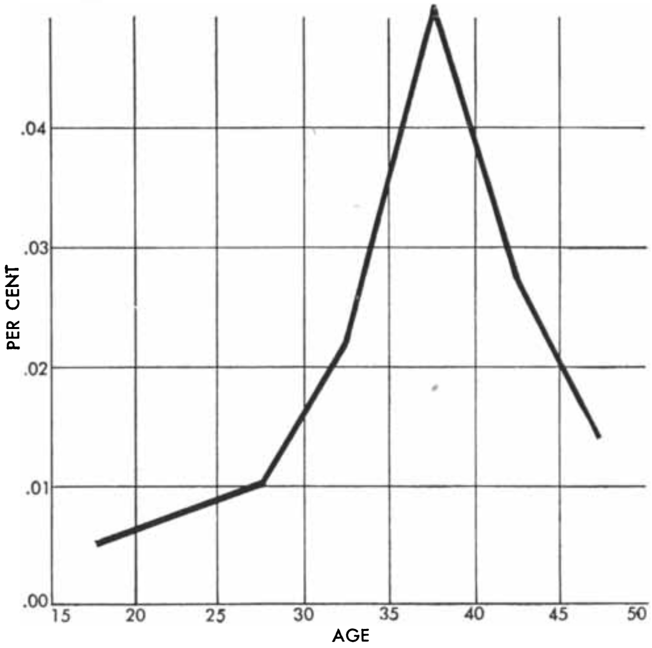
**ONE-EGG OR IDENTICAL TWINS** always develop from an egg which divides after fertilization. During gestation the twins have a common placenta.



**TWO-EGG OR FRATERNAL TWINS** appear to develop from two eggs or an egg which divides before fertilization. The twins have separate placentas.




**LIKELIHOOD OF TWINS** increases sharply with the age of the mother. The percentage of twins for mothers of 40 is three to four times that for mothers of 20.




**LIKELIHOOD OF TRIPLETS** increases even more sharply with the age of the mother. The percentage of triplets is about 10 times greater for older mothers.

urine. I proceeded to make this test, using part of a urine specimen from a woman known to be pregnant and liquid from the Graafian follicles of cows. Sure enough, the experiment had the predicted result: test animals that received the Graafian-follicle liquid showed no pregnancy reaction while control animals did.

I suspected that the inhibiting substance in the Graafian follicles might be the estrus-inducing hormone called folliculin or estrin, which is known to be secreted by mature eggs and by cells in the follicles. But the first experimental tests of this idea by myself and by Bernhard Zondek, the co-inventor of the pregnancy test, failed: the addition of pure estrin to the urine of pregnancy did not inhibit ovulation. Yet the idea seemed basically so sound that I refused to believe that these results were decisive. Perhaps pure estrin failed because it is absorbed quickly and produces only a transient effect. The estrin present in the follicle liquid, on the other hand, is absorbed slowly, on account of the presence of protein. Hence its effect, though less intense, is more lasting. If ovulation is to be inhibited, the effect must be continuous, to prevent the race of the eggs toward maturity from going so far that they cannot be stopped.

As a matter of fact, subsequent experiments indicated that estrin does indeed inhibit ovulation. It turned out that the doses we had used were too small; investigators who injected much larger estrin doses in mice obtained a sufficiently powerful and prolonged effect to inhibit ovulation in the Graafian follicles. Moreover, I found that when estrin is fed to young mice by mouth instead of by injection, so that it is absorbed more slowly, the hormone postpones ovulation as long as it is given.

So we have this picture of the normal cycle: Each month a group of eggs in the ovaries begin a race toward maturity. When one of the eggs arrives at a certain stage of maturity, winning the race, it causes the secretion of estrin, which halts the development of the rest. Now what happens to the losers of the race? Do they carry over to join the race at the next ovulation? This seems unlikely. Assume, for example, that 20 eggs enter the race at a given ovulation. If the 19 losers survived to join the 20 new eggs in the contest at the next ovulation, there would be almost twice as many contestants in the second month as in the first and therefore twice as high a probability for the birth of two-egg twins. During a single year the probability for twins would rise 12-fold. Actually the probability does not increase at anything like this rate.

Suppose, then, that only one new egg enters the race at each ovulation. This also is improbable, for it presupposes a precision and predestination in the development of individual eggs which we have already ruled out as absurd. Hence we are forced to the conclusion that after the end of each race the losing eggs die and a new group comes forward for the next competition. This conclusion is confirmed by the observation that the ovaries always contain large numbers of dying eggs. Nature, as we well know, is prodigally wasteful; it provides vast numbers of extra organisms to ensure the carrying on of its processes.

IF THE losing eggs all perish, how can we explain the fact that the probability of twins rises with women's advancing age? Probably the reason is that as the ovaries mature they produce larger and larger groups of new eggs before each ovulation, so that at the age of 40 the group of competing eggs is four times as large as at age 20. This may seem surprising, in view of the general impression that a woman is less fertile at 40 than at 20. Actually a study by Sten Wahlund of the Swedish Lapps, who do not practice birth control, showed that fertility in the sense of ability to conceive does not decline by age 40.

If the chance of getting two-egg twins quadruples with age, the chance of getting triplets should increase even more. This can be illustrated by the mathematics of a track meet. Other things being equal, if we quadruple the number of runners in a race, we quadruple the probability that two runners will finish in a tie. But the mathematical probability of a triple tie, which is very small to begin with, is multiplied 16 times when the number of runners is quadrupled. Thus if triplets always came from three separate eggs, a mother of 40 would have 16 times as great a chance of bearing triplets as a mother of 20. However, some triplets come from a single egg, the probability of which should not increase significantly with age, and some come from two eggs, where the probability only quadruples. The frequency of triplets can therefore be expected to increase somewhere between 4 and 16 times by age 40. The actual vital statistics from several countries show that the incidence of triplets is about 10 times greater in 40-year-old women than in 20-year-olds.

Is the tendency to bear twins or triplets inherited? We have no clear answer to this question; the figures are interpreted variously in different quarters. They do appear to show, however, that the tendency to one-egg twins may be hereditary both on the father's and the mother's side and that a disposition to bear two-egg twins is determined by the mother's heredity.

SOME study, though not enough, has been given to the mechanism of multiple births in other animals. Some of our domestic animals, notably mares and cows, as a rule bear only one young at a time, and twin births are rather less common among them than among women. Sheep have twins and triplets fairly often. In pigs, rabbits, dogs and cats the birth of a litter of several young is the rule rather than the exception. Generally these multiple births come from separate eggs, but they must sometimes spring from a single egg, as evidenced by the occasional birth of a two-headed calf or other partly double animal. Some species of armadillos, the peculiar little scale-covered animals found in North and South America, bear one-egg multiplets as a general rule; they usually have from 4 to 12 young in a litter, all from a single egg. Occasionally a mother armadillo discharges two eggs at a time, as women do.

We may therefore say that one-egg twins and multiplets probably occur in all species, and that multiple births from separate eggs are very common, especially in small animals. We can distinguish three mechanisms for multiple births: 1) division of a single egg after fertilization; 2) division of the egg into two or more separate eggs before fertilization, and 3) the simultaneous discharge of two or more entirely independent eggs from different Graafian follicles. In animals that habitually bear several young at a time the multiple births must surely be under some form of hormonal control similar to that which governs single births in human beings.

This theory offers an explanation of some known facts which hitherto have been practically inexplicable. To some extent it has been substantiated by experimental findings, but the theory certainly needs further development and verification.

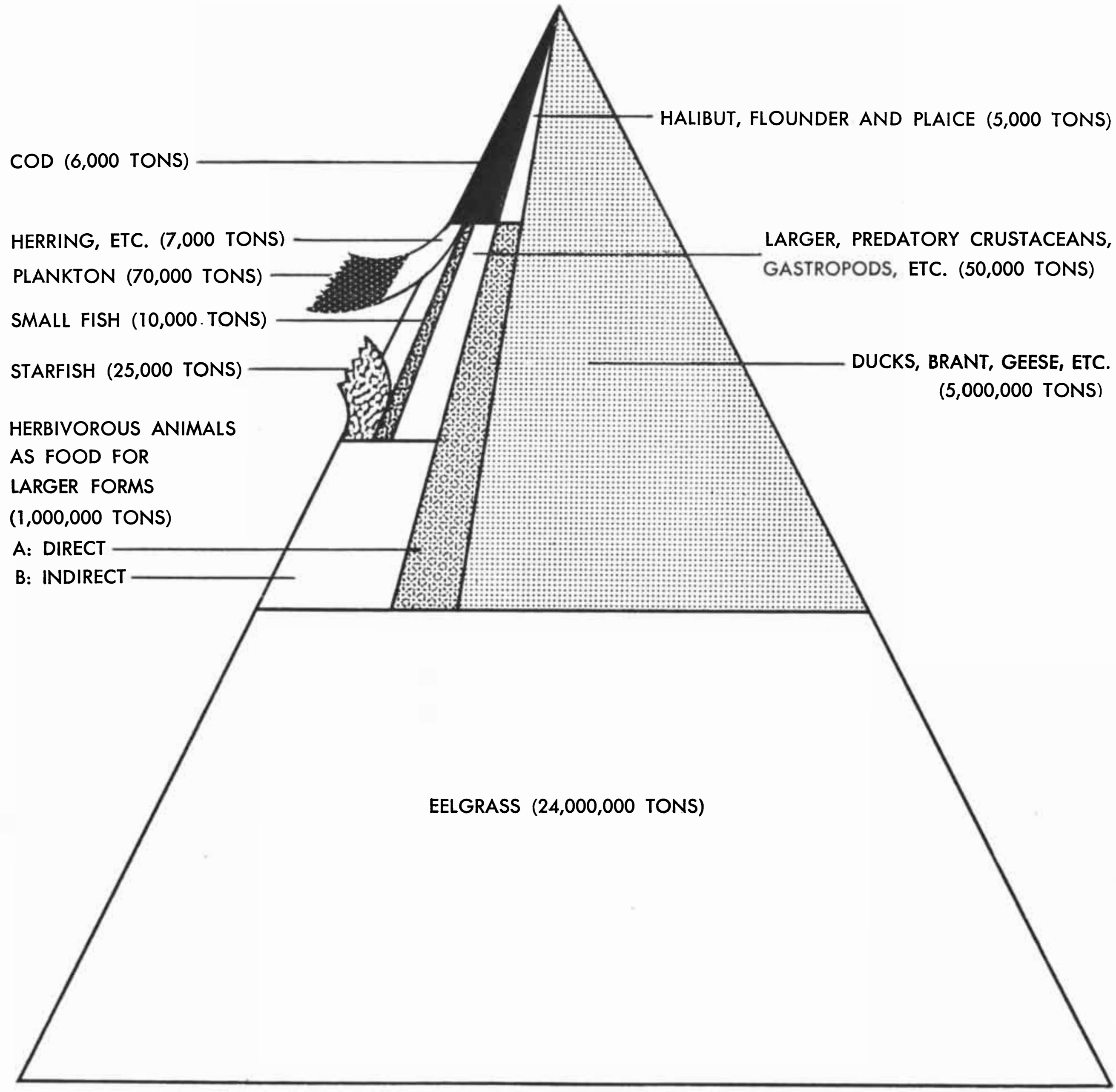
Goethe insisted: "Gray is all theory and green the rich tree of Life." No scientist would accept this pronouncement. The facts of everyday life are not *per se* interesting. What enthuses a scientist, guides his work and enables him to do what is expected of him is the development of theories to explain the facts. To him this is the most exciting part of his endeavor; the work of digging for the evidence to verify a theory is a more or less monotonous chore.

*Gunnar Dahlberg is head of the State Institute for Human Genetics and Race Biology at the University of Uppsala.*

# The Eelgrass Catastrophe

*Twenty years ago this weed of the sea began to disappear from the Atlantic coast. The far-reaching effects of its absence exemplify the interdependence of living things*

by Lorus J. and Margery J. Milne




**THE BASE OF A PYRAMID** of living things is occupied by eelgrass. Twenty-five million tons of eelgrass are needed to produce five million tons of birds, 5,000 tons of halibut, flounder and plaice, 6,000 tons of cod.

THE EMINENT bacteriologist Hans Zinsser once argued convincingly that epidemics of disease have done more to mold man's history than all the dictators, generals and feats of conquest. Epidemiologists look back with a kind of fascination on the Black Death just six centuries ago, which killed between a quarter and a half of the population of Europe alone and "came nearer to the extirpation of mankind than any other evil has ever come." The great influenza pandemic that followed World War I is still a fearful memory. Yet these dramatic catastrophes are not the whole story of the plagues that shape man's destiny. Occasionally nature produces one which passes almost unnoticed yet is fully as disastrous in its effects.

In 1931 along the eastern seaboard of North America there occurred a "Black Death" on a far more devastating scale than the plagues of the Middle Ages. In a single year the epidemic wiped out about 90 per cent of the populations it attacked. It evoked no headlines, and even now comparatively few persons are aware that it took place. But for a whole generation the plague of 1931 has influenced the lives and livelihood of millions of Americans.

The pestilence escaped general notice because its victim was only a plant. The plant was *Zostera marina*, better known as eelgrass. A common weed of the sea, it grew so rich and thick around the river mouths and shallow bays of the Atlantic coast that it often impeded boat travel. Suddenly, in the summer of 1931, the plant began to disappear rapidly. Biologists and conservationists were inclined to blame river pollution or the murkiness of the silt-laden water, but eventually they traced the plant's death to a parasitic fungus, the slime mold called *Labyrinthula*, which had suddenly grown virulent. This itself was astonishing, for a parasite seldom commits the suicidal folly of destroying the host on which it depends for life.

The destruction of the eelgrass led promptly to other disasters. Hunters soon noticed that the variety of geese called brant, one of the most prized game birds of New England, began to die off; in three years the brant declined to a fifth of their former numbers. Fishermen found that the abundance of cod, shellfish, scallops, crabs and other sea staples fell sharply. Plant and animal life at the river mouths was overwhelmed by raw, unfiltered sewage. In short, the eelgrass catastrophe played such havoc with the marine life of this part of the world that it has not yet recovered.

THE importance of eelgrass is that it forms the food base for a great many fish and waterfowl, exactly as the floating plant life of the sea called plankton sustains much of the marine life in deeper waters ("Food from the Sea"; SCIENTIFIC AMERICAN, October, 1949). Botanists had not paid much attention to eelgrass, regarding it merely as a biological curiosity. It grew profusely along the Atlantic coast from North Carolina to Greenland and down the eastern shores of Europe, as well as on the northern coasts of the Pacific. Eelgrass is not actually a grass, but it has slender, grasslike leaves up to five feet long growing from a creeping rootstock in the bottom mud. It lives in salty or brackish water and likes a sheltered situation where the waves are not too violent. In salty bays and estuaries it appears to spread chiefly by sending out runners, like strawberry plants, but in the brackish water near river mouths it bears underwater flowers and reproduces by means of pollen distributed by the tidal currents. Growing like a veritable weed, it transforms the energy of sunlight and the carbon dioxide and nutrients dissolved in the water into prodigious masses of rich food—carbohydrates, fats and protein—for a great pyramid of higher life that rests upon it. Periwinkles munch its leaves; microscopic plants and animals swarm over its foliage; clams, scallops, mussels and worms live on the rain of decaying organic matter it deposits on the bay bottoms. And these small fry in turn furnish the food for larger sea animals such as cod and flatfishes and waterfowl.

It was a Danish biologist, C. G. J. Petersen, who first called attention to the great usefulness of eelgrass to man. In 1918 he traced the diet of cod and certain other important fish consumed by man and found that the food chain led back principally to eelgrass (*see diagram on the opposite page*). He also determined that it takes roughly 10 tons of food plants to produce one ton of plant-eating animals. In turn, 10 tons of these herbivores (the equivalent of 100 tons of plants) are required to produce one ton of carnivorous animals. Since cod feed only on carnivorous animals, a ton of cod thus represents at least 1,000 tons of plant food.

It is therefore not surprising that the destruction of the eelgrass should have been followed by a decline in the catch of cod, flounder and the like in the North Atlantic. Other causes, notably overfishing, have been blamed for this decline, but there can hardly be any doubt that the eelgrass catastrophe played a major part.

Famine among the sea animals was not the only mischief caused by the eelgrass' annihilation. The disappearance of the weed accelerated and brought to full harvest the long-accumulating fruits of civilization's pollution of our coastal waters.

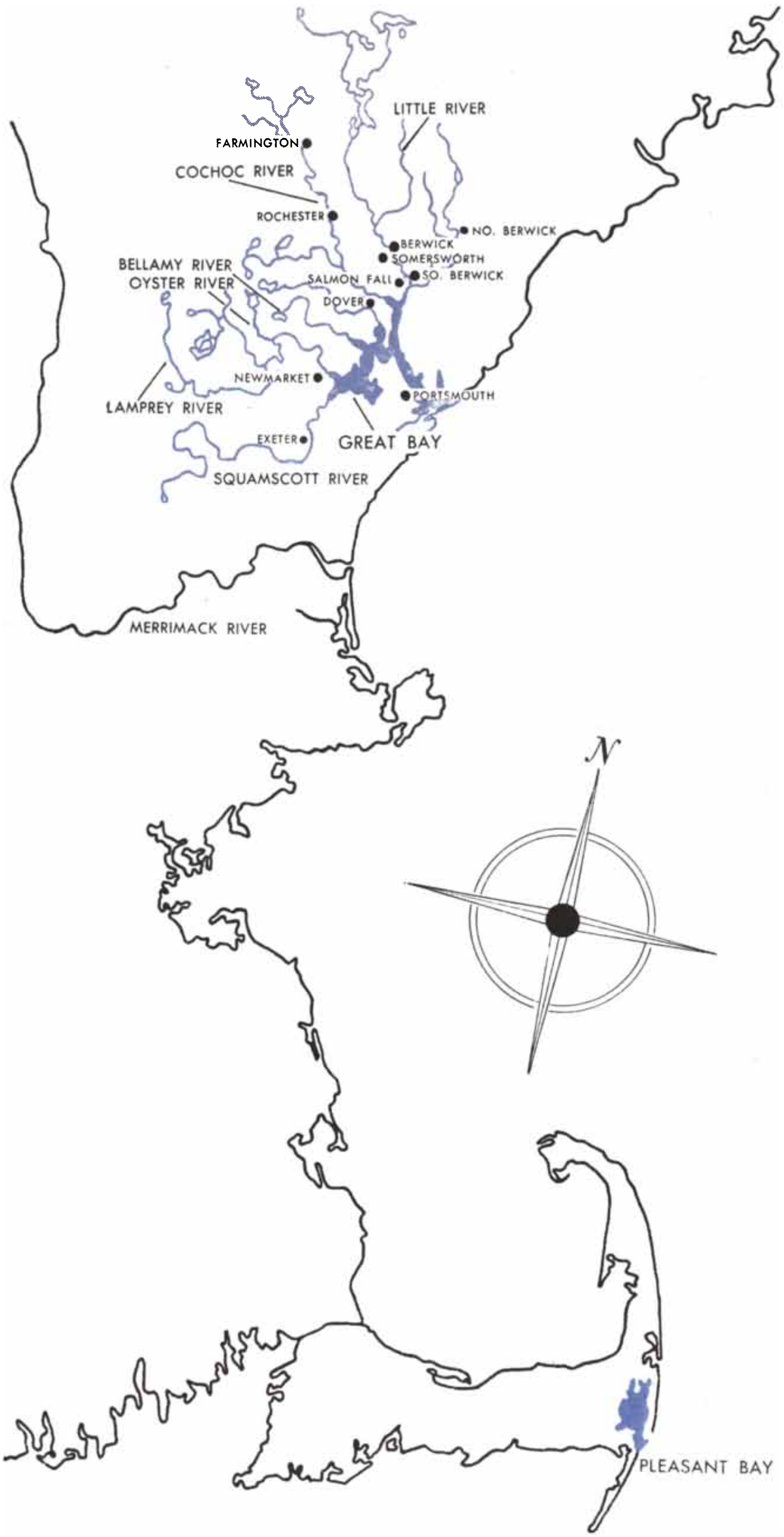
In the first centuries of man's settlement of New England, two things, mainly, made life and freedom possible—trees and fish. The colonists chopped down the trees in the magnificent virgin forests and rafted the great trunks down broad rivers to water-powered sawmills for lumber or shipped them across the ocean as masts for the King's Navy. The fish were even more fabulous. In the rivers the colonists found astonishing numbers of salmon, trout, muskellunge and sturgeon; offshore the waters swarmed with cod, herring, shad, smelt and other delectables. They ran in schools near the surface, and catching them was so easy that ships came all the way across the Atlantic to fill their holds with dried, salted and smoked fish to feed the peoples of Europe. Massachusetts took the cod for its state emblem and for the name of its most spectacular cape. The chain of islands off the coast of Maine and New Hampshire was named the Isles of Shoals for the great shoals of fish found there.

AS the trees came down and the soil was exposed,. the melting winter snows in the New England watershed began to wash the topsoil of thousands of square miles into the rivers and the sea. Gradually the lakes and river estuaries filled with silt. Mud flats spread where previously there had been clean gravel bottoms. Smelt and other fish could no longer cement their eggs to stones on the bottoms near river mouths, as they had been accustomed to do each spring, and the fish diminished to a tiny fraction of their former abundance. Oceangoing fishermen had to journey farther out to sea at greater expense to garner a similarly dwindling harvest.

To the silt the industrial communities that burgeoned along the river banks and coast began to add sewage. Eventually the pollution of the waters became so bad that the towns had to treat the water chemically to make some of it fit to drink and swim in. But this did not help the fish.

The thick growths of eelgrass did help them. The eelgrass leaves acted as a friction filter for silt and sewage sediments, which clung to their surfaces. This filter doled out polluted food to the shellfish burrowing in the bottom between the eelgrass roots. Though it made the shellfish inedible, at least it kept them alive. But with the destruction of the eelgrass in 1931 came the deluge. Silt and sewage swept unimpeded over the river mouths and smothered hordes of clams and oysters. It all but wiped out marine life in the bays and estuaries. Their bottoms became an underwater wasteland.

After almost 20 years of desolation the eelgrass fortunately has begun to come back. In the less salty waters near the river mouths a few plants survived the epidemic, and their offspring are gradually repopulating the mud flats. They are beginning to act again as friction




**NEW ENGLAND COAST** was hit by the catastrophe. At the top is Great Bay, into which empty several rivers bearing polluted waters from many industrial towns. There the eelgrass has made no appreciable comeback. In Cape Cod's unpolluted Pleasant Bay, however, the eelgrass is recovering.

filters and to provide root systems that stabilize the silt. The results, in terms of fish and wildlife, differ greatly according to the density of nearby human populations and the degree of pollution of the water. For contrast let us consider two representative bays, one polluted, the other not.

THE FIRST is New Hampshire's Great Bay. Into this irregular estuary, with nearly 110 miles of twisting shoreline, discharge six major rivers (*see map at left*). They bring down sewage from a dozen towns and a host of smaller communities along their banks, and to this is added the contributions of Portsmouth and Kittery on the bay itself. Thus the bay receives the wastes of about 70,000 people and their activities, including pulp mills and other commercial enterprises that dump in the rivers. The sewage, oozing into the ocean through the narrow neck of the bay, is regularly regurgitated back into the bay by the incoming tide.

For many years there have been no edible oysters in Oyster River and no salmon at Salmon Falls on the Piscataqua. Great Bay used to be a major channel for navigation, with boat yards and ocean shipping facilities. Today even a lobsterman's launch is hard put to find a channel through the ooze that covers its bottom. The sewage slime and shifting silt have also largely ended the annual invasion of ocean fish for which Great Bay was once a major spawning ground. And in Great Bay the eelgrass has yet to make any appreciable comeback from its 1931 disaster.

The contrasting illustration is Pleasant Bay, an inlet of comparable size on the outer side of Cape Cod (*see map*). Like Great Bay, Pleasant Bay also is full of silt, for the trees that once surrounded it and held the topsoil are gone, and no serious attempt has been made to rebuild the land. But it receives no sewage, because no river or community of any size dumps into it. Its water is clear, and except in the gutters between the barren hillsides its bottom is firm. In Pleasant Bay the eelgrass is now recovering rapidly. The gravelly bottom through which eelgrass spears began to thrust upward in 1947 became a "scallop garden" in 1948; half-inch members of this attractive, blue-eyed swimming clam cavorted in every direction. In 1949 the scallops were more mature and plentiful, feeding on the microorganisms that slid from the growing, waving leaves of eelgrass. Periwinkles reappeared. Blue crabs scuttled about. Hermit crabs dragged snail-shell coverings from place to place, trying new-found empty ones for fit or competing with one another for possession of these limy shelters. Waterfowl waded, swam and dived in the bay. Pipefish returned in large numbers.

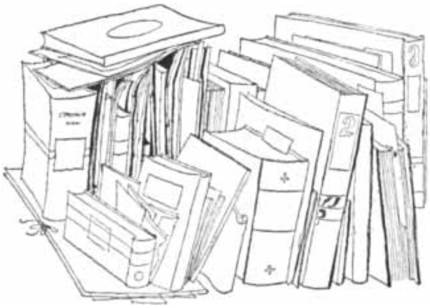
These pipefish neatly demonstrate the complex interrelationships of the eelgrass community and man's general lack of information about the matter. They are relatives of the familiar sea horse, and, like it, they feed on microscopic organisms that thrive on eelgrass blades. The pipefish suck their food daintily through round mouths that look very much like built-in soda straws. The most remarkable fact about them is that few fishermen had ever seen a pipefish before the eelgrass disappeared. In shape and coloring they simulate the eelgrass leaves so closely that they are practically invisible. When the eelgrass disappeared in 1931, the pipefish were suddenly exposed. But they did not last long. With the loss of their food supply, they soon went, too. Now they are coming back with the eelgrass.

Fish and wildlife experts and some fishermen have now become keenly aware of how much the loss of the eelgrass has meant to New England. Clam beds or oyster beds yield more cash per acre than any other crop man can find. When eelgrass is present as a barrier to the shifting of sediments and sewage, these mollusks can grow large and fat, even on the bacteria and other microorganisms that pollute the water. The eelgrass may make a general recovery in these waters. But the problem of pollution will still remain. So long as the water is polluted and shellfish can therefore not be taken for human consumption, there is no incentive to seed these areas with clams and oysters. And without shellfish, fish and wildfowl cannot thrive. Moreover, the sewage prevents the production of fish in another way: it smothers the fish eggs laid on the eelgrass leaves or coats the leaves with a slippery surface so the eggs do not stick to them.

THERE are ways, however, in which man could help the eelgrass and restore the safety of the coastal waters for marine life and for human recreation. These ways all involve treatment of the sewage at the source. One method even puts the sewage bacteria to use. The sewage is run into covered tanks. Bacteria soon exhaust the oxygen in the sediments. Then anaerobic bacteria (those that can live without oxygen) take over, breaking down the chemical compounds in the solid sewage. The disease-producing types of bacteria die. Ultimately the solids liquefy, and this material, as well as the original liquid part of the sewage, can be made harmless and odorless by mild chemical treatment.

By attending to the sewage and industrial wastes in such manner, and by building back the topsoil and the trees on the watersheds, we can, if we will, bring back the conditions under which fish and wildfowl thrived so mightily before that landing on Plymouth Rock.

*Lorus J. and Margery J. Milne, biologists at the University of New Hampshire, have contributed several articles to this magazine.*



# BOOKS

## *The problems of security and science with respect to our experience in World War II*

by I. I. Rabi

SECURITY, LOYALTY AND SCIENCE, by Walter Gellhorn. Cornell University Press ($3.00).

EVEN before our entry into World War II the scientists of this country spontaneously rose to join the defense effort. In many cases they had to force on an unwilling military new ideas and devices which were to prove of vital importance in the war. They not only willingly accepted security restrictions, but often imposed them by voluntary action in fields such as atomic energy before their importance was understood by government. In many large establishments security regulations were administered with complete success by the scientists themselves. A nice and informed balance was maintained in these laboratories between the handling and dissemination of classified information on the one hand and rapid and successful progress with the job on the other. This difficult problem lies at the heart of management of scientific research and development laboratories devoted to "weaponeering." The value of the great wartime laboratories was recognized widely, especially by the armed forces.

After such an enviable record, it was to be expected that the scientists would be considered among the most trusted members of the community. Walter Gellhorn's book *Security, Loyalty and Science* shows how mistaken this expectation was. The success and devotion of the scientists to the war effort seems to have left many people with a feeling of unease. Somehow these men were too idealistic to ring true.

Gellhorn, professor of law in Columbia University, tells in a lively and highly readable style the depressing story of the administration of the government's "security" policies as they have affected science and technology in the years since the war. The net impact of the volume is an overwhelming impression of how far this country has retreated from the gay *laissez-faire* liberalism of prewar days.

Before World War II the existence of two totalitarian powers, Soviet Russia and Nazi Germany, with their opposing ideologies left us in a happy middle ground to pursue our science in its traditional atmosphere of freedom. The news of the arrest of a prominent Soviet scientist or the dismissal of a German or Italian professor for un-Nazi opinions was distressing but also reinforced our pride in our traditional institutions.

Apparently the country at large, and especially Congress and government officials, does not understand or appreciate the deep patriotism and loyalty of the scientific fraternity. The reasons for the scientists' loyalty are clear. Our traditional laws and institutions which guarantee freedom of thought and expression, our national interest in novelty and experiment, our regard for the individual, the absence of totalitarian pressures—all are consonant with the spirit and tradition of science. Loyalty to the U. S. is as natural to a U. S. scientist as loyalty to his science. No country which is run entirely or in large part on totalitarian principles can hope to command the same loyalty. Certainly the record of Nazi Germany and Mussolini's Italy bear out this point, and that the Kremlin does not trust its scientists is very evident even from the scant reports we get.

Loyalty to the U. S. as opposed to loyalty to a foreign nation does not necessarily mean agreement with the principles and policies of the party in power. Even intense disagreement generally has little or no effect on the fundamental loyalty to the U. S. I can cite an interesting personal experience on this point.

In the early spring of 1941 I had occasion to travel all over the country as a lecturer for the scientific society Sigma Xi. I utilized this opportunity to recruit scientists for the Radiation Laboratory in Cambridge, Mass. This laboratory, where I had worked on leave from Columbia University since November 1940, was devoted to microwave radar, then an extremely hush-hush subject.

I would enter a laboratory where a scientist, generally a young scientist, was happily working away on his experiments and tell him that we had a laboratory in Cambridge where he was needed, that of necessity the purpose of the laboratory could not be revealed but that I was convinced that his services were necessary in the national interest. As part of the pep talk, I could assure him that the working conditions were poor and the problem had no relation to his present interest nor would it necessarily advance him scientifically. Furthermore, would he please show up in Cambridge in ten days or two weeks? The spirit in which this call to action was received can be judged by the fact that I had only one refusal in about two dozen solicitations in various parts of the country. The man who refused genuinely felt that he was not good enough for the job.

The political opinions of the scientists ranged over the whole spectrum of confusion that was typical of the spring of 1941. There were those who wanted us to declare war on Germany, and others who saw Russia or Japan as the principal enemy. There were many who sincerely felt that we had already gone too far in our support of the British and the Allied cause. This group consisted chiefly of people who were strongly opposed to the Roosevelt administration. Nevertheless they joined the Radiation Laboratory and made notable contributions to the war effort.

These cases have been cited to show the latent power of a free society. If the postwar conditions described in Professor Gellhorn's book had then obtained, these antiwar individuals never would have been asked to join our laboratory in the first place. Enough "derogatory" information would have been cited against them to keep them out of the war effort entirely; they would have been lucky to escape a detention camp. Neither would the response of the other scientists have been so unanimous. The doubtful and difficult clearance procedure would have been a deterrent, and a period of many months would have elapsed before they could have become available. The advantages of our head start in the field of microwave radar would have been exploited less effectively.

There are some scientists who, basing their judgment on their experience in World War II, feel that our policy should be "full speed ahead and damn the torpedoes." They are impatient of security restrictions which slow up our progress and add irritation and frustration to a task which is inherently of extraordinary difficulty. Their feeling is reinforced when they realize that the whole dismal security procedure can be vitiated by a hitherto unsuspected pathological Klaus Fuchs. Many of these people feel that if the efforts of the security agencies were devoted more strongly to counterespionage and less to fruitless searching for "derogatory" information about patriotic and loyal citizens, Fuchs and others like him would not have been able to complete successfully their treacherous betrayal. Nevertheless most scientists believe that security of scientific and technical information with respect to weapon development is a necessary evil forced upon us by conditions which prevail in the world today. Very few will object to this principle.

It is well known that for commercial reasons a degree of secrecy has always been the rule of many industrial laboratories. Temporary secrecy is usually necessary for patentable matters. In some industries a patent monopoly is no real protection, and the new processes are kept secret for long periods of time. Secrecy in many branches of research and development is therefore a normal atmosphere for many scientists and engineers.

Professor Gellhorn might well have considered this phase of scientific effort. No one beats his breast over the sad fate of these captive scientists who cannot broadcast their discoveries to the world, nor do they individually appear to be particularly depressed by their condition. They took and hold their present jobs voluntarily, and they enjoy the work and the pay. The commercial security system must be pretty good, or else the companies would not continue the policy of secrecy with its concomitant loss of efficiency.

Yet the commercial companies have no Federal Bureau of Investigation to check on their scientists' activities. There may be some scientists in commercial employ who doubt the value or wisdom of the system of private enterprise, or who think that some other company is better run. But as long as they give effective service to the companies, their positions are secure. The scientist or engineer will indeed very often attend a convention where scientists or engineers of rival companies are present and discuss their mutual interests but not their secrets, perhaps even over a glass of something more potent than grape juice. An association with a member of a rival company is not in itself suspect. In contrast to the Federal government, industry is not protected from treachery by an elaborate criminal law with very severe penalties for conviction. Although conditions are not strictly comparable, the Federal government can learn a great deal from a study of industrial practice in secret research and development.

From Professor Gellhorn's book one can, after a little reflection, see clearly what is lacking in the administration of the security of scientific information of military significance. The missing ingredient is apparently nothing but common sense. The objectives of the procedures are most laudable but they are set up in such a way that it is difficult for the saving grace of common sense to operate at any level.

This leads to too great a premium on passing the buck and evading responsibility. The FBI says it merely develops information in its own way from its sources which must remain veiled, but it does not pass judgment. Clearly this is impossible, because some judgment must be made in order to develop intelligible information. The FBI then passes this folder on to another agency, let us say the Atomic Energy Commission. Now the AEC has this hot potato which it cannot handle because if it were too strict in its judgments, there would be an outcry from its employees and contractors who would find it too hard to get on with the job; if too liberal, some members of Congress would pillory it before the nation. The AEC therefore appoints a board of distinguished citizens who know nothing about the subject and are not responsible for getting a job done but who are willing to take the blows of fate, which are always forthcoming.

Perfect security of scientific information is clearly impossible. When this fact is realized and procedures changed to admit discretion and common sense on the part of the men who are responsible for getting the job done, a maximum combination of achievement and security can be realized, perhaps even under existing laws. If Congress shows forebearance and the Executive is firm and responsible, the enthusiastic and patriotic loyalty of scientists and engineers will continue to bring great progress in the national defense.

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DIANETICS: THE MODERN SCIENCE OF MENTAL HEALTH, by L. Ron Hubbard. Hermitage House ($4.00). This volume probably contains more promises and less evidence per page than has any publication since the invention of printing. Briefly, its thesis is that man is intrinsically good, has a perfect memory for every event of his life, and is a good deal more intelligent than he appears to be. However, something called the engram prevents these characteristics from being realized in man's behavior. During moments of unconsciousness and pain and at any time from conception onward, the "reactive mind" can still record experience, but experiences so recorded—engrams—are a major source of man's misery, his psychosomatic ills, his neuroses and psychoses, his poor memory, and his generally inefficient functioning. By a process called dianetic revery, which resembles hypnosis and which may apparently be practiced by anyone trained in dianetics, these engrams may be recalled. Once thoroughly recalled, they are "refiled," and the patient becomes a "clear," who is not handicapped by encumbering engrams and who can thenceforth function at a level of intellect, efficiency and goodness seldom if ever realized before in the history of man. The system is presented without qualification and without evidence. It has borrowed from psychoanalysis, Pavlovian conditioning, hypnosis and folk beliefs, but, except for the last, these debts are fulsomely denied. The huge sale of the book to date is distressing evidence of the frustrated ambitions, hopes, ideals, anxieties and worries of the many persons who through it have sought succor.

THE SCIENCE OF FLIGHT, by O. G. Sutton. Penguin Books (35 cents). This little book will be a joy and delight to anyone desiring an easy physical introduction into the aerodynamic principles underlying flight, and can be read with great profit even by those who have already been introduced to the subject by heavier accounts. To many of the latter it will probably come as a great surprise that the subject can be dealt with in such a direct and simple way. The book should be required reading for every man in the Air Force. The first half of it is devoted to a clear discussion of the principles affecting lift and drag on airplane wings and propellers, and of the general questions of stability and control of aircraft in the usual region of subsonic flight. In the second half the reader is introduced to the special problems associated with flight at higher speeds, especially the transonic and supersonic, at which effects arising from the compressibility of the air become of dominating importance. There is also an elementary presentation of the physical principles underlying jet and rocket propulsion, and a sane and sensible account of the technical difficulties in the problem of building a rocket capable of leaving the earth.

OUR REJECTED CHILDREN, by Albert Deutsch. Little, Brown & Co. ($3.00). This is a justifiably indignant account of the conditions and policies found by Mr. Deutsch in visits to 14 state training schools for delinquent children. These institutions, he concludes, deserve the name of school only in the sense that they are "effective crime schools, organized on a mass level," whose "tools of control" are often the most brutal and sadistic kinds of corporal punishment. Although such conditions may be ameliorated by an aroused public opinion and an enlightened school administration, the general causes of juvenile delinquency, Deutsch believes, are class and cultural attitudes and poverty.

ASTRONOMY OF STELLAR ENERGY AND DECAY, by Martin C. Johnson. Faber & Faber, Ltd., London ($4.00). Dr. Johnson, an astronomer and physicist who has made his reputation as an able expositor of difficult scientific ideas, attempts a bridge between the popular and the technical in this essay on the natural history of a star: what it is, where the energy comes from to keep it shining, what its future is likely to be, what possible catastrophe overhangs many familiar stars, including the sun. Part One is a general reader's outline of facts and theories; Part Two, a "student's introduction" to an analysis of the theories, makes considerably more demands.

PAVLOV, A BIOGRAPHY, by B. P. Babkin. University of Chicago Press ($6.00). Dr. Babkin, a distinguished physiologist now associated with the Montreal Neurological Institute, was a pupil of Pavlov's and for 10 years his assistant at the Institute of Experimental Medicine in St. Petersburg. His biography is a work of veneration and affection, but it is both honest and sharp in its description of a man at once brilliant, childish, tyrannical, lovable, spoiled, stubborn, generous and impossible. The many sidelights and anecdotes, the intimate glimpses of Russian social and intellectual life from 1890 to 1930, the clear, full account of Pavlov's laboratory work, the easy unaffected style, together make for a wholly appealing and valuable book.

SPEAKING OF MAN, by Abraham Myerson, M.D. Alfred A. Knopf ($3.00). A collection of essays—literate, interesting and often witty—in which the late neuropsychiatrist expresses his attitudes and beliefs concerning a wide variety of subjects, ranging from "Momism" to "The Illusion of Individuality." Not often profound, the essays are engaging and give a picture of an active, alert, kindly intelligence. A typical comment: "There is a tendency today to put the psychiatrist in the place of priest as absolute authority. I know most of the distinguished psychiatrists of America, and the distribution of wisdom and wise living among them is about equal to that in the general population."

A NATURAL HISTORY OF TREES, by Donald Culross Peattie. Houghton, Mifflin Company ($5.00). All anyone except an arboriculturist would want to know about the trees of Eastern and Central North America, including information about their range, clear descriptions of their leaf, flower, fruit, bark, the uses of different kinds of lumber, the way trees have entered into our folkways. Some of the chapters originally appeared in this magazine.

## Also Noteworthy

HOW TO SURVIVE AN ATOMIC BOMBING, by Richard Gerstell. Combat Forces Press ($1.95). Various suggestions—from wearing a hat to keeping your icebox door closed—for getting through the first few seconds and even a while longer after an atom bomb lands in your vicinity. Perfectly sensible and perfectly unreassuring.

THE MATHEMATICAL ANALYSIS OF LOGIC, by George Boole. Philosophical Library ($3.75). A reprint of Boole's 1847 essay, which was a landmark of mathematical logic. A useful publishing venture, but the price is exorbitant.

GEOMETRY, by H. G. Forder. Longmans, Green and Company ($2.00). This recent addition to Hutchinson's University Library is somewhat unusual for attempting in 180-odd pages to describe almost every branch of geometry, from the elementary to the most advanced. Purportedly for the nonspecialist but difficult.

THE VOYAGES OF CAPTAIN COOK, edited with an introduction by Christopher Lloyd. Chanticleer Press, Inc. ($2.00). Selections from the journals describing the three famous voyages of James Cook have been gathered into a most attractive and superbly readable volume.

THE ANATOMY OF MATHEMATICS, by R. B. Kershner and L. R. Wilcox. The Ronald Press Company ($6.00). The nature of modern mathematics exhibited in terms of the axiomatic method for teachers and graduate students.

THE HUMAN SPECIES, by Anthony Barnett. W. W. Norton & Co., Inc. ($3.75). This readable and interesting treatment of human biology is especially designed for the nonspecialist whose taste for the science centers on its social aspects, on the contributions that biology can make to contemporary problems.

THE EVOLUTION OF SCIENTIFIC THOUGHT FROM NEWTON TO EINSTEIN, by A. d'Abro. Dover Publications, Inc. ($3.95). The second edition of a well-known semipopular account of the development of mathematical and physical knowledge from Newton to Einstein.

THE SEA AND ITS MYSTERIES, by John S. Colman. W. W. Norton & Co., Inc. ($3.75). An excellent popular introduction to oceanography and the natural history of the sea by the Director of the Marine Biological Institute of the Isle of Man.

ASIA, by L. Dudley Stamp. E. P. Dutton and Company ($6.50). Eighth revised edition of a standard reference work on regional and economic geography. Numerous maps and tables.

THE THEORY OF PROBABILITY, by Hans Reichenbach. University of California Press ($12.50). A translation of a well-known German work on the logical and mathematical foundations of probability. New material has been added.

# THE AMATEUR ASTRONOMER

**Conducted by Albert G. Ingalls**

IN RECENT years a number of astronomers have said that the 200-inch Hale telescope is the biggest that will ever be built. This has not discouraged the proponents of still larger instruments. Two European astronomers have notably continued to experiment with an unconventional method of constructing very large mirrors. They propose making the large mirrors out of smaller ones united on a single fixed support of great rigidity.

The pessimists do not mean that engineers could not build larger telescopes, or that if built these would necessarily be defective in an instrument-engineering sense. The outer limit would be set not by engineering limitations but by irregularities in the earth's atmosphere which blur the images of stars: the larger the telescope, the greater the blurring.

It has almost been forgotten that in 1926 F. G. Pease of the Mount Wilson Observatory published a design for a proposed 300-inch telescope. His design called for a 25-foot mirror in a mounting carried on a horseshoe-bearing similar to the one that now carries the 200-inch, a feature proposed by Russell W. Porter in 1918. Pease, an astronomer, precision optician and engineer who with G. W. Ritchey designed the 100-inch telescope, was not frightened by magnitude; he stated that "anything up to 100 feet in aperture can be built provided one wants to pay for it." But the financing of a conventional telescope larger than the 200-inch would be a very serious problem. The 200-inch cost $6,550,000, and might cost twice as much today, and a 300-inch would be theoretically three times as bulky and costly. These difficulties have been tackled in a radical way by Guido Horn-D'Arturo of Italy and Y. Väisälä of Finland.

In 1932 Horn-D'Arturo, an astronomer at the University of Bologna who had worked at the Lick Observatory in California, was meditating upon methods of building very large telescopes. He recalled an experiment made a century earlier by William Parsons, otherwise known as Lord Rosse (the same Lord Rosse who in 1845 built a six-foot telescope and became one of the great figures in the history of the telescope). In 1828 Lord Rosse had described an experiment with a composite mirror of speculum metal. As shown at the upper left-hand corner of Roger Hayward's drawing on the opposite page, the mirror consisted of only two pieces: an inner circle and a ring around it. The purpose was not to attain great size but to cope with spherical aberration without the necessity of parabolizing the mirror. By adjusting the screws in the brass plate beneath the mirror, Lord Rosse was able to alter the sphere to a two-step approximation of a paraboloid.

The article by Lord Rosse gave Horn-D'Arturo an idea for a method of making gigantic mirrors. They could be built up of identical smaller mirrors that were spherically concave, relatively thin and inexpensively mass-produced. These would be mounted on an extremely rigid common backing. By means of adjusting screws, each ring of mirrors could be raised a little above the ring within it, and each mirror could be tilted to focus on the same spot.

Such a composite mirror could also be constructed of individually figured paraboloids. Obviously these would be more expensive than identical spheres. Their resolving power would moreover only equal that of a single mirror, as explained in *Amateur Telescope Making*, page 317. This would not be true of spheres.

Horn-D'Arturo calls his mosaic mirror a tessellated mirror, and each piece of the mosaic a tessera. His experiments were performed in the 160-foot high, 30-foot square stone tower of the University of Bologna, built in 1712. In its upper part is a large room with a 33-foot ceiling. Here Horn-D'Arturo erected a solid timber table with a thick marble top, on which he assembled the 10 tesserae then in his possession. Each was approximately trapezoidal and about four inches across. When they were assembled as shown at left center in the drawing on the opposite page, they could be used to test a hypothetical 41-inch telescope. The focal length of the tesserae averaged 410 inches or about 34 feet.

In the ceiling directly above this assembly was an opening 50 inches in diameter. Across this Horn-D'Arturo mounted a spider and testing equipment for collimating the tesserae. Later there would be a motor to move a photographic plate horizontally as the earth rotated.

Here is revealed the major feature of the Horn-D'Arturo telescope: only the plate is moved, while the mirror remains fixed firmly, immovably and permanently in the horizontal position. It is backed, braced and held rigidly to the earth, while a tiny motor moves the plate to compensate for the earth's rotation.

Thus the Horn-D'Arturo telescope "sees" only the relatively tiny area of the sky directly above it. As the earth rotates the telescope sweeps out around the sky a band or torus less than two degrees in width. A chain of these telescopes, however, could cover a relatively broad belt. Six of them spaced at 115-mile intervals could photograph the heavens above all of Italy.

At the bottoms of six pits 200 feet deep would be six composite mirrors of 230-inch diameter. At the surface a 3½-by-12-inch photographic plate would be moved horizontally westward as the earth turned eastward. This would afford exposures of 6 minutes and 15 seconds before the whole width of the mirror was used. Other fields along the band of sky would then be photographed, but the same one could not be photographed again until another night.

SIX huge telescopes of the Horn-D'Arturo type should not cost as much as a single one of the conventional type. Each telescope would consist only of a hole in the earth, a composite mirror, and a spider with motor drive and plate holder. Because we are so familiar with conventional telescopes many of us unconsciously take it for granted that a telescope must include all the standard mechanisms, and thus we accept their cost and complexity as inevitable. To emphasize this complexity, here is a description taken from an article in the August, 1948, issue of this magazine:

"The optical essence of the two-million-pound telescope weighs less than a quarter of an ounce. Light from the stars reaches a paraboloidally curved aluminum mirror 200 inches in diameter and 1/200,000-inch thick—an amount of metal approximately the bulk of a nickel—which reflects it to a light-sensitized sheet of photographic emulsion a thousandth of an inch thick. All the remainder of the telescope consists of accessories: the glass plate that supports the emulsion; the glass disk that supports the aluminum; the 36 levers with counterweights that support the glass disk and the platform or cell that supports both; the tube that carries the cell; the yoke the carries the tube; the base frame that carries the yoke. . . . The function of all these accessories is to support the mirror and emulsion in correct geometrical relation and to move them precisely and controllably."

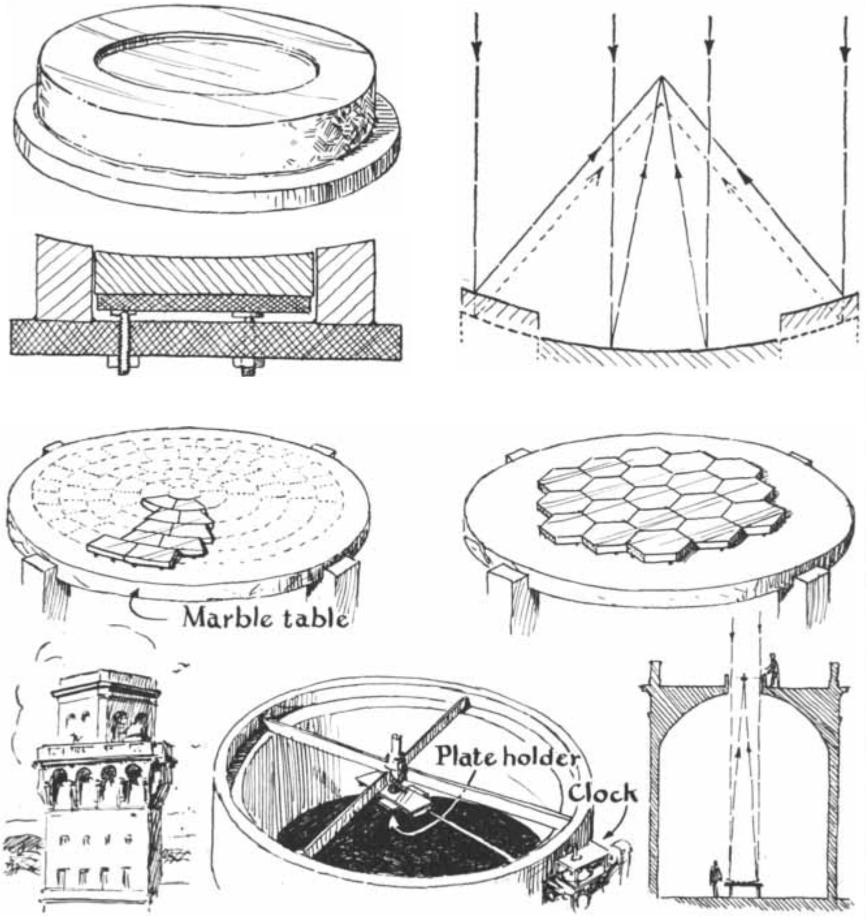
The key to the argument is in the final six words of this quotation, with heavy emphasis on the word *move*. If we can subtract from our telescope this necessity for moving the large mirror without deforming it, there remains a need for only a very small mechanism. This is why the Horn-D'Arturo telescope is inexpensive. The mechanism that contributes the motion is free: it is the rotating earth.

The limited view of the tubeless, mountingless telescope might be corrected by adding a coelostat of two mirrors to bring the light from any part of the sky to the composite mirror. Unfortunately each of these two mirrors would then have to be as large as the main mirror and to have elaborate equipment for maintaining its rigidity as it moved. This would require almost as much paraphernalia as a conventional telescope or, rather, twice as much, since there would be two mirrors. Roger Hayward suggests a group of telescopes all in the same place with mirrors attached to the earth at differing slants. This might cost little less, but would concentrate the observing staffs.

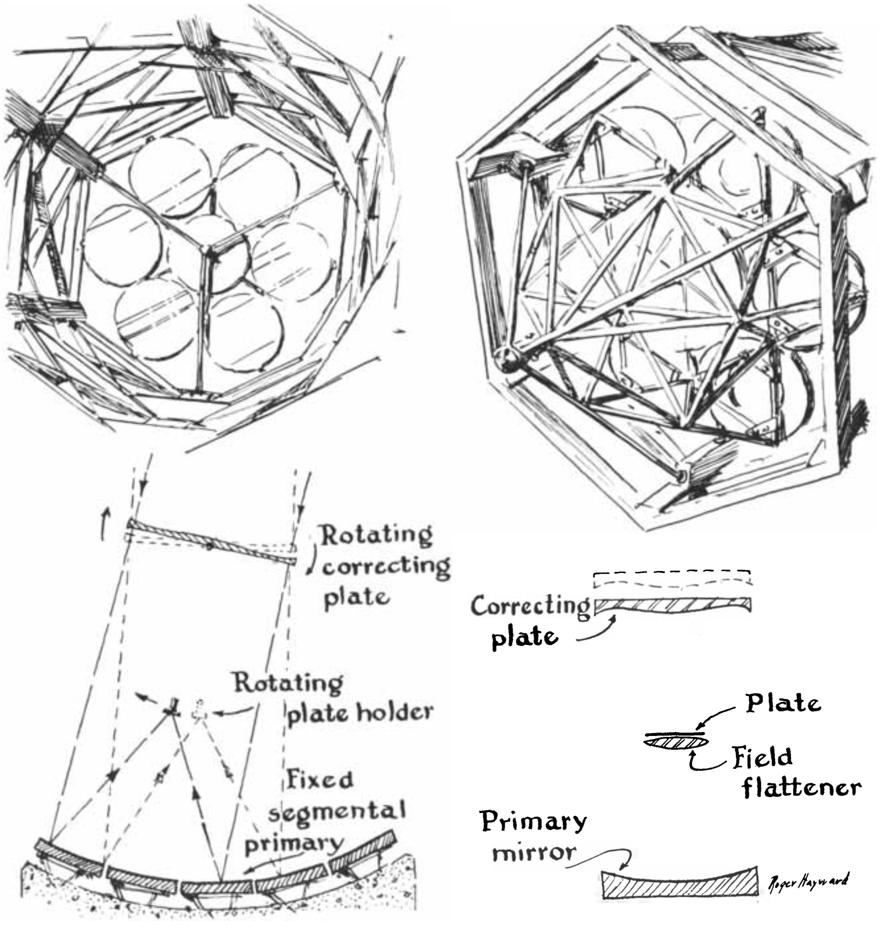
In 1936 Horn-D'Arturo obtained 10 additional tesserae and with 20 now in hand he was able to assemble a quadrant of his 41-inch mirror. Then anti-Semitic persecutions in Italy delayed his experiments until 1945. In a new publication of the Observatory of Bologna, dated 1950 and entitled "Further Experiments with the Tessellated Mirror," Horn-D'Arturo has described his last five years of research. Assisted by his technician Aldo Galazzi, he began afresh. He assembled a mirror with 19 tesserae, this time of hexagonal outline and 8 inches across. They fitted together within a twelfth of an inch. The focal length was as before: 410 inches.

The German optical works of Carl Zeiss had been able to give the first lot of tesserae focal lengths within one part in 250. Galazzi now produced the new lot to within one part in 300. Either these discrepancies or the diffraction from the additional edges of the tesserae might have been detrimental to the imagery of the assembled mirror, but they were not. While working at the Lick Observatory Horn-D'Arturo had placed over the mirror of the Crossley reflecting telescope a cardboard mask representing a composite mirror's network of tesserae edges. R. J. Trumpler photographed a star field through it and then, as a control, without it. A diffraction effect was of course revealed by the plate; the effects of the concentric rings of tesserae were more noticeable than those of the radial division lines between them. An analogous experiment at the Zeiss plant also revealed that the diffraction effect was small and on the whole harmless.

Each hexagonal tessera was placed on three adjusting screws projecting through the marble slab. All the tesserae were then adjusted to compensate for



*Details of experiments toward a giant telescope*




*Another experimenter's approach to immense telescopes*

spherical aberration. This elevated the first circle of 6 tesserae about 1/50-inch above the central hexagon, and the second circle of 12 tesserae about 1/16-inch above the first.

A more precise problem was to bring all the 19 foci to coincidence at the same spot. This required adjustment in parallel rays of light, and such rays were manufactured successively above each tessera by means of a small collimating telescope. In each instance the collimator was accurately adjusted perpendicular to the same reference plane—the surface of a basin of colored water—by means of interference fringes. The basin was then removed and the image reflected by the tessera was brought to the common focus. Two persons, one manipulating the screws under the marble slab, the other 34 feet above in the next story of the tower, watching the focused image and directing its movement by electric signals, were able to complete the collimation in two hours.

A small mechanism compensates for the rotation of field during exposure of the plate. An actual photograph of a star field made by the 41-inch telescope is shown in the Horn-D'Arturo report and reveals that "all the small images at the edges and in the corners are equally round." Coma is "lost in the diffusion disk."

In two other papers, publications of the Astronomical Observatory of Bologna, Horn-D'Arturo analyzes "The Deformation of Stellar Images Due to Coma, Resolved into its Elements" and "Extra-axial Stellar Images Generated by Paraboloidal, Spherical and Tessellated Mirrors." These are available for loan to advanced amateur telescope makers who can brave mathematical optics in Italian. The last-named paper demonstrates "that the form and dimension of the images theoretically obtained from the tessellated mirror are practically identical with those generated by a paraboloid of revolution."

THE SECOND European proponent of the large composite mirror is Professor Y. Väisälä of the University of Turku in Finland. In optical literature Väisälä's name has often been linked with that of the American Franklin B. Wright. As George Z. Dimitroff and James G. Baker state in *Telescopes and Accessories*, both Väisälä and Wright have independently investigated the possible positions of the correcting plate of the Schmidt camera, and both have found that by varying these positions a spherically corrected and coma-free system may be had for each distance of the correcting plate along the axis.

As in the Wright camera, and as in the drawing on the opposite page, Väisälä's correcting lens is not at the center of curvature of the spherical primary but is a little closer to the mirror. A field-flattening lens lies in front of the plate, which is therefore plane instead of curved as in the Schmidt.

In 1934 Väisälä built a 6¾-inch $f/1.9$ instrument of this type. It worked so well that he next built a 20-inch $f/2$ of the same type. These were the first wide-field telescopes with flat plates and the first anastigmats in the world. Väisälä has been optician, engineer, architect, carpenter and bricklayer of the Turku observatory; now he is its director. In *Urania,* an astronomical journal published in Madrid and Barcelona, Väisälä has described in Spanish his proposal for fixed composite-mirror telescopes with moving photographic plates, to be erected in deep pits in the earth. It appeared under the title "A New Procedure for Constructing Gigantic Telescopes." The following is a translation of the major portions of this article. The amateur telescope maker may discover a hint for a way to build a large mirror at less expense than that of a single blank.

"I shall present here a new procedure for building large telescopes. At first glance it seems audacious, but I believe that it is worthy of much experimentation. The mirror of the telescope, instead of having a continuous surface, is a compound of separate mirrors solidly united by a rigid support of skeleton construction made of steel bars or tubes. By this method it is not necessary to make the component mirrors very large, for by increasing their number a gigantic mirror is obtained.

"In the spring of 1949 I began to build a trial telescope, a miniature model for immense telescopes. Its spherical mirror is composed of seven individual mirrors of 12½-inch diameter and 1⅛-inch thickness. Their total surface corresponds to that of a single mirror of 33½-inch diameter. Each one of the individual mirrors rests on three adjustable screw points above the steel framework. In the extreme top of the tube, which is made of heavy slats of wood, will be placed the spherically corrected lens of 35½-inch diameter.

"We intend to use the telescope as a simple Schmidt, or as an anastigmat with the correcting lens in the neighborhood of the focus, in such a way that it will have a wide field on a flat plate. Perhaps we can equip the telescope in addition with a flat removable secondary, inclined at 45 degrees, to perform visual observations.

"The mirrors with their support weigh 187 pounds. The skeleton construction should be capable of resisting flexures and should follow well the temperature changes by freely circulating air between the mirrors and the steel bars of the support. It is not necessary to locate the individual mirrors exactly in the same spherical surface; that is, not with 'interference' precision. To obtain near enough to point images it is sufficient that the light rays reflected by the various mirrors fall on the same point on the photographic plate with a precision of some hundredths of a millimeter since, as experience shows, the star images always measure some hundredths of a millimeter on the plate.

"In dealing with immense telescopes we need take into account only the reflecting type. To reduce the difficulties of fabrication and adjustment it will be best to make the component mirrors spherical. In such a case we shall have to provide the telescope with a correcting plate. There are other solutions if one is content with a narrow field. The fabrication of the correcting lens, even in large dimensions, does not offer any insuperable difficulties. It may be made very thin, so that flexure will cause only a minimum deviation of the light ray. Thus it should be possible to make a correcting lens of a single piece of glass, even with a diameter of 16 to 33 feet, thereby avoiding the inconveniences which arise from constructing it in separate parts.

"If the practical trials show that the principle of composite mirrors is useful, the construction of a telescope of 200 to 400 inches will become considerably easier and more economical than was the telescope at Palomar Mountain. To avoid excessively high towers, large relative apertures will be chosen, perhaps one to two or one to three. For example, with relative aperture of 1:2.5 the tube of a Schmidt telescope of 16½-foot diameter will become 82 feet long.

"When we discuss a super-giant telescope the difficulties of building the tube, mounting and dome increase with each increase of dimensions. But we can assume that supergiant telescopes will be built only for observing limited regions of the heavens; for example, the neighborhood of zenith; to compensate for this, such instruments will be built in different latitudes. The spherical mirror can then be mounted fixed in the earth. Let us suppose that an $f/2$ super-Schmidt is 66 feet in aperture. The correcting lens will be 262 feet above the earth's surface, supported by appropriate towers. At 131-foot height will be the cabin of the observer, who will move the photographic plate on a surface whose center of curvature falls at the center of the correcting plate. But the mirror, whose center of curvature is the same, may remain fixed. During the exposure a new part of the mirror will be used each time. Even if the exposures cannot be very long, perhaps a maximum of half an hour, that will be enough time, given the enormous aperture.

"The construction of a telescope of 66-foot aperture will not, then, encounter insuperable difficulties. We have only to cut out 200 mirrors of 6½-foot diameter, although it would be more economical to cut 800 of 40 inches diameter."

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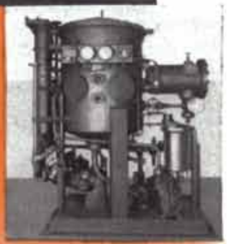

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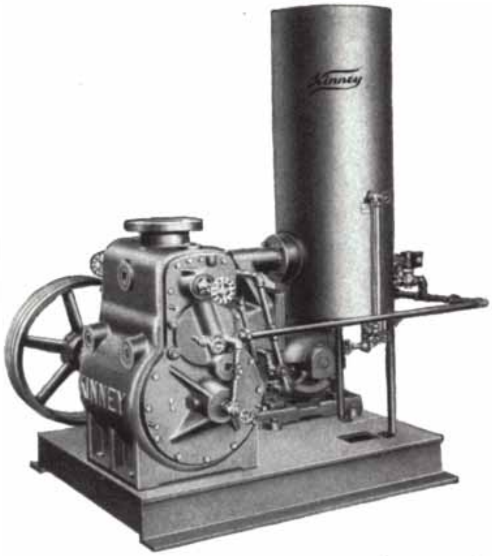


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