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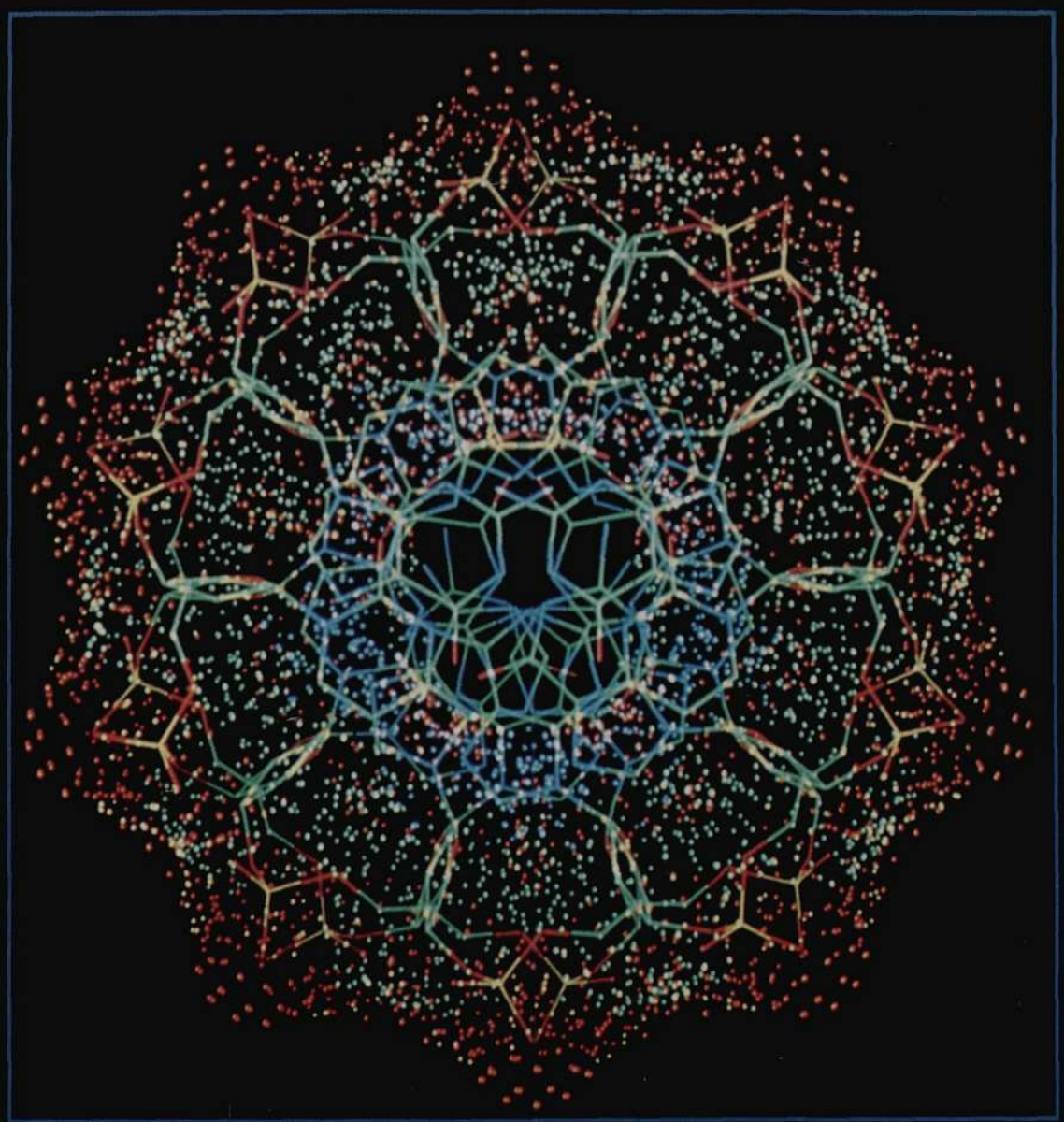

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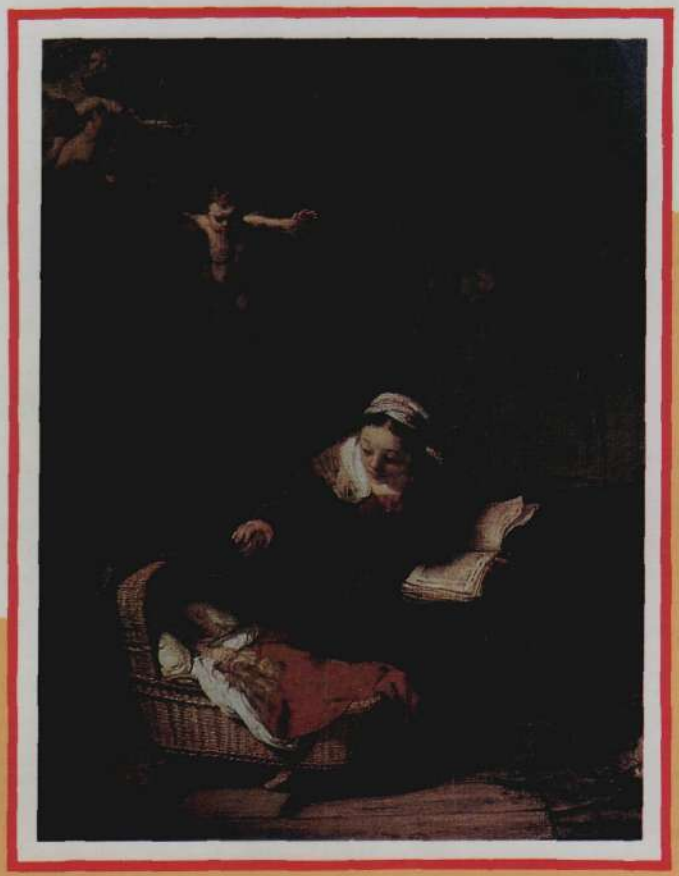

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Features

News

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Note to Libraries and Subscribers

We apologize for irregularity in our printing schedule, but we assure readers that the only pro-nuclear science magazine in the country intends to continue publishing! Because of financial difficulties, the FEF published only 4 issues of FUSION in 1983. The FEF will now regularly publish 6 issues a year, but only 4 issues in 1984, beginning with Vol. 6, No. 1, May-June 1984.

Subscribers who purchased a 10-issue subscription and those who purchased a 6-issue subscription will receive the number of issues they paid for.

Contributions to the FEF are welcome (and tax deductible).

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On the cover: Computer simulation of a DNA molecule, end-on view. The decagon shape can be visually resolved into two overlapping pentagons. For details, see page 49. Cover design by Virginia Baier; photo courtesy of Computer Graphics Laboratory, University of California, San Francisco.

The Legacy of Riemann

This issue offers the first English-language translation of Bernhard Riemann's last, and unfortunately incomplete work, "The Mechanism of the Ear," an essay written literally while he was on his deathbed.

It is painful to speculate just how far physics might have progressed beyond its present level had Riemann not died so prematurely from tuberculosis. Even today we have yet to fully mine the treasure he has left us. (It is a scandal in this regard that so little of his work is translated into English.)

While the debt owed him for the development of modern aerodynamics and fluid dynamics is freely acknowledged within the scientific community, it is perceived in a delimited way. No one would deny the essential nature of Riemann's discovery of shock waves, but the method that underlay that discovery is, to put it politely, overlooked.

Despite the obvious accretion to the body of applied science over the 120-year span since the death of Riemann, there has been an absolute decline in scientific knowledge. The average practicing scientist today is unable to comprehend points of method that were hotly debated in the 19th century.

A Question of Method

Science is in the same sorry state as music. We perform the great classical compositions of Beethoven, Mozart, and Bach, and the music of Schubert, Schumann, and Brahms, but the art of composition has atrophied. The Platonic method, which underlay the German classical revival in both the sciences and the arts in the 19th century, has been systematically attacked by the enemies of Riemann.

Hermann von Helmholtz was at the center of this attack, which was organized largely out of France and England. His attack on Riemann, however, was not any different methodologically from Aristotle's attack on Plato, or from the debate between Newton and Leibniz. Its significance for us today is only in the extent to which empiricism has now become hegemonic among scientists.

Aristotle, Newton, and Helmholtz are typical of the house servants of a feudal elite. Their job was to apply the discoveries of a Kepler or a Leibniz—or, as in Newton's case, to plagiarize these discoveries—in order to suppress the method by which they were accomplished.

Why? Because an oligarchy that wishes to maintain its political and financial control must do so by controlling culture.

Populations that are irrational are easily subdued; they will accept oppression as their predetermined fate. Therefore, the oligarchies always patronize cults, to ensure the predominance of irrationality. It is the astrological paradigm that shapes all cults, and is also the paradigm for the scientific cult popularly known as empiricism. What else is the probabilistic formulation of scientific "laws" but worship of the pagan goddess Fortuna. Albert Einstein's bitter attack upon the Copenhagen school, "God does not shoot dice," was precisely to the point.

The Challenge to Physics

Republics can survive only by fostering a scientific outlook in the broadest strata of the population. Such an outlook emphasizes the responsibility of citizens to inform their decision-making by the precepts of natural law. More important, it places upon the citizen the task of perfecting his ability so that he may know natural law.

Such knowledge is not acquired by the study of facts; it is not accumulated. Rather, it is continuously acquired in the act of learning or creative discovery—providing only that that learning is directed to the ultimate purpose of ennobling the human species. Any scientific discovery, no matter how inherently important, is useless if it cannot be communicated and applied. True science, however, does not lie within any particular discovery, but rather in the method by which the discovery was generated.

This principle of generation is the subject of Riemann's essay on the ear. It is this application of the Platonic method that Helmholtz and his associates worked all too successfully to suppress. One metric of that success is the degree to which biology is thought of as a lesser science, or at the least, as a suppliant at the table of quantum physics from which it humbly borrows its theory.

The greatest challenge to all science is to understand life. It is absurd that scientists are willing to accept theories that deny the lawfulness of their own existence. It is surely easier to accept the improbability of theories that depend on the so-called Second Law of Thermodynamics than the improbability of life itself. The currently degenerated state of science will not be reversed without sweeping away the perversions of theory that have predominated in this century.

Biology, in the sense that Riemann defines its tasks, will be one of the major tools in this process of revision. It is our hope that this issue of *Fusion* will catalyze this process.

Letters

How the Pesticide Ban Kills 100 Million People

To the Editor:

I would like to correct some editing errors that occurred in my interview "How the Environmentalist Campaign Against Pesticides Kills 100 Million People a Year" [May-June 1984, p. 12].

First, the Environmental Protection Agency's ban on DDT in 1972 was on its use in the United States, not on its export. Second, I want to make it clear that the mosquito population, not the malarial victims, develop resistance to the pesticide. Falciparum malaria, however, has already developed a resistance to the usual medications, chloroquine and primaquine. This means that these medications are practically useless against malaria in many parts of the world.

Third, the headline is indeed correct; 100 million people, indirectly or directly, are dying per year as a result of the antipesticide campaign by the environmental groups. The text of the interview incorrectly has this as 200 million.

Fourth, the substitutes for DDT are three to twenty times more expensive as DDT, not three to four. Also, one of these substitutes is carbaryl, not carborol.

I suspect that these are errors of transcription that were not caught because I was traveling in Europe and could not check the final copy for the interview.

Dr. Gordon J. Edwards
Department of Biological Sciences
San Jose State University
San Jose, Calif.

The Editor Replies

We apologize for any errors that occurred in the article.

'Vile Slanders' About Shuttle

To the Editor:

There has recently been a media flap over the allegation that NASA's Space Shuttle "Challenger" was directly involved in some anti-Soviet espionage in concert with the doomed Korean airliner of flight KAL-007 last Sept. 1. The fact that this preposterous fantasy was given the slightest credence by any supposedly responsible newsman is appalling. This seems to be yet another example of the widespread passion to rush to publish the vilest slanders as long as they are anti-American, without any evident attempt to verify factual plausibility with experts.

Merely checking with experts could easily have established the fact that the claims were physically impossible: The Shuttle's orbit of 300 kilometers altitude, inclined 28 degrees to the equator, put it over the curvature of the Earth with regard to all locations involved in the airliner atrocity. No radio signals could possibly have been exchanged, a limitation set not by policy or practice but by natural law.

Yet, many leading news media sources merely mentioned "official denials" without reference to the absolute physical impossibility of the scenario. Some nitwit at NBC-TV news in New York even created a graphic illustration of the claim showing the Space Shuttle hovering over Alaska as the airliner relayed radio spy data.

Closer examination of the actual Shuttle mission STS-8, provides more details for a damning refutation. At the time the airliner was destroyed, "Challenger" was over central Africa and the astronauts were asleep. On earlier passes across the Pacific, the spacecraft was never closer than 3,800 kilometers to the doomed plane—almost twice the effective radio range.

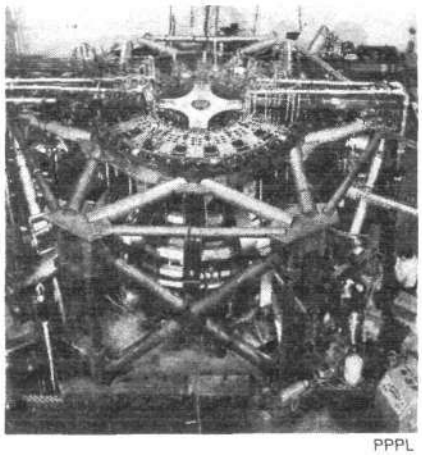
Published claims that an earlier scenario of aircraft/satellite coordination in 1964 set the precedent for last year's exercise are also not based on reality. The satellite which "P.Q. Mann" [P.Q. Mann was the byline of an article published in the British magazine *Defense Attaché* and cited by the Soviet news agency Tass claiming that the Space Shuttle was coordinating a spy mission with KAL-007] designated an electronic "ferret" was nothing of the sort: It was one of the "P-35" series of military meteorological observers that later evolved into the still-existent DMSP (Defense Meteorological Support Program) series.

This would have been obvious to an expert, since the 1964 satellite was in a retrograde polar orbit of the type called "sun-synchronous"—a trajectory utilized almost exclusively for optical observation satellites. This kind of orbit automatically places the satellite over the same locations at the same clock times, a characteristic that "P.Q. Mann" found—in his obvious ignorance—to be "too coincidental." Electronic eavesdropping satellites (so-called ferrets) of that era followed distinctly different orbital paths: The Air Force version had an inclination of 82 degrees and the naval version 70 degrees. All these facts would have been almost instantly available to anyone consulting with any expert, for example, at the Congressional Research Service of the Library of Congress. But despite the widespread media attention to this claim, not a single newsman to my knowledge has published these facts. . . .

In my judgment, anyone—newsman, researcher, or citizen—who believed for a moment that America's Space Shuttle could be deliberately involved in any activity risking innocent lives must be sick in the head or the heart. The story was *a priori* absurd and viciously insulting. . . .

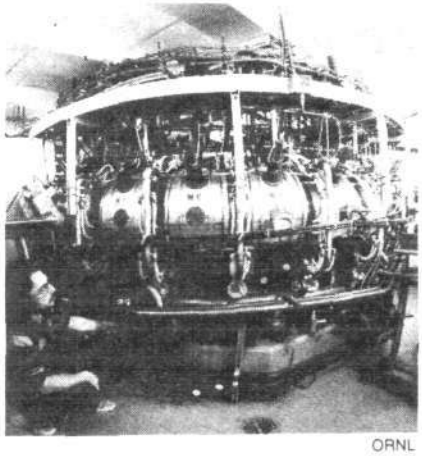
James E. Oberg
Dickinson, Tex.

News Briefs



PPPL

The PLT tokamak (above) and the Elmo Bumpy Torus: Condemned to an early death by the administration and Congress.



ORNL

FUSION BUDGET CUTS COULD SHUT DOWN LEADING U.S. EXPERIMENTS

Program administrators in the Department of Energy are considering shutting down some of the most productive fusion experiments in operation and delaying future projects in response to massive cuts by Congress in the fiscal year 1985 magnetic fusion energy budget. A House and Senate compromise sets the fusion budget at $437 million, which is $46 million below the administration's request to Congress, and $33 million less than the current fiscal year 1984 budget level.

To absorb this drastic cut, the DOE says it will have to shut down a number of existing experimental devices, possibly including the Princeton Large Torus, which still holds the world record of more than 88 million degrees for plasma temperature; the high-density Alcator at the Massachusetts Institute of Technology; and the Elmo Bumpy Torus at Oak Ridge National Laboratory. The DOE also plans to postpone until 1988 the demonstration of energy breakeven in the Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory, which was to be the first machine in the world to reach the breakeven milestone. It is also likely that the Mirror Fusion Test Facility at Lawrence Livermore National Laboratory will be delayed about one year and that across-the-board cuts will be implemented in technology research programs.

FEF executive director Paul Gallagher called on the hundreds of thousands of FEF members and *Fusion* readers to mobilize nationally to let their congressmen and senators know that shutting down—or even slowing down—the U.S. fusion program is unacceptable. "We mobilized in 1980 to get fusion on an accelerated timetable, and we succeeded. This country could have fusion in 10 years, or 20 years, or 100 years, depending on the funding. At stake here is the same question posed by the de facto 'phase-out' of the U.S. nuclear program: Is the United States going to be an industrial leader or a formerly industrialized nation?"

ABRAHAMSON: SOVIETS AHEAD IN ABM DEFENSE; U.S. MAKING PROGRESS

The Soviet Union will probably develop advanced antiballistic missile defense capabilities before the United States does, said Lt. Gen. James Abrahamson, head of the President's Strategic Defense Initiative. "In view of the fact that the Soviets have been working on the appropriate technologies since the 1960s, and, in fact, lead the United States in some of these technologies," Abrahamson said, "it is unlikely that we would have an opportunity to deploy an effective defense system unilaterally, even if we wished to do so. What we must strive for is a mutual U.S. and Soviet deployment. What we must avoid is a unilateral Soviet deployment."

As for the possibility of eventually sharing strategic defense technologies with the Soviets, Abrahamson said he thought that was a plan "worth thinking about." "A great deal more needs to be known about the Soviet program and the nature of their intentions with respect to the technology they are developing" before such a plan is put into action, he said. "The United States has twice proposed substantive discussions with the Soviet Union. . . . We have received no reply to our proposals."

In a report to Republican congressmen Aug. 9, Abrahamson also told them that at least four major technology programs in beam defense were currently producing successful results and being scaled up to the required characteristics for ABM defense. "Even my optimism has been exceeded by some of the progress I have seen," Abrahamson said.

LEADING SCIENTISTS CHALLENGE OPPONENTS OF BEAM DEFENSE

Three leading U.S. scientists have challenged the opponents of President Reagan's beam weapon defense program, proclaiming in an open letter that "no fundamental scientific or technical obstacles stand in the way of achieving the President's objectives." The three are Dr. Robert Jastrow, founder and former director of the Goddard Institute for Space Studies; Dr. Frederick Seitz, past

president of the National Academy of Sciences and president emeritus of Rockefeller University; and William A. Nierenberg, former chairman of the NASA Advisory Council and director of the Scripps Institute of Oceanography. Among the points the letter makes are their "strong disagreement with the judgments reached by a panel of the Union of Concerned Scientists and by Dr. Ashton Carter in a background paper prepared for the congressional Office of Technology Assessment."

SCHILLER INSTITUTE LAUNCHES NEW TRANS-ATLANTIC CONSPIRACY

The Schiller Institute, a new think tank whose purpose is to promote the Western Alliance, was launched on Independence Day in the spirit of von Steuben, Lafayette, and Benjamin Franklin as a new trans-Atlantic conspiracy to defeat the political heirs of George III. Initiated by Helga Zepp-LaRouche, the Institute aims to reverse the political situation in the United States that is typified by Henry Kissinger's call in *Time* magazine March 5 to decouple Europe from the United States, or by the Nunn amendment in Congress, which proposed to cut by one third the number of U.S. troops in Europe.

"The clock has moved to 1 minute before midnight," said Mrs. Zepp-LaRouche. "The Soviet Union is putting the utmost pressure on West Germany to leave the Western Alliance. All the other existing think tanks, from the Council on Foreign Relations to the Institute for Policy Studies, as well as various forces in the U.S. State Department, are pushing degrees of decoupling. . . . West Germany and Europe cannot be defended without the United States and without beam weapon defense. There is no neutralist position possible. . . . In founding the Schiller Institute, we want to prove that the forces for the Alliance are stronger than the so-called peace movement."

More than 1,000 persons, including an impressive delegation of political and military leaders from Europe, attended the founding meeting in Arlington, Va., July 3-4.

Stuart K. Lewis

Schiller Institute founder Helga Zepp-LaRouche: It's 1 minute before midnight for the Western Alliance.

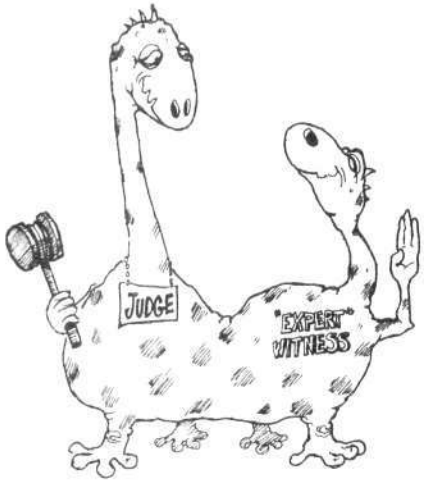
ECONOMIC DOWNTURN INCREASES DEATH RATE

The economic downturn of 1973-1974 caused an increase in the U.S. death rate of 2.3 percent and an increase of fatal heart attacks (the leading cause of death in the United States) of 2.8 percent, Dr. Harvey Brenner of Johns Hopkins University reported at congressional hearings held by the Joint Economic Committee. Brenner's study showed an increase in fatal heart attacks numbering 169,000. By correlating unemployment and fatal heart attacks, Brenner showed that fatal attacks peak one year after unemployment peaks; there is a one-year delay of the maximum stress effect.

In a parallel study on the effects of the downturn on other aspects of morbidity, Jeanne Gordus of the University of Michigan showed that during a time of recession there is an increase in the suicide rate; a decrease in nutritional status and the use of health care facilities, with increases in infant mortality and deaths among the chronically ill; and higher levels of mental illness including depression, insomnia, anxiety, marital problems, and drug and alcohol abuse.

LOUSEWORT LAURELS TO MICHIO KAKU AND JUDGE JOHN DOWLING

This month's Lousewort Laurels award is shared by nuclear physicist Michio Kaku, a New York City College professor, and Dauphin County (Pennsylvania) Judge John Dowling, who presided over the recent trial of nine antinuclear protestors who blocked the gates at Three Mile Island in May 1983. Kaku, a popular antinuclear speaker on the college lecture circuit, testified on behalf of the protestors: "We came within a half an hour to an hour of the actual initiation of the melting of the reactor itself." Judge Dowling echoed Kaku: "Regardless of your verdict," he instructed the jury, "the defendants in a sense cannot lose their case. It was their purpose to bring to the public's attention the awesome dangers inherent in restarting TMI, and they have certainly accomplished this." Despite these awesome antinuclear antics, the jury convicted all nine protestors.



CO_2 Greenhouse Effect: The Big Scare

by Dr. Sherwood B. Idso

Sherwood B. Idso is a research physicist with the U.S. Department of Agriculture's Agricultural Research Service at the U.S. Water Conservation Laboratory in Phoenix, Ariz., as well as an adjunct professor in the departments of geology, geography, botany, and microbiology at Arizona State University.

* * *

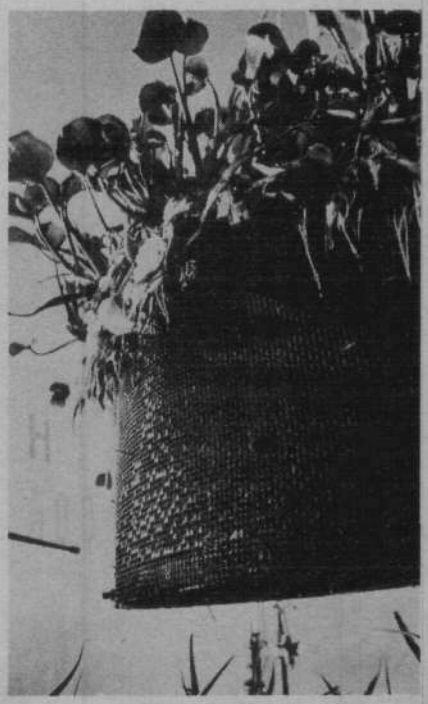
An unprecedented global heat wave. Melting polar ice caps. Rising sea levels. Withered water supplies. Uncertain agricultural productivity. These are but a few of the calamities said in a recent report of the U.S. National Research Council (NRC) to be looming on the horizon, as the atmospheric concentration of carbon dioxide (CO_2) continues to rise inexorably in response to mankind's gratification of its insatiable appetite for fossil fuels such as coal, gas, and oil. And, in the opinion of a recent report of the U.S. Environmental Protection Agency (EPA), there is absolutely nothing we can do about it.

Pretty scary? You bet. Edgar Allan Poe must be smiling down (or is it up?) at his modern-day imitators.

But is it true? Now there's the rub. Whereas the great master of the macabre never intended that his words be read as gospel, the NRC and EPA reports come to us with the blessings of such venerable organizations as the U.S. National Academy of Sciences, whose good offices seem to rank close to those of Deity. At least that is the feeling one gets when confronted with the publicity hype generated by the two reports. Nevertheless, the question still remains, are the reports true?

There is no question that the atmospheric CO_2 content has been rising steadily over the past quarter-century. That much has been proven by direct measurement. Neither is there any question that it has been generally increasing ever since the inception of the Industrial Revolution, although some question still exists about the magnitude of rise.

Even the proposition that atmospheric CO_2 will continue to rise for decades and centuries to come is questioned by but few people. Indeed, there is even no controversy over the NRC report's estimate that a nominal doubling of the atmospheric concentration from 300 to 600 parts per



CO_2, PLANT GROWTH, AND WATER EFFICIENCY

One of the experiments designed by Dr. Sherwood Idso and his colleagues to study effects of atmospheric CO_2 enrichment on plant growth and water use efficiency over a wide range of conditions. A fork lift with a boom attachment lifts a wire-mesh cage full of water hyacinth plants from a sunken evaporation tank in an open-top, polyethylene-sided chamber continuously enriched to a $C0_2$ concentration of approximately 500 parts per million (ppm). The operation is designed to determine the plants' weekly weight gain. Other chambers are enriched to 650 ppm and 900 ppm, and there is also an ambient control chamber.

million (ppm) will most likely occur by the year 2065. So what's all the fuss about?

To answer this question, an elite cadre of the atmospheric sciences community has turned to complex numerical models of how the atmosphere is believed by them to function. Requiring high-speed computers to obtain solutions to their many sets of simultaneous equations, these models predict that the most likely consequence of a 300 to 600 ppm doubling of the atmospheric CO_2 concentration will be a 0.3 ± 1.5°C. rise in mean global air temperature. The models additionally indicate that the warming in polar regions, particularly the north polar region, will be several times greater than the global mean. And from these two major conclusions flow all of the subsequent calamities mentioned at the beginning of this article.

Numerical Models Versus Reality

A bothersome fact, however, is that the real world does not appear to behave as the models predict. For instance, from data and equations in the NRC report, it can be calculated that over the 100-year period from 1880 to 1980, the mean surface air temperature of the northern third of the globe should have increased by about 3.0°C. However, actual temperature data for this time period and region, also in the NRC report, indicate a warming of only 0.3°C. This result, as well as those of several other "natural experiments" conducted by myself and others, implies that the Earth's surface air temperature sensitivity is a full order of magnitude less than that suggested by the models.[1]

An even greater discrepancy is uncovered when the last four decades of this 100-year span are considered. During this period of most rapid increase in atmospheric CO_2 concentration, the temperature trend of the northern third of the globe was actually downward—and downward at the dramatic rate of more than a tenth of a degree Celsius per decade.[2]

Not only have temperatures dropped; snowfall has increased as well. Indeed, a recent satellite study has shown that between 1966 and 1980 there was a net increase in the areal extent of Northern Hemispheric seasonal snow cover amounting to 3,000,000 square kilometers, with the increase in snow cover being accompanied by a trend toward earlier accumulation in the fall and later ablation in the spring.[3]

Of course, all of this is in contrast to the computer model predictions that "snowmelt arrives earlier and snowfall begins later with increasing CO_2." But it is in striking harmony with a singularly unique model study that neglected the conventional greenhouse effect of CO_2 and looked at the consequences of the supposedly weaker interaction of CO_2 with solar radiation.[4]

In that case, the predictions matched reality. Enhanced concentrations of atmospheric CO_2 were found to "delay the recrystallization of snow and dissipation of pack-ice and result in a cooling rather than a warming effect" and to "contribute to an extension of snow and ice seasons . . . marked by delayed snowmelt in spring, and early snow deposition in autumn."

Scientific Heresy

But that suggests that CO_2 is an *inverse* greenhouse gas, which is tantamount to scientific heresy. Perhaps. But let it be remembered that many heretics of yesteryear are the acknowledged fathers of many of today's respected fields of research. Moreover, evidence is rapidly accumulating to indicate that the proponents of this radically new view of CO_2 may ultimately be so immortalized as well.

One compelling piece of evidence comes from a recent study of the so-called continuum absorption of water vapor.[5] Previously neglected in all prior model studies of CO_2 effects on climate, inclusion of this factor reduced the size of the CO_2-induced enhancement of thermal radiation to the Earth's surface by a full order of magnitude over more than approximately 40 percent of the globe. This reduction was enough to make the CO_2-induced enhancement of thermal radiation in this broad equatorial region less significant than the CO_2-induced depletion of solar radiation, as I demonstrate in a forthcoming article in the *Journal of Climatology*.

In addition, I also indicate in that article how the Arctic haze of high northern latitudes may similarly preempt the conventional greenhouse properties of CO_2, to produce the dramatic north polar cooling of the past four decades.

Of course, none of this evidence actually *proves* the case one way or the other. But it certainly provides reason for keeping an open mind on the question—at least for the next few decades.

So what else is new? In addition to climatic consequences, the recent greenhouse reports consider a number of biological ramifications. One that is probably more of a cross between biology and physics involves streamflow. Based upon the supposition that runoff is the simple difference between precipitation and eva-

potranspiration, and the assumption that evapotranspiration is controlled solely by temperature, the NRC report concludes that streamflow rates of the major western U.S. watersheds will be reduced by some 40 to 75 percent with a doubling of the atmospheric CO_2 content.

Fortunately, this analysis fails to account for the proven effects of increased CO_2 concentrations on plant stomates. In a recent review of the literature pertinent to this topic, for instance, it was found that a 300 to 600 ppm doubling of the atmospheric CO_2 concentration generally reduces plant evaporative water losses by about a third.[6] And including this effect in a model used to simulate the significance of changed stomatal resistances for steamflow, A.R. Aston of the Australian CSIRO has concluded that "we can expect streamflow to increase from 40 to 90 percent as a consequence of doubling the atmospheric CO_2 concentration."[7]

Thus, once again, conventional wisdom, particularly as expressed in the NRC and EPA greenhouse reports, appears to be rebuffed by experimental data from the real world.

Agriculture: Fantastic Benefits

In the area of agriculture the two reports appear more conservative, even exuding a mild optimism, as they conclude that the incremental yield increases of the recent past will probably continue into the future. However, this is the one area where the effects of CO_2 *are* well known, and simple extrapolations—and not speculations, as in the reports' treatments of climate—provide a clear picture of *fantastic* benefits for the entire world.

To begin with, CO_2 is one of the prime raw materials consumed in the photosynthetic process, and well over a century of documented scientific research has demonstrated that when atmospheric CO_2 is increased, so also is photosynthesis increased.

Indeed, B.A. Kimball has recently reviewed the literature on this topic and analyzed results of literally hundreds of observations of this phenomenon, concluding that a doubling of the CO_2 content of the atmosphere will in all likelihood lead to a 33 percent increase in global agricultural production, and that a tripling of the atmospheric CO_2 content will boost it by 67 percent.[8] Consequently, it is not unreasonable to believe that the quadrupling or six-fold increase in atmospheric CO_2 foreseen in the NRC and EPA reports could well *double* crop yields the world over.

Concomitant with this yield increase is the reduction in plant evaporative water loss mentioned in connection with streamflow. When the two factors are combined to create a water use efficiency parameter, defined as the yield produced per unit of water used, it is found that plant water use efficiency doubles for a mere doubling of the atmospheric CO_2 content. And a recent report by H.H. Rogers *et al.* indicates that this increase in plant water use efficiency is a linear function extending to at least a quadrupling of the atmospheric CO_2 concentration, for both C_3 and C_4 crops and even trees.[9]

As a result, the amount of water needed to produce the doubled yield foreseen above should drop to a small fraction of what is currently needed to produce but half as much food.

Not only will these changes in plant water use efficiency benefit existing agriculture; they will also allow the bringing into profitable production of great tracts of arid and semiarid lands presently not suitable for cultivation. In addition, the unmanaged biosphere will benefit as well; for natural plant communities should be able to greatly extend their ranges, pushing into areas where they are currently not able to survive and successfully reproduce because of a lack of water. Indeed, the desert should "blossom as the rose" (Isaiah 35:1) and the face of the whole terrestrial landscape be dramatically transformed.

Nothing could be better for the planet.

Notes

1. *Boundary-Layer Meteorology*, Vol. 22 (1982), p. 227.
2. *Journal of Environmental Quality*, Vol. 12 (1983), p. 159.
3. *Bulletin of the American Meteorological Society*, Vol. 63 (1982), p. 1132.
4. *Nature*, Vol. 280 (1979), p. 668.
5. *Journal of the Atmospheric Sciences*, Vol. 39 (1982), p. 2,923.
6. *Agricultural Water Management*, Vol. 7 (1983), p. 55.
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8. *Agronomy Journal*, Vol. 75 (1983), p. 779.
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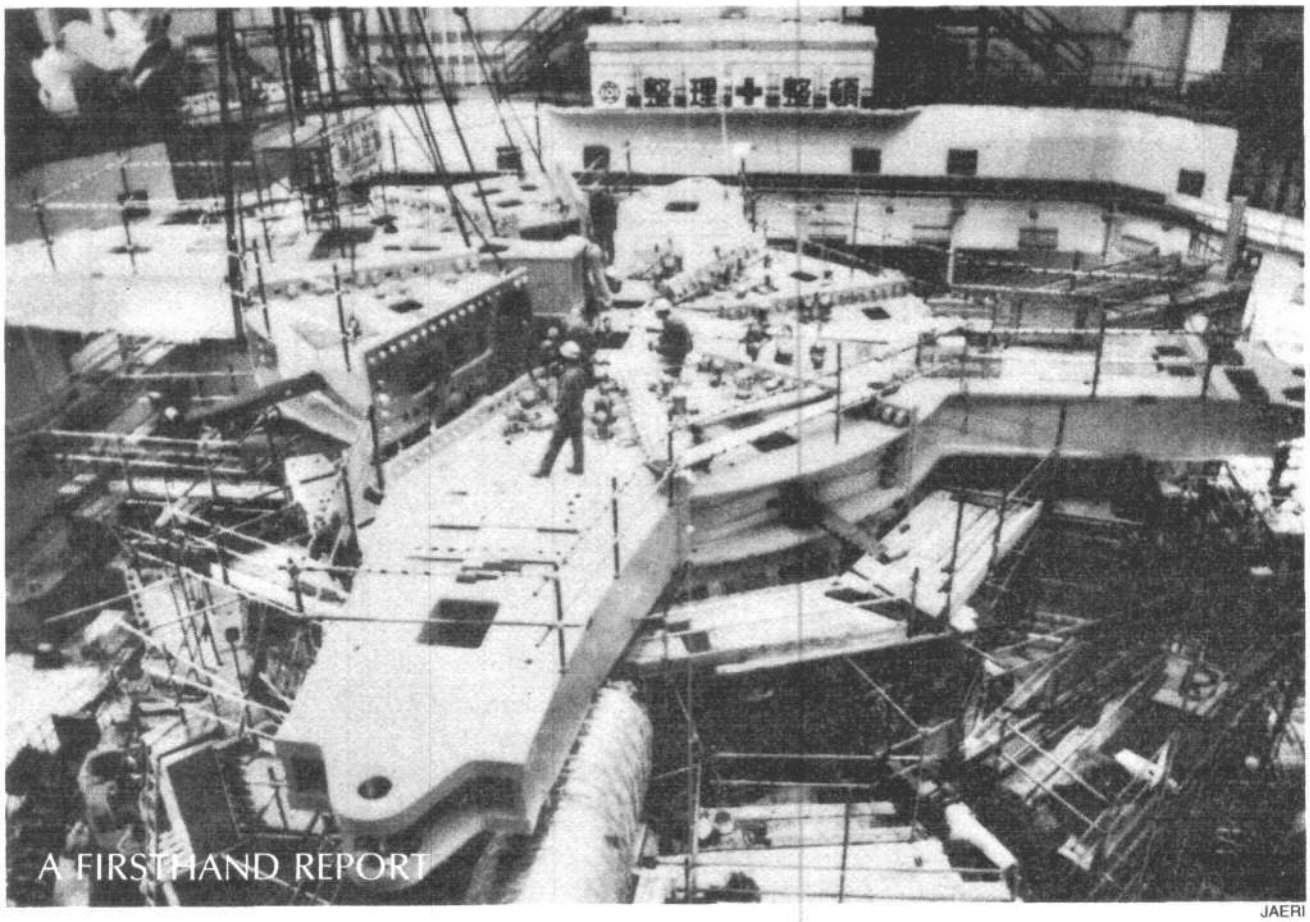


JAERI

JT-60: Japan's Frontline Fusion Effort

In February 1984, the editor of Fusion Asia *magazine, Ramtanu Maitra, visited several Japanese fusion facilities and met with leading fusion scientists. This article is adapted from a special report Maitra wrote on the Japanese fusion program, which appears in the July issue of* Fusion Asia.

* * *

The construction of Japan's most advanced fusion test reactor, the JT-60, is now nearing completion at Tokai, about 120 miles north of Tokyo, and should be ready for experiments in September. The Tokai Research Establishment, where Japan's first nuclear power reactor was built, is the hub of the R&D fusion program run by the Japan Atomic Energy Research Institute, or JAERI.

Above, the huge platform, the so-called diagnostic bridge, being lowered into place in February.

JT-60 is the most expensive Japanese test device and the most promising machine in terms of attaining energy breakeven—generating as much or more energy than that required to fire the fusion reactor. With completion scheduled for 1985, the JT-60 will join the ranks of the world's major experimental tokamaks—the Joint European Torus, JET, at Culham, England; the Tokamak Fusion Test Reactor, TFTR, at Princeton, N.J.; and the T-15 in the Soviet Union.

JAERI's fusion program is Japan's largest single research effort and accounts for 75 percent of the total national fusion R&D budget. The tokamak program began with the installation of the first JAERI tokamak, the JFT-2, in 1972. The device was used to carry out basic plasma physics experiments and some diagnostics work. But as early as 1970, Japanese fusion scientists had planned to scale up their research to approach the machine size needed to reach energy breakeven.

In 1978, JAERI undertook a program of collaborative work in a bilateral agreement with the United States on the Doublet III experiment at General Atomic in San Diego to gain first-hand experience with a medium-size tokamak (the Doublet III has a radius of nearly 1.5 meters). This experience encouraged Japanese scientists to rec-

ommend going ahead with the large-scale Japanese device.

On Schedule

Dr. Ken Tomabechi, director of JAERI's Department of Large Tokamak Development and the man in charge of the JT-60 effort, and Dr. Iijima, general manager of the JT-60 program office, showed us around the JT-60 complex west of Tokai and reviewed the site plan.

Tomabechi said that the fusion reactor will be ready for experiments in September, and he confirmed that everything is on schedule to meet that deadline. By April 1985, plasma testing will be started, and after that, the Tokai Research Institute will formally hand over the project to JAERI for operation. By the end of July 1986, most of the heating devices will be completely installed, and deuterium heating is scheduled to begin soon after.

The truly remarkable fact about the JT-60 is the speed with which the entire project has been built. Fabrication of the JT-60 machine components and accessories began in 1978, and the construction of the reactor housing was started a year later in 1979. Both were completed by spring 1983.

In the 12 months since then, the entire JT-60—with two neutral beam injection systems and their power supply, the radio frequency heating system, and myriad diagnostic devices—has been fully assembled and aligned. It was an effort that involved a large workforce, working three shifts around the clock, and is a testimony to the efficient integration of industry and science in Japan. While we were there, the workforce consisted of 700 workers—200 JAERI staff members and 500 from industry. When completed, the JT-60 will be manned by about 400 JAERI employees.

The JT-60 Parameters

Tomabechi, Iijima, and other project officials described the JT-60 in detail. The machine, which is awesome in magnitude, contains more than 100

Kiyoshi Yazawa

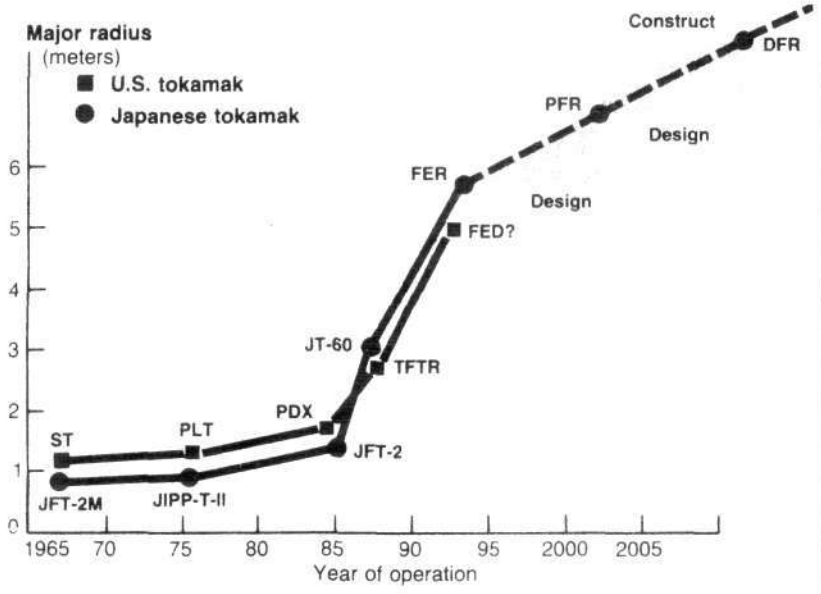
JT-60 Director Dr. Ken Tomabechi discussing the scope of the tokamak project.

diagnostic apertures both below and above the torus. The building housing the tokamak is about 120 feet high (the equivalent of an 11-story building); with only a ground floor and a roof, it gives the impression of a mammoth hangar.

At the roof level is a huge traveling crane, which has been used to erect the vessel and equipment. While we were there, the crane was being used to lift and place on top of the machine a huge platform—the so-called diagnostic bridge—providing access for diagnostic work (see photo).

The vacuum vessel, where the fusion reaction will take place, is egg-shaped and consists of eight rigid sectional rings and eight parallel bellows made of Iconel 625 alloy. The cross section of the vessel, known as the torus, has been made egg-shaped to house the three magnetic limiter coils. These coils produce a figure-eight-shaped separatrix field line that reduces the direct interactions of the plasma with the vacuum vessel walls and thus limits the impurities in the plasma. The vessel also has inner molybdenum limiters and liners.

The massive toroidal field coils, 18 of them in all, and the poloidal field coils, 5 in all, are made of copper and surround the vessel on the toroidal and poloidal axes. The toroidal field coils are placed at regular intervals to produce a maximum toroidal magnetic field of 4.5 teslas. This magnetic field



COMPARISON OF U.S. AND JAPANESE TOKAMAK DEVICES

When Japan's Fusion Experimental Reactor (FER) comes on line in the 1990s, Japan will surpass the United States in the tokamak fusion program, reversing the 20-year U.S. lead. As shown, Japan has firm plans to follow the FER with a Prototype Fusion Reactor (PFR) and then a Demonstration Fusion Reactor (DFR) in the early 21st century. By contrast, since the U.S. administration has failed to implement the Magnetic Fusion Energy Engineering Act of 1980, in deference to the shortsighted "cost-benefit" faction in Washington, the Fusion Engineering Device mandated in this legislation is now in doubt and a low-cost alternative is now being debated.

will help stabilize the hot plasma within the vessel and keep it away from the body of the vessel. The poloidal coils, on the other hand, will reduce current in the plasma and control the plasma position and shape.

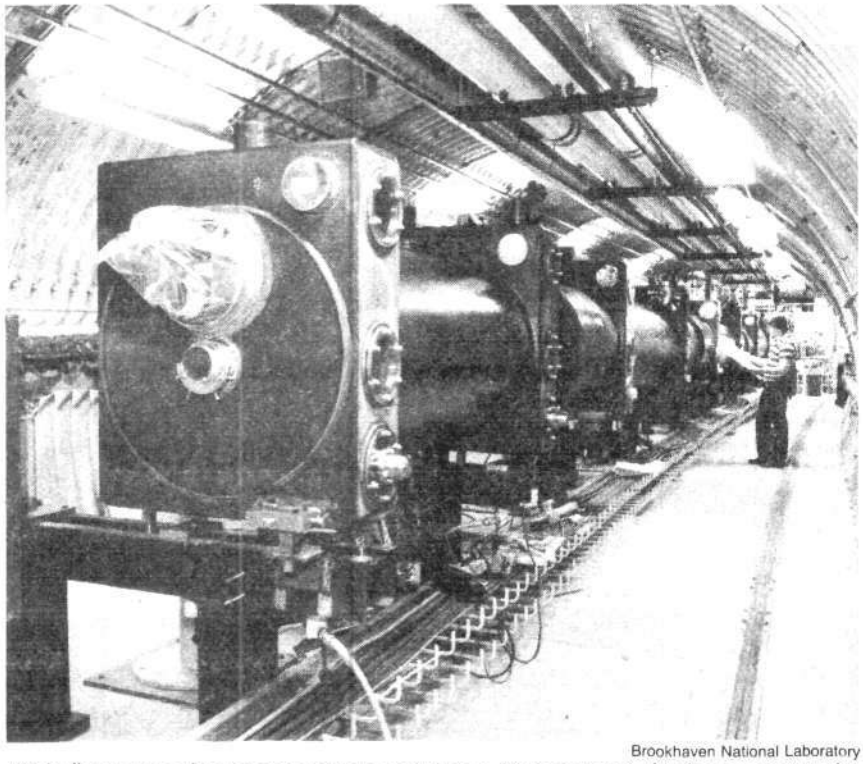
The JT-60 will use combined radio frequency and neutral beam injection heating. The neutral beam system consists of 14 beams, capable of injecting a total amount of energy into the plasma of close to 20 MW for 10 seconds, at a beam energy of 75 KeV. The radio frequency heating will require about 10 MW of heating power.

Experimental Reactor in the Wings

Knowledge gained in operating JT-60 will be applied to the next generation fusion device, whose design is already well advanced. The Fusion Experimental Reactor, or FER, as it has been named at JAERI, is expected to be operating by the turn of the century. The conceptual designs for the device have already been completed, and the working design is now in progress. The aim of FER is to demonstrate the engineering feasibilty of nuclear fusion for commercial use, specifically to fulfill the requirements of self-ignition and to sustain deuterium-tritium burning for about 100 seconds. In this sense, FER is conceived as the last step before an actual prototype fusion reactor, whose design is scheduled to begin in 1990.

JAERI participates in the various international fusion programs and collaborates on a bilateral basis with the United States and with the Soviet Union. JAERI is involved in the INTOR program, and through the International Atomic Energy Agency participates in information exchange on atomic and molecular data and a variety of expert workshops on plasma physics and fusion research.

Japan is also a participant in the Joint Experiment on Superconducting Magnets with the Compact Torus, the so-called LCT project based at Oak Ridge National Laboratory, to which it has contributed a 40-ton magnet with a maximum field strength of 8 teslas. JAERI is also contributing to the TEXTOR Project for the Interaction of the Plasma and the Vessel Wall, and in joint research and development on the Fusion Material Irradiation Test Facility.



Brookhaven National Laboratory

High-flux muon beam generation requires a high-current, high energy (multi-GeV) accelerator of the sort projected for the Fusion Materials Irradiation Test facility, which the U.S. fusion program was to have built by the late 1980s, before the program funding was cut back. The technology exists, however, and suitable accelerators will be built as part of the beam weapon program.

Shown here is a mock-up of the Isabelle accelerator at Brookhaven National Laboratory, another project that is now in limbo.

Muon-Catalyzed 'Cold' Fusion Shows Promise

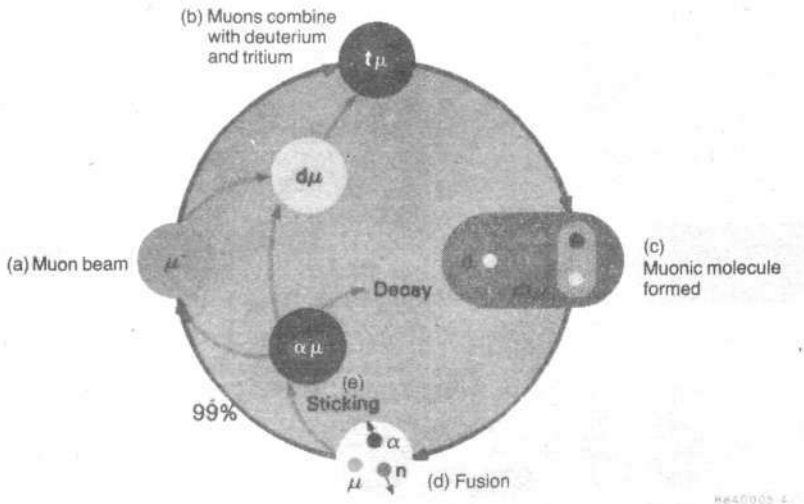
Although most fusion research is directed at achieving superhot temperatures to ignite nuclear fusion, some fusion scientists are now exploring a cold type of nuclear fusion that utilizes subnuclear muons to catalyze fusion reactions. The possibility of utilizing muons to catalyze fusion reactions in hydrogen gas at only a few hundred degrees Celsius has been known for decades. However, only recently has theoretical and experimental research at EG&G, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory opened up the prospect that this method could be used to achieve net energy production.

How Muon Fusion Works

Muons are short-lived subnuclear particles generated in high-energy particle accelerators. For example, when 10-billion-volt proton beams are collided, the protons disintegrate into streams of mesons. After a short period of time, the meson beam decays into a beam of muons. Muons also will decay eventually into electrons, but can stay around long enough to catalyze fusion reactions.

The muon is like a heavy electron. It has the same negative electric charge as the electron, but it also has several hundred times the electron mass. It is this mass differential that allows the muon to achieve catalyzed fusion.

First, a beam of muons is generated in a high-energy accelerator. This beam is then directed into hydrogen gas made up of the heavy isotopes of hydrogen—deuterium and tritium, which



MUON-CATALYZED FUSION

A negative muon beam is slowed down and then introduced into a chamber containing a mixture of deuterium and tritium gas (a). The muons collide with the atoms, and in some of these collisions the muon will knock the electron out of the atom and replace it in an orbit around the nucleus (c). When a muonized tritium atom combines with a deuterium atom to form a molecule in which the muon, along with an ordinary electron, is shared by the deuterium and tritium nucleus, the tighter orbiting muon brings the two nuclei much closer together than in an ordinary hydrogen molecule (c). In fact, the muon "shields" out the positive charge with its negative charge to such an extent that the two nuclei can overcome their electrostatic barrier and fuse (d). In this sense, the muon electrostatically catalyzes the fusion reaction.

After the fusion reaction, the muon either can be carried out of the fusion fuel by sticking to the nucleus of the helium produced by the fusion reaction (e), or can escape to go through the fusion cycle once again (a).

is the best fusion fuel. As a gas, hydrogen exists in a molecular form with two hydrogen atoms bound together; for example, deuterium-2. As the muon beam penetrates the gas, a single muon will replace one of the two electrons in the deuterium molecule. But since the muon is far heavier, its orbit around the deuterium nucleus is much tighter—closer to the nucleus.

The muonized deuterium molecule is much smaller than the ordinary hydrogen molecule because of the muon's tighter orbit. This muonized molecule is able to easily penetrate a tritium molecule. Once this happens, the tritium and deuterium nuclei will be brought quite close to one another by the tight orbit of the muon. (In a molecule some electrons—the muon in this case—orbit both nuclei.)

The main objective of high-temperature, thermonuclear fusion is to utilize high relative velocities of nuclei so that they can overcome their mutual electric replusion and be brought into close proximity to one another, at which point they undergo nuclear fusion. The tight orbit of the muon achieves this at cold temperatures. Another way of looking at muon-catalyzed fusion is that the tight orbit of the negatively charged muon shields out the positive charges of the two nuclei. The electric charge is sufficiently balanced to permit the two nuclei to come in close proximity.

Practical Dynamics

While it has been demonstrated for decades that muons can catalyze fusion reactions, the practical question is whether enough fusion energy can be generated to pay back the energy invested in generating the muons with the particle accelerator. The muon fusion energy output depends on the rate at which the muons catalyze reactions and the rate at which the muons decay or are somehow lost to the reacting fuel. Previous estimates based on theoretical and experimental results projected that, at best, five times more energy would be used up in generating muons then the energy that would be produced by the resulting fusion.

New studies indicate that these estimates were too pessimistic and that the fusion energy production can be increased by a factor of 6. This means that 20 percent more fusion energy than that invested in the accelerator can be generated by muon catalysis.

The new studies indicate that both the rate of muon catalysis and the efficiency of utilization of muons are much better than previously thought. For example, it was previously projected that the fusion product nucleus—a helium nucleus formed by the fusion of the two hydrogen nuclei—would carry a significant portion of the muons out of the reacting hydrogen gas. But now the helium sticking problem has been shown to be far less of a problem.

Potential Applications

Before muon catalyzed fusion can be demonstrated on a sufficiently large scale, high-energy particle accelerators with sufficiently high powers and currents must be developed and built. Actually, the accelerators required are quite similar to those needed for both heavy ion beam inertial confinement fusion and for beam weapons. Also, this type of high-current accelerator could be utilized to breed fissile fuel for nuclear power plants.

Even with the now far more optimistic estimates for muon fusion, however, the potential net energy output falls short of what would be an economical energy system: The projected net energy output is only marginal. Yet, if the muon-generating accelerator is also used to breed fissile fuel, the combined outputs would be economically viable.

Far more important, though, are the fundamental aspects of muon-catalyzed fusion on a large scale. This research combines high-energy nuclear physics with the most advanced aspects of atomic physics. Muon research could lead to major advances in both fields.

—Charles B. Stevens

Princeton Beta Experiment Shoots for Breakthrough

Princeton Plasma Physics Laboratory, the largest U.S. magnetic fusion research facility, has launched a new experiment that promises to greatly improve the economics of fusion power reactors based on the tokamak designs—the Princeton Beta Experiment or PBX. A $1 million modification of the existing Princeton PDX tokamak, its chief objective will be to demonstrate that tokamaks can be made more efficient in confining hot fusion fuel. Success could mean a substantial reduction in the projected costs for power reactors that are based on the tokamak magnetic confinement approach.

Plasma Beta

Plasma beta is a measurement of the efficiency of fusion fuel confinement. To obtain fusion, hydrogen gas must be stably confined with magnetic fields at temperatures above 100 million degrees Celsius. Hydrogen gas at these temperatures is ionized and becomes a plasma. When properly configured, magnetic fields can balance the gas pressure of hot plasmas that is directed outwardly with an inward force, thus confining and insulating hot fusion fuel.

The efficiency by which this confinement is accomplished is expressed by the ratio of the plasma gas pressure to the pressure of the magnetic field, usually in percentage form, with 100 percent being the most efficient use of magnetic fields for confining hot plasma. The percentage representation of the ratio is called the plasma beta.

Aiming for 10% Beta—or More

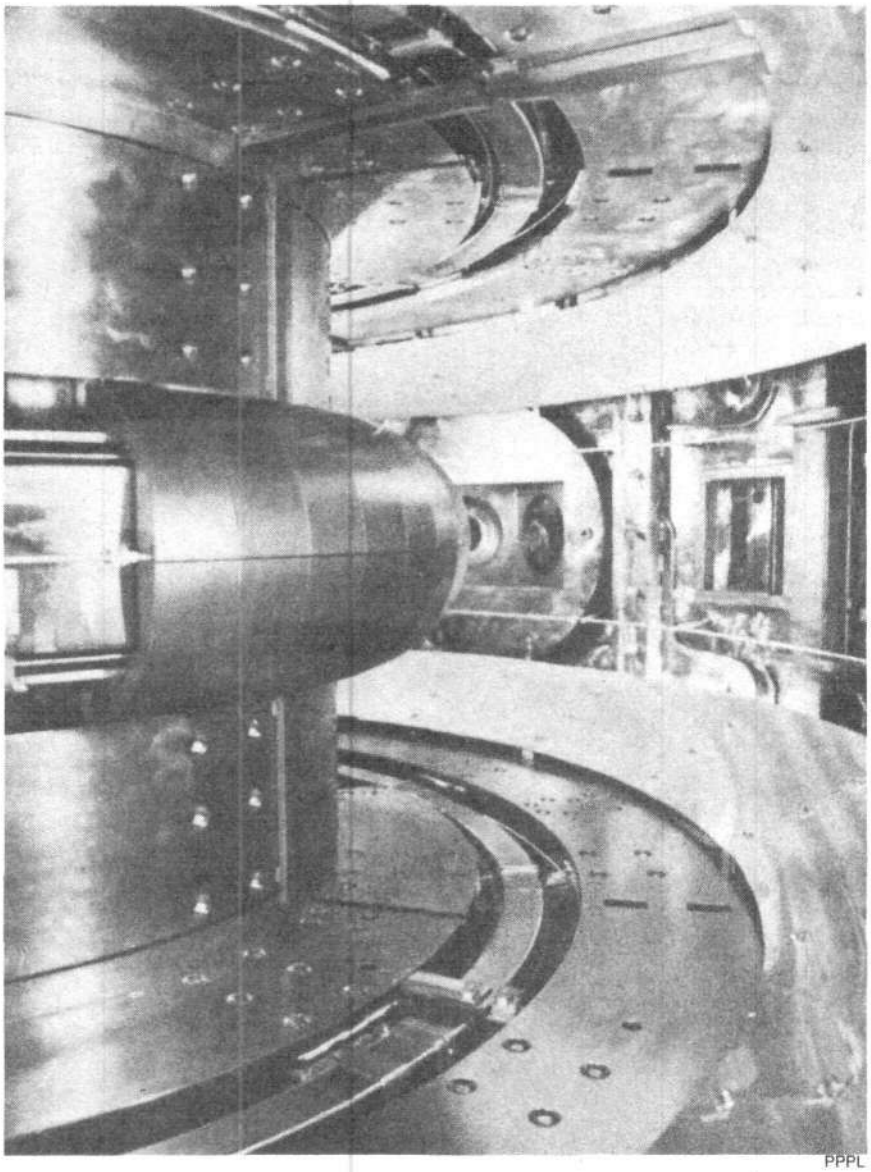
Most tokamak experiments have operated with plasma betas below 1 percent; for a fusion reactor to be economical, it is projected that plasma betas on the order of 5 percent must be attained. The Doublet III tokamak in San Diego has achieved a plasma beta of more than 4.5 percent. And there is little doubt that properly designed tokamaks can reach the required 5 percent betas needed for minimal reactor operation.

The PBX intends to demonstrate that tokamak betas can be made greater than 10 percent and possibly upwards of 20 percent.

Reactor studies have shown that tokamak magnets account for about 25 percent of the reactor cost. And the amount of magnetic field needed varies with the plasma beta by a factor of 4. Therefore, doubling the plasma beta could reduce magnet costs by as much as a factor of 16 and reactor capital costs by as much as 23 percent. High-beta operation also opens up prospects for more compact fusion reactor power plants and the utilization of higher-temperature advanced fusion fuels.

How the PBX Will Work

Hot, confined plasmas interact macroscopically with magnetic fields to generate fluidlike unstable motions called magnetohydrodynamics, or MHD motions. An analogous motion is the jumping about of an unrestrained high-pressure fire hose. If they become too large, these MHD mo-



PPPL

Interior view of the PBX vacuum vessel, with the pusher coil visible in the left foreground. The pusher coil produces an indentation at the inner side of the plasma's major radius. When a kidney-bean-shaped plasma has been formed, 7 MW of neutral beam power is injected to raise the beta.

tions take the donut-shaped tokamak plasma column into the vacuum chamber wall, where the plasma is rapidly cooled.

One such unstable MHD motion found in tokamaks is known as the ballooning mode. At betas below 5 percent, the tokamak is stable against the ballooning mode; but above 5 percent it is not. However, theoretical and experimental studies indicate that there is a second region of stability with plasma betas above 10 percent.

The tokamak achieves stability in this second region by transforming its own magnetic field geometry. The higher plasma pressure, relative to the magnetic field, still drives a ballooning-type motion in this second region, but the plasma pressure is now large enough to change the magnetic field geometry into a configuration that is stable against the ballooning modes, and these modes do not substantially increase.

The problem the PBX will attempt to solve is how to pass through the region of instability that must be traversed in order to reach the new, high-beta, stable region. PBX will try to do this by using external magnets to generate the stable configuration that the plasma itself would otherwise assume at high beta. To do this, the PBX configuration will be changed from the circle-shaped cross section of the tokamak to a cross section that has a kidney-bean shape. A special "pusher" magnet coil will be used on PBX to make the change.

The key to achieving the high-beta stable region will be to heat the plasma rapidly, and 7 MW of neutral beam heaters will be used on PBX to do this.

The PBX project is codirected by Michio Okabayashi and Kees Bol.

—Charles B. Stevens

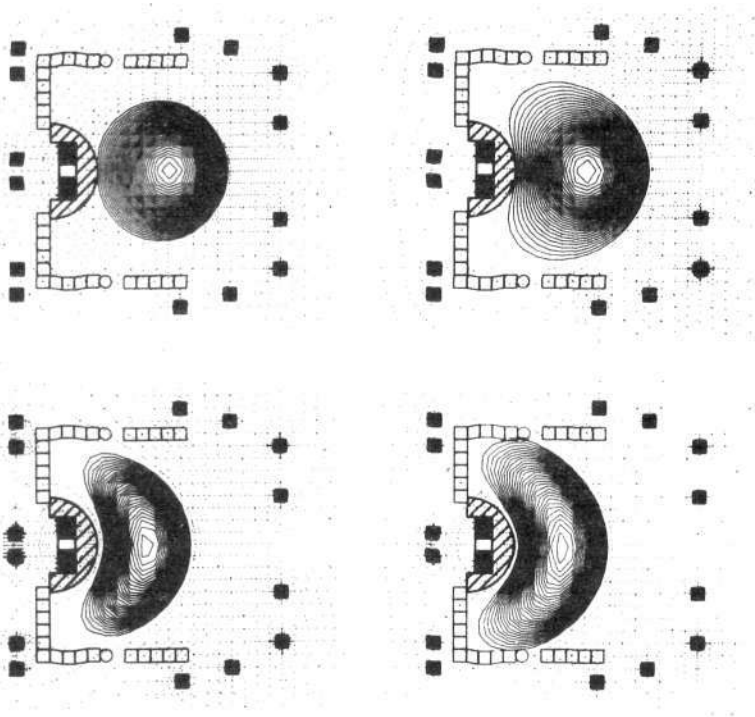


Figure 1
CREATION OF A PBX PLASMA
A circular plasma is formed within the PBX and is increasingly indented as the pusher coil produces an indentation at the inner side of the plasma's major radius.

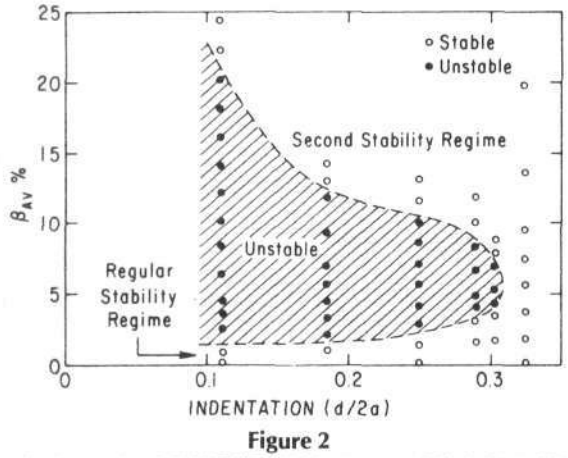


Figure 2
INCREASING INDENTATION PROTECTS AGAINST BALLOONING IN THE PLASMA
Increasing the indentation of a plasma (horizontal axis) can provide protection against ballooning mode instabilities accompanying increasing beta values (vertical axis).

TFCX: Next Step for the U.S. Fusion Program

U.S. fusion leaders met in July under the auspices of the Department of Energy's Magnetic Fusion Advisory Committee, known as MFAC, to determine which design would be best for building the next major fusion facility to operate in the 1990s.

Since the DOE has all but abandoned the mandate of the 1980 Magnetic Fusion Energy Engineering Act to develop a demonstration fusion electric power plant by the year 2000, the U.S. program has been unfortunately redirected toward planning a minimum-cost facility to permit exploration of reactor-grade fusion plasmas. Dubbed the Tokamak Fusion Core Experiment, or TFCX, the purpose of this minimum cost facility is to achieve long-pulse operation with ignited fusion plasmas in order to simulate both the physics and engineering conditions that will be encountered in actual power plants.

The designs discussed at the MFAC meeting at the Princeton Plasma Physics Laboratory ranged in cost from $992 million to $1,350 million. A much smaller, high-risk approach was presented by Dr. Bruno Coppi of the Massachusetts Institute of Technology. Called the Ignitor, this would cost about half what is proposed for the TFCX.

In a tokamak, magnetic fields trap and insulate the hot hydrogen gas so that it can be efficiently heated to fusion temperatures. The donut-shaped "magnetic bottle" of the tokamak has been experimentally demonstrated to be a stable method of containment, in which fusion fuel has been successfully heated to more than 77 million degrees Celsius.

In a tokamak fusion plasma, thermal energy diffuses and radiates out of the magnetic bottle confining the plasma. Breakeven occurs when fusion energy is generated at a faster rate than plasma energy is lost. Fusion ignition occurs when the rate at which the fusion energy is being trapped within the burning plasma exceeds the rate of plasma thermal energy loss. Since much of the fusion energy is in the form of neutrons produced by the reaction, and neutrons escape the magnetic bottle without depositing their energy in the plasma, the net fusion energy production rate must be much greater for ignition than for breakeven.

The helium nuclei are the primary source of ignition energy in tokamaks. And they, too, can escape the magnetic bottle before depositing much of their energy into the plasma, because of their high energies. The efficient trapping of the helium fusion product energy is increased by increasing the strength of the confining magnetic fields and the size of the burning plasma.

Tokamaks Versus TFCX

In tokamaks, the confining magnetic field is generated by both the plasma current and external magnetic field coils. In the TFCX designs, long pulse operation is combined with very high plasma currents. In the Ignitor proposed by Coppi, the externally generated magnetic fields are increased to the technological limit to achieve ignition conditions.

The decision on which TFCX design option will be pursued awaits the findings of the MFAC group. It would appear, however, that the use of superconducting magnets is the best option, since this particular type of design is not much more expensive than utilizing copper magnets and would provide the maximum potential for upgrading the TFCX to simulate reactor conditions. At the same time, the higher-risk Ignitor design should be pursued as a nearer-term option for the U.S. fusion program.

—Charles B. Stevens

TFTR Demonstrates Better Scaling

Although it has been virtually certain that tokamaks can attain the conditions needed for fusion energy generation since 1978, when the Princeton PLT achieved fusion temperatures, the actual performance of recent experiments is far better than previously projected.

Recent experiments on the Princeton Tokamak Fusion Test Reactor (TFTR)—announced at the July meeting of the Department of Energy Magnetic Fusion Advisory Committee—are demonstrating that energy confinement time is increasing as the cube of the major torus radius of the reactor. That is, if the tokamak device is scaled up to be two times as large, the energy confinement time will increase by a factor of 8. The initial projections were that confinement time would increase by a factor of 4, the square of the radius.

The Confinement Problem

To achieve nuclear fusion, hydrogen fuel must be heated to more than 100 million degrees Celsius and efficiently maintained at that temperature. Tokamaks use a donut-shaped magnetic field to confine and insulate hot hydrogen plasma, and the efficiency of this process is measured as the energy confinement time.

For tokamak reactors, energy confinement time must be about 1 second in order for the fusion energy process to exceed the loss of thermal energy and thus sustain a fusion reaction.

The primary objective of early magnetic fusion experiments was to demonstrate that any experimental device could be scaled up in some way to attain adequate energy confinement times. The tokamak was the first to show a sufficiently good enough scaling of energy confinement time so that projected designs of practical fusion reactors could be made.

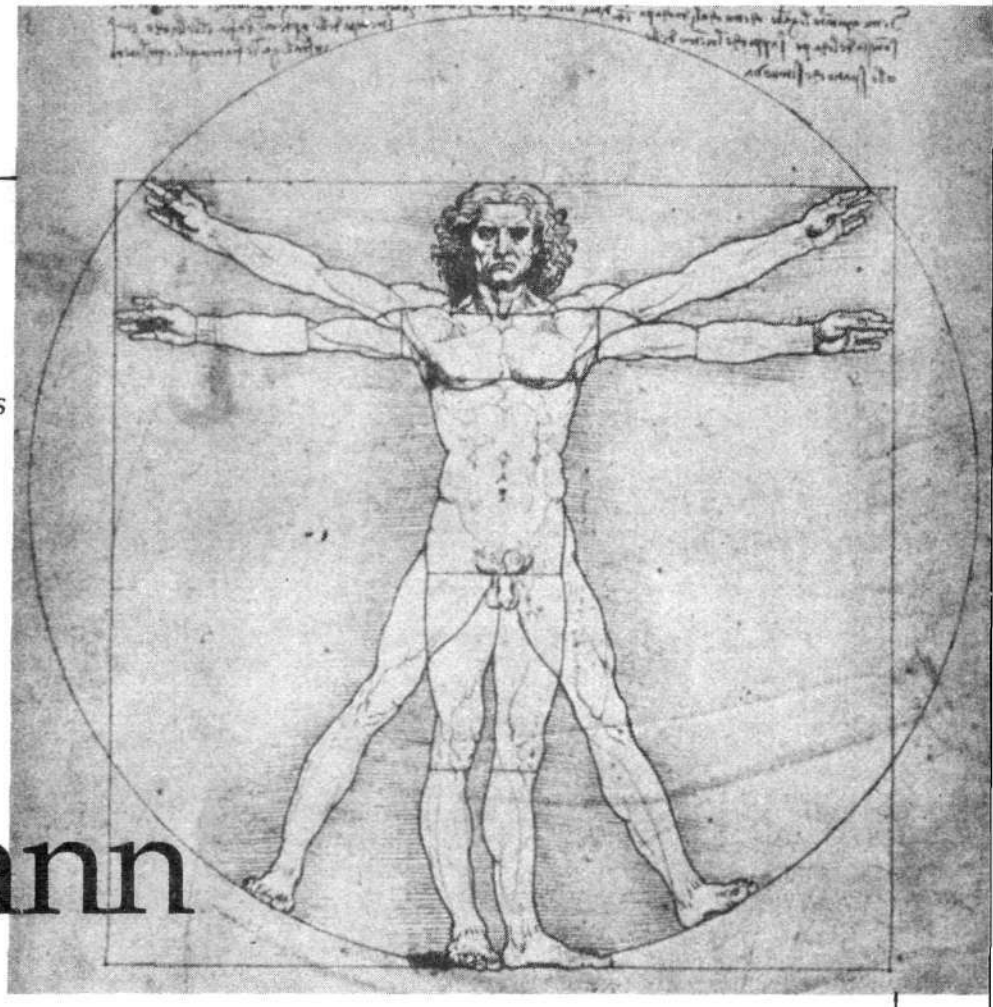
This original tokamak scaling indicated that if the tokamak donut was made twice as fat, the energy confinement time would increase by a factor of 4. This was sufficient for scaling to practical reactor sizes.

Then, in 1974, the high-magnetic-field Alcator tokamak at the Massachusetts Institute of Technology showed that energy confinement time also increased with the density of the fusion reaction.

In the past, good scaling results were

Continued on page 59

Riemann's method of the "hypothesis of the higher hypothesis" proved correct in his analysis of the mechanics of the ear—and is essential today if we are to put biological research onto the right track.



Riemann and the Science of Life

by Jonathan Tennenbaum

The remarkable progress over the last three decades in diagnostic and surgical instruments, in biotechnology and its medical applications, and in the applications of molecular biology has saved large numbers of lives and made possible a generally higher level of health for those parts of the world population to which they have been made available. At the same time that we admire this breathtaking technical progress, we cannot but be aware, in contrast, of the relative poverty of fundamental theoretical progress in the most basic questions concerning the phenomena of life and disease. Apologists of modern medical research methods may argue that the problem of cancer, for example, is just very, very complex and that is why we are still a long way from any satisfactory solution, either theoretical or in treatment. Yet, a lot of new ideas and hypotheses are needed, ideas that are not being produced because the scientific community has failed to master certain fundamental conceptual problems.

To illustrate what I mean by a fundamental conceptual problem, take the example of Watson and Crick's so-called discovery of the structure of DNA in 1953. Much has been written and said to the effect that some fundamental theoretical breakthrough was involved, that some deep mystery of life had been fathomed. Yet, on closer examination, the DNA work, like most work in molecular biology today, was purely technical and tells us nothing at all about the life process as such—at least, nothing fundamental. And how could it? The basic premise of molecular biology—namely, to apply the principles of physics from the realm of dead matter to the functioning of living organisms—systematically rules out of consideration the very characteristics that make life life. In other words, molecular biology studies the

A study of the proportions of the human body by Leonardo da Vinci, an influential member of the great Platonic school of science.

"dead" part of living processes. To say that the unraveling of the mechanical structure of DNA uncovers a secret of life is like proposing that aspiring authors dissect a typewriter in order to master the principles of poetic composition.

Like molecular biology, much of the science of our times suffers from an epistemological disease or defect known as reductionism—the attempt to reduce the study of processes, like life, to interactions between inert objects. On the contrary, all evidence, including the evidence of modern physics and biology, proves the opposite; namely, that only processes as such are elementary, and all objectlike entities are merely subsidiary aspects, singularities, of processes. In fact, such reductionism was fully analyzed and refuted by Plato more than 2000 years ago, who proposed in detail an alternative approach to the methodology of science. To clinical epistemologists, however—those who, like Plato, attempt to treat crippling errors in the method of thinking of their contemporaries—the current state of science presents a delicate problem: We must attack the absurdities of reductionism, but at the same time we must prevent the weakened patient—our scientific culture—from falling victim to another, equally dangerous affliction known as romanticism (in all its various forms—Hegelianism, Schopenhauerism, anthroposophy, and the more modern strains of aquarian kookery).

A Historical Point of Reference

Let's look at a historical point of reference for the problem at hand. By the middle of the 19th century, the great Platonic school of science—flowing from Nicholas of Cusa, through Leonardo da Vinci, Kepler, Leibniz, the Ecole Polytechnique, and Gauss—had come under heavy attack from two sides: On the one side, the axiomatic, reductionist British school was represented by Lord Kelvin and Hermann von Helmholtz, and later by Ludwig Boltzmann and the positivists; and on the other side was the romanticist Schwämerei of Schopenhauer, Hegel, Schelling, and so forth. In the middle of this fight stood the great Platonist mathematical physicist, Bernhard Riemann, whose work was crucial in maintaining the vitality of natural science through the turn of the century until today.

It is generally known that Riemann's 1854 paper, "On the Hypotheses Which Underlie Geometry," laid the foundation for Einstein's theories of special and general relativity. Somewhat less known is the fact that Riemann had developed the theory of the "retarded potential" in electromagnetism, and thereby for the electromagnetic theory of light, years before Maxwell. Riemann did this from a superior standpoint that anticipated the electron theory of Lorentz, as well as more modern developments in quantum mechanics. Of more crucial importance, however, is Riemann's epistemological approach, his insistence on absolutely rigorous method in the face of the reductionist and romanticist tendencies threatening science. An illustration of this approach is a little-known work of Riemann, his last, unfinished paper, "The Mechanism of the Ear," which touches upon some of the most delicate points of method encountered in biology and medicine.[1]

The immediate occasion for Riemann's work was the publication in 1863 of Hermann Helmholtz's treatise *On the Sensations of Tone As a Physiological Basis for the Theory of Music*. It should be recalled that Helmholtz, a follower of the famous Swiss physiologist Johannes Müller, was a leading promoter of the reductionist view (1) that biology and physiology should be based entirely on physics—that is, the physics of nonliving systems; and (2) that physics itself should be based on the assumption that all phenomena can be derived from the interaction of particles. In other words, all science should be based on the methods of Newtonian mechanics.

In his *Sensations of Tone*, Helmholtz puts forward a theory of the functioning of the ear, attempting an analysis based on the observed anatomy of the organ together with the laws of acoustics as then known. Then Helmholtz attempts to apply his theories of acoustics and the physiology of hearing to explain the principles of musical composition, harmony, and counterpoint, more or less as they had been formulated by the musical school of Jean Philippe Rameau (1683-1745).

To anyone with a rigorous grounding in the music of Bach, Mozart, and Beethoven, Helmholtz's choice of Rameau and his school as the point of reference for musical theory demonstrates that Helmholtz understood nothing about music. Rameau's theories were, in fact, denounced at the time of their publication, around 1722, by Johann Sebastian Bach and his school as incompetent and injurious.[2] It is therefore no surprise when Helmholtz arrives at the conclusion in his *Sensations of Tone* that Beethoven was an inferior composer because of his frequent modulations of key.

At the outset of his paper on the ear, Riemann comments as follows:

> Since I am frequently compelled to oppose the conclusions that Helmholtz draws from his experiments and observations, I believe I am all the more obliged here to state how much I recognize the great merits of his work on our topic. These merits, however, are in my view not to be found in his theories of the motions of the ear, but rather in his improvement upon the empirical foundations for the theory of these motions.

How, then, does Riemann's approach differ from Helmholtz's? First, Riemann does not begin with what we would call textbook knowledge—the then-accepted laws of physics and biology—and attempt to analyse the ear as a complicated system based on those laws. In other words, Riemann rejected a "systems analysis" approach. Quite the contrary, Riemann stated explicitly the results of his investigations in terms of their implications for the necessary physical properties of the components of the ear:

> . . . conclusions about the physical characteristics of the constituent parts can have universal scope, and can give rise to advances in our knowledge of the laws of

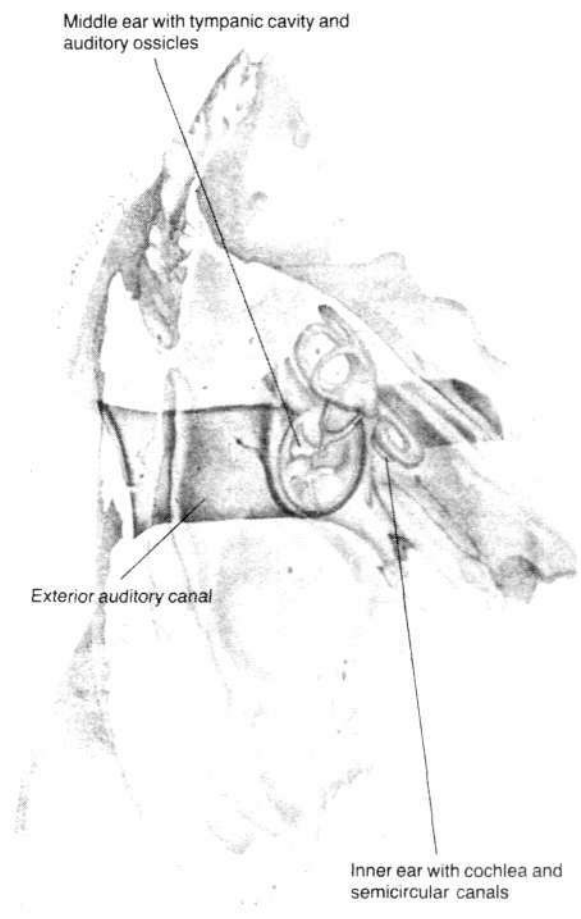


Figure 1
STRUCTURE OF THE EAR
Helmholtz applied a "systems analysis" approach to try to explain the functioning of the ear from its anatomy using textbook physical laws. In contrast, Riemann took as his starting point the extraordinary sensitivity and discrimination of human hearing, believing that its investigation would lead to the discovery of new physical laws.

nature, as was the case, for example, with Euler's efforts to account for achromatism of the eye.

Riemann is referring to a quite humorous chapter in the history of science; namely, the debate between Euler and the followers of Newton concerning the possibility of building telescope lenses that would not blur the images of the stars into little rainbows as a result of the unequal diffractions of different colors. The Newtonians claimed that such an achromatic lens was theoretically impossible on the basis of the laws of optics. Euler, on the other hand, remarked simply that because stars appeared as unblurred points to the naked eye, the human eye must be achromatic! Euler's subsequent analysis led directly to the construction of excellent, achromatic telescope lenses.

The example of Euler is directly relevant to Riemann's main methodological point. Riemann says that in order to arrive at new hypotheses concerning the functioning of the ear:

> We must, as it were, reinvent the organ, and, insofar as we consider what the organ accomplishes to be its purpose, we must also consider its creation as the means to that purpose. But this purpose is not open to speculation, but rather is given by experience, and so long as we disregard how the organ was produced, we need not bring into play the concept of final cause.
>
> In order to account for what the organ actually accomplishes, we look to its construction. In our search for this explanation, we must first of all analyze the organ's task, the problem it must solve. This will result in a series of secondary tasks or problems, and only after we have become convinced that these *must* be solved, do we then look to the organ's construction in order to infer the manner in which they are solved.

What Riemann is proposing is a rigorous method, not drawing logical conclusions from existing hypotheses, but *forming new hypotheses*. He is asserting what Plato called the "hypothesis of the higher hypothesis." In doing so, Riemann adds a critique of Isaac Newton, whose famous "hypotheses non fingo" (I don't make hypotheses) anticipated the positivists of later centuries. Riemann states:

> We *do not*—as Newton proposes—completely reject the use of analogy (the "poetry of hypothesis"), but rather afterwards emphasize the conditions that *must* be met to account for what the organ accomplishes, and discard any notions that are not essential to the explanation, but that have arisen solely through the use of analogy.

How does Riemann then proceed in his study of the ear? Citing experimental evidence, Riemann remarks on the absolutely extraordinary sensitivity of the organ, in particular on the implied capability of the small bones in the inner ear to faithfully reproduce tiny nuances of sound over a vast range of magnitudes of volume (Figure 1):

> The apparatus within the tympanic cavity (in its unspoiled condition) is a mechanical apparatus whose sensitivity is infinitely superior to everything we know about the sensitivity of mechanical apparatuses.
>
> In fact, it is by no means improbable that it faithfully transmits sonic motions that are so small that they cannot be observed with a microscope.
>
> The mechanical force of the weakest sounds detectable by the ear can, of course, hardly be estimated directly; we can show, however, by means of the law according to which the intensity of sound decreases

with its propagation in the air, that the ear does pick up sounds whose mechanical force is millions of times weaker than that of sounds of ordinary intensity.

Riemann adds a further observation; namely, that the deformation of the components of the middle ear, caused by even minute temperature changes occurring in this part of the ear, are very large compared to the mechanical accuracy required for these components to transmit weak sounds faithfully to the inner ear. He concludes that some "corrective mechanisms" must exist to compensate for these changes. In other words, the apparatus of the middle ear is no mere passive mechanical system.

Riemann died before he could finish this work, leaving behind only a small fragment of what was obviously meant to be a major work. The fragment was published after Riemann's death by the famous anatomist and researcher Jacob Henle in Henle and Pfeuffer's *Journal for Rational Medicine*, Vol. 29 (1866), to the great dismay and discomfiture of Hermann von Helmholtz.

Modern Development of Research on the Ear

Riemann's suggestion that new physical principles would be necessary to understand the functioning of the ear has been massively confirmed by subsequent research. Today we know that for the tiny hairs in the cochlea, a mere displacement on the order of several *atomic radii* is sufficient to trigger a nerve impulse to the brain! We know that the ear, like the eye and the brain, depends essentially on microscopic quantum effects, a completely different physics from the mechanics and Maxwellian electromagnetics that Helmholtz had applied. The sensitivity of eye and ear are limited essentially only by the magnitude of the least quantum of action in the Universe. Despite the breathtaking progress in experimental science and the creation of an entire new body of atomic physics, Riemann's paper remains valid today in its basic thrust, in its identification of the crucial area within which new physical hypotheses have to be made.

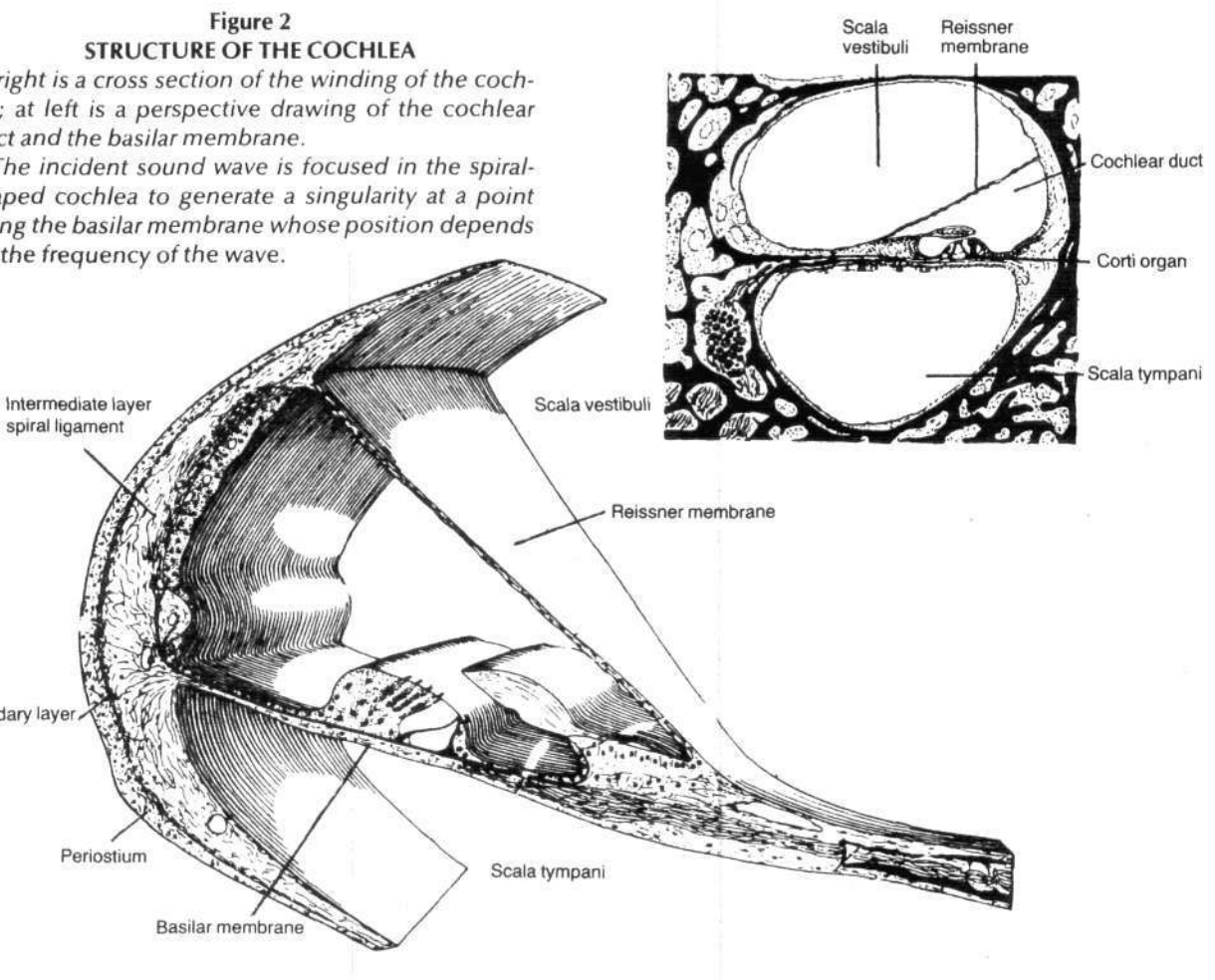
As we can see from a brief examination of the highlights of the development of research into the ear, Riemann was completely correct in his suggestion that the kind of physics employed by Helmholtz, what today is known as classical physics, would be totally unable to explain the observed functioning of the ear. In a sense, Riemann anticipated the 20th-century development of quantum physics.

The major focus of work on the ear has naturally been the inner ear, where the sound vibrations communicated

Figure 2
STRUCTURE OF THE COCHLEA

At right is a cross section of the winding of the cochlea; at left is a perspective drawing of the cochlear duct and the basilar membrane.

The incident sound wave is focused in the spiral-shaped cochlea to generate a singularity at a point along the basilar membrane whose position depends on the frequency of the wave.



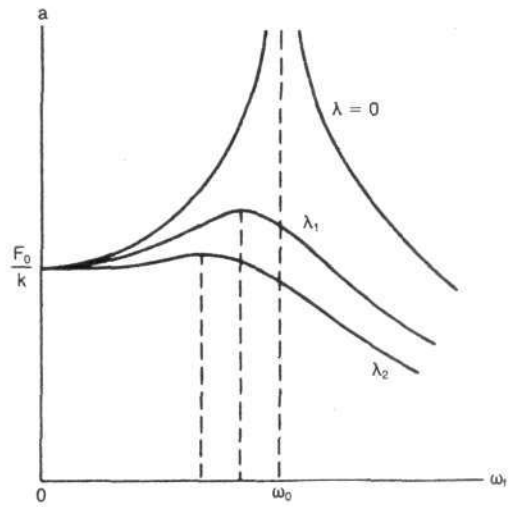


Figure 3
DAMPING OF RESONANCE VIBRATIONS
The damping of resonance vibrations for different damping factors, λ, are shown. The smaller the damping, the more pronounced is the amplitude of the resonance ($\lambda_2 > \lambda_1$). For $\lambda = 0$ the amplitude of the resonance is infinite.

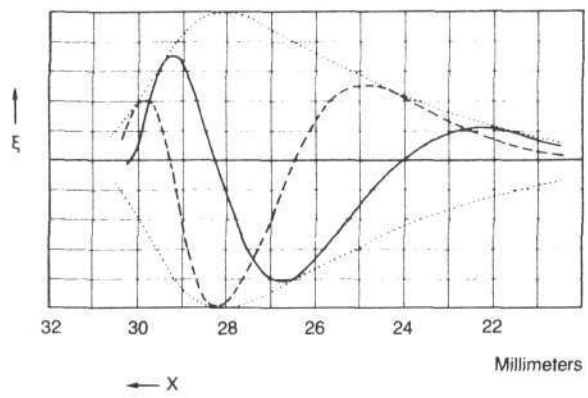


Figure 4
TRANSVERSAL TRAVELING WAVE OF THE BASILAR MEMBRANE
A traveling wave is shown here in two positions: one following the other by a quarter period. The tone has a frequency of 200 hertz. The x-axis represents distance from the oval window, considered to be toward the right.

from the eardrum by the small bones of the tympanic cavity are transformed into a pattern of electrical pulses transmitted to the brain along the auditory nerve fiber bundle. Unfortunately, the fragment left by Riemann does not include his ideas concerning the inner ear. Until the turn of the century, the hegemonic theory of the inner ear was that proposed by Helmholtz, broadly known as the resonance theory.

Helmholtz assumed that the basilar membrane, which runs the entire length of the cochlea (see Figure 2), consists of a series of loosely coupled parallel fibers, all with different resonant frequencies. The fibers near the end of the spiral chamber are longer and presumably resonate at lower tones, while the shorter fibers at the mouth of the chamber respond to higher tones.

Having reached the oval window of the inner ear, a given sound pulse was supposed to set the fibers into vibration in such a way that the amplitude for a given fiber would depend on the closeness in frequency of the exciting tone to the fundamental resonant frequency of the given fiber. The greatest amplitude of oscillation would obtain for the fiber whose natural frequency of oscillation exactly corresponded to the frequency of the stimulus. Thus, according to Helmholtz, every frequency determined a particular position on the basilar membrane at which the largest resonant amplitude occurs. It was furthermore assumed that the nerve cells on the corti organ (which runs along the length of the basilar membrane) somehow register this maximum position and transmit the information to the brain. Opinions differed as to whether or not the small hairs attached to these nerve cells also were tuned to resonate at different frequencies.

In 1905, the physicist Wilhelm Wien, who not by accident was the discoverer of the Wien displacement law that led to Planck's discovery of the universal quantum of action, raised a devastating objection to this resonance theory.[3] Like Riemann, Wien began with the actual functioning of the organ, in particular the ability of the ear to discriminate between tones differing by a mere 1 to 2 hertz (cycles per second) in frequency. Assuming the resonance theory to be true, this would imply that the individual resonators must have a very sharp resonance peak; that is, that the amplitude of the oscillation caused by an externally applied tone must drop off very rapidly as the frequency of the applied tone shifts away from the fundamental frequency of the resonating fiber (or hair).

The basic theory of resonance shows that the sharpness of the resonance curve of a linear oscillator (such as a vibrating fiber) depends on the amount of *damping* in the oscillator. An undamped oscillator has the sharpest resonance curve, while increased damping "smooths out" and broadens the curve (Figure 3). Hence, the excellent discrimination capability of the ear would imply a very low damping rate for the linear oscillators assumed responsible for that discrimination.

However, this leads to a paradox, as Wien observed. Lightly damped oscillators take a relatively long time to reach their maximum resonant amplitude and also continue oscillating for a relatively long time after the external exciting tone has ended. Low damping would tend to "blur" the perception of a rapid series of consecutive tones. In other words, a kind of "indeterminacy relation" would obtain for any "ear" based on Helmholtz's proposed resonance mechanism. In particular, Wien showed by a quantitative analysis that any Helmholtzian "ear" having the frequency discrimination capacity observed for the actual hu-

man ear, would be incapable of distinguishing the individual tones in a rapid musical trill. Since the human ear can, in fact, distinguish the sequence of notes in a trill, Wien concluded that our ear must be based on a different principle from that proposed by Helmholtz.

Later in the 1930s and 1940s, G. von Békésy found a highly nonlinear traveling wave, somewhat similar in its characteristics to surface water waves, which changes its amplitude and form as it travels down the length of the cochlea.[4] Both the basilar membrane *and* the fluid contained in the cochlea participate in this hydrodynamic wave, which attains its maximum amplitude at a certain point along the basilar membrane whose position varies according to the pitch of the input tone (Figure 4).

Until recently, however, experiments indicated that the locus of maximum amplitude was not sharp enough to account for the tonal discrimination properties of the ear. In particular, recordings of the nerve impulses coming from a single auditory cell on the corti organ indicated a very sharp response curve, a degree of "tuning" seemingly incompatible with the hypothesis that the cell merely monitors the amplitude of oscillation of the portion of basilar membrane upon which it is located. This situation changed, however, in 1982, when S.M. Khanna and D.G. Leonard at Columbia University showed that the smooth amplitude curve obtained in earlier experiments had been caused by damage to the organ during the experiments.[5] By minimizing this damage, Khanna and Leonard uncovered almost the same, sharp response curve observed in monitoring individual nerve fibers. Thus, the apparatus of the cochlea has the capability of nonlinearly "focusing" a large part of the incident action onto a very small region of the basilar membrane whose position varies as a function of the frequency. The maximum amplitude of oscillation of the basilar membrane, corresponding to hearing a tone at the sound level of ordinary conversation, is approximately equal to an atomic radius (10^{-8} cm).

The remarkable sensitivity of the ear, already emphasized by Riemann, has been precisely quantified in modern experiments. The results are extraordinary: The total energy imparted to the human eardrum by the softest audible musical tone is of the order of 10^{-11} erg. This is only about twice the energy carried by a single quantum (photon) of visible light. Another revealing comparison is the thermal energy assigned to air molecules by the Boltzmann statistical theory of heat, which works out to about 10^{-14} erg. This means that the energy of the softest audible sound wave is less than the "random" thermal energy of motion of a mere 1,000 atoms of the air that is supposed to carry the sound wave. This raises important questions about the nature of sound propagation itself.

What these tiny energies and displacements imply is that the functioning of the ear, like that of the eye and the synaptic processes of the brain, depends essentially on quantum effects—processes in which the amount of action involved is not much larger than the least quantum or smallest division of action possible in the Universe at this time. Far from behaving in the manner to be expected by the Boltzmann statistical theory of heat, the mechanism of the ear is able to coherently "focus" a tiny amount of action,

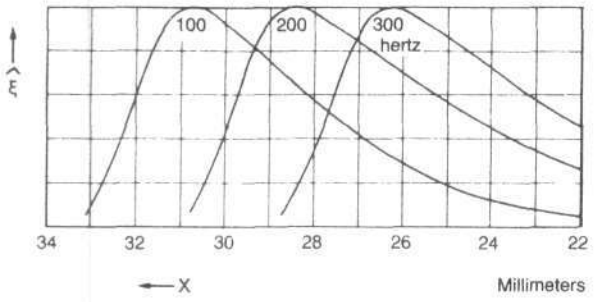


Figure 5
AMPLITUDES OF TRANSVERSAL VIBRATIONS OF THE BASILAR MEMBRANE
The place on the basilar membrane where the amplitude of the traveling wave is at its maximum shifts in accordance with the frequency of the tone presented to the ear.

embedded within a medium whose Boltzmannian "noise level" should be thousands of times larger than the signal, in such a way as to generate a perceptible singularity—a nerve pulse propagated to the brain.

Therefore, it is not surprising to find, as recent experiments have indicated, that an effect much akin to the coherent amplification of light by lasers actually takes place in the cochlea. It has been discovered, in fact, that "negative damping" occurs to the traveling wave propagating in the cochlea. That is, the wave actually draws energy from the medium and amplifies itself in the course of propagation, much like a light pulse in a laser. This effect is now thought to be responsible for the tones that the ear itself produces, which were precisely measured for the first time in the 1970s. These spontaneously emitted tones are thought to arise from "feedback oscillations" of the ear's own amplification system.

Fundamental Questions

Apart from such analogies with quantum systems like as the laser and maser, the actual physical mechanism of hearing remains largely unknown. If we adopt Riemann's methodological standpoint, rather than that of Helmholtz and systems analysis, we find reason to expect that even the physics of today will be inadequate to explain the ear's functioning. In fact, the problem of the ear, just as many other problems posed by the physics of living systems, is ideally suited to help us locate the points at which fundamental theoretical breakthroughs must be made.

If one had to sum up the fundamental weaknesses of present-day physics, one would necessarily point to the interrelated absurdities presented by the Boltzmannian statistical approach (including its projection into quantum physics by Max Born, Niels Bohr, and others) and the commonly used physical concept of work.

Take Boltzmannian statistics, in particular, the "statistical theory of gases." According to this view, for example, a sound wave is propagated by collisions of air molecules. If

a small portion of air is compressed to a higher density, then the increased frequency of collisions in that region, as opposed to neighboring regions, will cause that portion of air to expand. This expansion, in turn, compresses the neighboring regions, creating a propagating wave of alternately denser and more rarified layers of air. This all might sound plausible, except when we extrapolate the collision theory to the case of very small amplitudes such as those corresponding to the lower limit of sensitivity of the ear. Consider such a weak sound wave traveling down the outer channel of the ear toward the eardrum. According to statistical gas theory, the air molecules contained in that channel are in constant, random "thermal" motion, with a total energy of motion more than 1 million-trillion times larger than the energy of the sound wave whose propagation is supposed to be mediated by their random collisions. Why is the weak signal not dispersed and destroyed by the much larger "noise" of random fluctuations in the gas carrying the signal?

Possibly the information theorists believe they can resolve this paradox within the confines of Boltzmann's statistical theories. However, the conceptual absurdity involved—that lawful processes are merely "average effects" of a large number of essentially random elementary processes—should lead us to suspect that the statistical gas theory has turned reality upside down. Should we not rather regard a sound wave as an *electromagnetic wave of higher order* and the molecules simply as singularities, as complex electromagnetic configurations? Then, the condensation and rarification of air molecules is the result, not the cause, of sound propagation. Heat need not be equated with random collisional motion of molecules; instead, it is enough to hypothesize that the sound wave represents a qualitatively different geometric mode of organization of electromagnetic action than heat. What, then, is the function of the ear?

This question leads us to the problem of work and energy. Riemann suggests the correct concept of work in his emphasis on the functioning of the ear, meaning the *useful transformations of action* accomplished by that organ. In contrast, the formal definition of work currently employed in mathematical physics references only *motion against force*. We tend to forget that when a weight is lifted from the surface of the Earth, that action is actually a change in the ordering of the entire solar system. In other words, we are doing work against the existing ordering of the whole

LaRouche's Concept of Negentropic Potential in the Economy

Lyndon H. LaRouche has dared to say directly what others have only vaguely grasped: that economics is the basis of all science. In the case of medicine and biology, we must realize that the processes of a healthy economy provide us with the highest form of living process available on the Earth, as well as the most typical of all life processes. As against other living systems, we have the further advantage of being *inside* the process as opposed to *outside* it.

The crucial point is that no economy can continue to exist in a state of equilibrium. The mere continuation of the existing range of productive activities of an econony leads inevitably to the exhaustion of the economically utilizable raw materials and other resources defined as resources by the existing technologies. For example, without the introduction of coal, man would have deforested the Earth and in time collapsed. Without fission and fusion energy, the human population of the Earth will not be able to sustain itself, and will collapse not later than the relative exhaustion of cheap coal and oil reserves. In order to continue to exist, an economy must continually transform itself; it must continually improve its methods of material production, opening up new resources and cheapening the effective cost of exploiting existing resources. In particular, scientific and technological progress is necessary to the continued existence of an economy.

It is this quality of transformation and improvement that LaRouche defines as the unique, living quality of an economy.

Furthermore, LaRouche provides a precise definition and means of measurement for what is meant by "improvement" in terms of the notion of *relative potential population density*. This magnitude is defined as the number of persons who can be sustained by their own labor on an average square kilometer of land, using the methods of production existing in the given economy (when this number is "normalized" or corrected for variations in the relative fertility, natural wealth, and related qualities of the land). To a first approximation, improvement of an economy means increase in relative potential population density. However, instead of the word improvement, we choose the more precise physical notion of *work*. The capacity of a given economy to do work, that is, to increase its own population potential, defines the work potential of that economy. An economy is healthy when it is continually increasing its own work potential; otherwise, it is dying. And a dying economy means a dying population, in very literal terms.

From the standpoint of this concept of potential, LaRouche proceeds exactly as Riemann outlined: How must an economy be organized in order to accomplish the required continuous increase in its work potential? LaRouche arrives, for example, at the requirement that health levels and longevity of the population must be increasing: Scientific progress requires a longer educa-

solar system, thereby accomplishing a transformation of its mode of action. There is no such thing as a linear displacement of a body, in isolation from the rest of the Universe.

For the case of the ear, we must not exclude from the question of functioning the fact that the act of perception involves, at least potentially, a permanent reordering of the mind; something new is created—a singularity. Therefore, the ear must fulfill the functioning of causing the incident wave to generate a singularity, and this singularity-creation is *work*. Riemann had already uncovered the paradigm for singularity-generating processes in his 1859 paper on acoustical shock waves. There he showed that a large-amplitude acoustical wave modifies its form under propagation, up to the point of forming a singularity known as a shock front (Verdichtungs-stoß).

This singularity is characterized by a change in the mode of propagation of the wave, corresponding mathematically to a discontinuous jump in pressure across the shock front. Something of this sort must actually take place for the hydrodynamic wave in the cochlea. It is relevant to remember that in his early work on thermodynamics, Erwin Schrödinger hypothesized that the so-called elementary particles are the manifestations of shock waves. Thus, for example, we might think of the photon as the shock-wave singularity formed by a simple electromagnetic wave when constrained by some obstacle or limit to do work.

Recently, economist Lyndon H. LaRouche, Jr. and Fusion Energy Foundation staff member Ned Rosinsky, M.D., put forward a similar hypothesis concerning the functioning of DNA. Rather than thinking of the DNA as a mere passive "code" in the manner of present genetics, they suggest that the DNA molecule actually performs work.[6] The essential idea is that the double-helical geometrical form of DNA reflects a mode of organization of electromagnetic work, whereby the DNA molecule can absorb light at low frequency and reemit the energy in the form of high-frequency photons capable of triggering specific chemical reactions within the cell. A number of recent experiments on the photoactivity of large protein molecules indicated strongly that such frequency upshifting may be a general feature of biological processes at the molecular level. Since higher-frequency (smaller-wavelength) electromagnetic radiation generally represents a higher quality of energy, with respect to accomplishing physical transformations, this frequency-upshifting activity coheres with the negentropic characteristics of life processes as a whole.

It is exactly in this direction that Riemann's methodology, so successfully proven in the case of the human ear and in many problems of mathematical physics, points our attention in seeking the answers to the most fundamental problems in biology. Following Riemann, we do not begin by pulling a living system apart into its chemical components and trying to analyze their interactions on the basis of physical chemistry as presently known. Rather, we must first ask, what does the life process actually accomplish? What are its functions? What is the essential capability that characterizes life as a process uniquely, as opposed to the nonliving processes studied in ordinary physics?

Once these questions are answered, then we can look at the details of organisms, cells, DNA, and so on, not from the standpoint of what the textbooks claim to be going on, but rather in terms of what we know must be accomplished by the life process. Then, we can expect to be led to conclusions having far-reaching consequences for basic physics itself.

Jonathan Tennenbaum is the editor-in-chief of the German-language Fusion *magazine.*

and Biology

tion for more people, which means that the active life of a working person must be extended, and LaRouche develops the entire science of economy on this basis.

LaRouche's notion of work potential can be directly applied to biology. In the first approximation, we look at the biosphere as a whole, the "economy" of the Earth's life process. Instead of potential population densities, we look at the potential quantity of biomass that can sustain itself per unit area of the Earth's surface, "normalizing" for variations in the natural conditions (temperature, precipitation, soil quality, and so on) for the unit area.

How do changes in the organization of the life process—changes in metabolic paths, changes in the relationships of various populations of life forms and in their behavior, evolutionary modifications leading to new species—change the biomass potential? How does the overall life process act upon the biosphere so as to increase the biosphere's work potential? For example, the development of photosynthesis transformed the atmosphere of the Earth, opening the way for oxygen-breathing organisms with much increased population potentials.

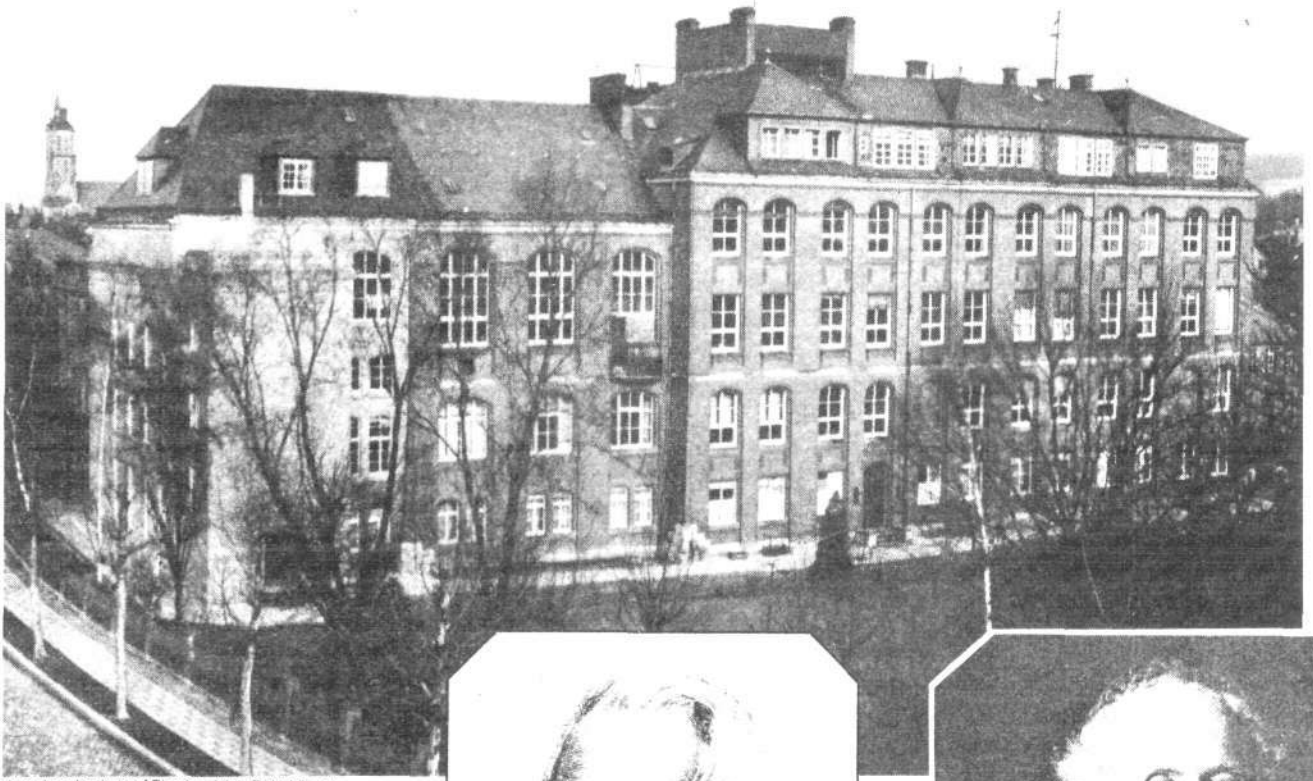
Finally, having provisionally identified the role of individual organisms in the process of improvement of the biosphere, we apply the same approach within the given organism.

Notes

1. The first English translation of Riemann's 1866 essay "The Mechanism of the Ear" appears on page 31.
2. In a letter to Bach's student Kirnberger, Karl Philip Emmanuel Bach, the son of J.S. Bach, stated: "You can declare that my father's and my methods are completely opposed to those of Rameau."
3. Wilhelm Wien, Collected Works, *Aus dem Leben und Wirken eines Physikers* (Leipzig, 1930).
4. G. von Békésy, *Experiments in Hearing* (New York: McGraw Hill, 1960) and *Journal of the Acoustical Society of America*, 21:233, 1947.
5. Shyam Khanna and Deborah Leonard, "Basilar Membrane Tuning in the Cat Cochlea," *Science*, 215 (Jan. 1982) p. 305-306.
6. This hypothesis is described in "The Geometry of Life," on page 39.

Riemann and the Göttingen

One hundred years later, Riemann's view on how the ear works and his criticism of Helmholtz have been proved correct by modern biophysics.



American Institute of Physics, Niels Bohr Library

Among Riemann's collaborators and closest friends were the leaders of the Neoplatonic school of physiology, based in Göttingen and Leipzig, including Jacob Henle and the Weber brothers. Here (from left): Henle, Wilhelm Weber, and Ernst Weber. Above: the Physics Institute at Göttingen.

School of Physiology by Robert Gallagher

Bernhard Riemann's short essay "The Mechanism of the Ear" set off a storm of angry denunciations and counter-arguments from Hermann von Helmholtz that continued for years after Riemann's death in 1866. One hundred years later, modern biophysics has left no doubt that Riemann was absolutely correct about the workings of the middle ear, and Helmholtz was wrong. Most important for science today is Riemann's method of scientific inquiry.

Riemann was fully cognizant that he had but months to live when he embarked on this investigation of the physiology of hearing, his last work. Why did the greatest mathematician of his time exert himself literally on his death bed in a study of the workings of the eardrum and the auditory ossicles of the middle ear, the mechanism that communicates sound to the inner ear? Göttingen physiologist Jacob Henle begins to answer this question in his brief introduction to Riemann's essay:

> Riemann . . . was spurred by Helmholtz's new theory of the sensations of tone to devote the last months of his life to the theory of the organ of hearing. . . . Riemann's spoken views give us grounds to suppose that the difference between the two approaches would only have first come into focus over the problem of transmission of sound waves to the organs of the cochlea, and that Riemann thought that the mathematical problem to be solved was in fact a hydraulic one.

Riemann did not choose to write on the mechanism of the inner ear, the cochlea in these last months. Apparently, he concluded that the study of the ossicles—known as the hammer, anvil, and stirrup—was more important.

These little bones had become the center of a major scientific controversy that touched nearly every one of Riemann's close associates. "The Mechanism of the Ear" became for Riemann an opportunity to provide a lesson in scientific method to his collaborators at Göttingen and elsewhere by applying the method of his 1859 "On the Propagation of Air Waves of Finite Amplitude" to hearing.[1] Today his work on the ear is relevant not only for its method, but for its specific applications, such as the development of new physical principles for submarine detection.

Riemann applied himself to the problem of the middle ear in response to an 1863 book by Hermann von Helmholtz, *On the Sensations of Tone As a Physiological Basis for the Theory of Music*, a work that rejected every universal of science established since Plato.

First, Helmholtz asserted that in hearing, man did not perceive the sound wave as a whole, as a geometric entity, but perceived only its component frequencies and their intensities. The ear, Helmholtz argued, was simply an analyzer. Every tone of recognizable pitch, he said, stimulated a specific resonator in the cochlea of the inner ear, and this action was conveyed to higher brain centers via specific nerve fibers. This was Helmholtz's "theory of specific energies": The ear, as it were, dissects the harmonics of a sound into separate tones that the brain then perceives. The ear thus "knows" only the pieces of a sound, not the sound itself, that is, its geometric form. It would not be an exaggeration to assert that Helmholtz's view was that human hearing perceives music as a Moog synthesizer produces it.

At the same time, Helmholtz maintained that every sound "is subjected to *distortion* in its passage through the middle ear" by the auditory ossicles.[2] When it enters the inner ear, he said, the sound carries tones that were not present in the sound at the eardrum—some of the harmonics and all combination tones. Helmholtz attributed this to a "clicking" and "clashing" of the cogs of the hammer-anvil joint. He maintained, therefore, that the auditory ossicles do not reliably transmit sound to the inner ear.[3] Later, in reply to Riemann's "The Mechanism of the Ear," he emphasized this:

> I must oppose his [Riemann's] statement "that it is the task of the apparatus of the middle ear to transmit to the fluid of the labyrinth the changes in atmospheric pressure at every moment of time, with perfect accuracy and constant relative strength."[4]

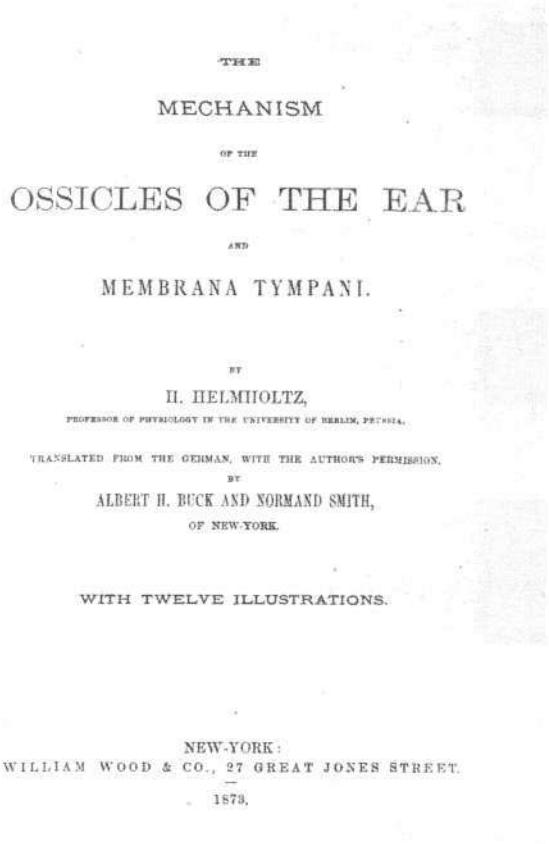
Furthermore, Helmholtz argued that the intensity of the "clicking" varied with temperature and with the air pressure inside the tympanic cavity of the middle ear so that not only did the ossicles destroy the fidelity of the sound wave, but they did so to different degrees—literally—depending on the weather.

At least in part, Helmholtz based his theory of harmony on this peculiar analysis:

> This phenomenon [the "clicking" of the ossicles] is also of great importance in its relation to the sensation which harmony produces in the ear, since strong tones which take place outside of the ear, and without overtones, must of necessity develop harmonious overtones in the ear. In this way sounds with harmonious overtones, which correspond to a regular periodical movement of the air, acquire a natural preference over those with unharmonious overtones, especially as *the whole doctrine of consonances becomes, through this circumstance, independent of the overtones connected with external sound* [emphasis added].[5]

In a letter to Riemann's friend Gustav Fechner, Helmholtz wrote:

> This [harmonic clicking of the ossicles] unmistakably gives the series of harmonic overtones a new subjective meaning. . . . *I do not believe that music would ever have been discovered if the relation of tones and overtones had always been lacking* [emphasis added].[6]



THE

MECHANISM

OF THE

OSSICLES OF THE EAR

AND

MEMBRANA TYMPANI.

BY

H. HELMHOLTZ,

PROFESSOR OF PHYSIOLOGY IN THE UNIVERSITY OF BERLIN, PRUSSIA.

TRANSLATED FROM THE GERMAN, WITH THE AUTHOR'S PERMISSION,

BY

ALBERT H. BUCK AND NORMAND SMITH,

OF NEW-YORK.

WITH TWELVE ILLUSTRATIONS.

NEW-YORK:
WILLIAM WOOD & CO., 27 GREAT JONES STREET.

1873.

Helmholtz devoted this 1869 essay, The Mechanism of the Ossicles of the Ear, *to an attempted refutation of Riemann.*

It had been known for some time that in response to two strong tones close in frequency, the ear produced tones that are not in the original sound wave, but perceived nonetheless. These additional tones generated by the ear itself are known as "combination tones," because their frequencies are some algebraic combination of the frequencies of the original two tones. For example, in response to a tone of 1,000 hertz (cycles per second), sounded with a tone of 2,800 hertz, you may hear in addition to those tones a tone of 1,800 or 3,800 hertz.

Furthermore, in response to a pure tone of a single frequency, the ear produces some harmonics for the tone that *again are not in the original sound wave, yet are perceived.* Helmholtz's motivation, however, does not seem to have been simply to explain the existence of these "anomalous" perceived tones. Rather, he had an axe to grind. He was a committed nominalist in the philosophical tradition of John Locke, Bishop Berkeley, and David Hume. Helmholtz rejected natural law, the coherence between man and the Universe, and thus aligned himself with Aristotle, Isaac Newton, and René Descartes, who denied that the Universe undergoes creation continuously. For this reason, Helmholtz denied the very existence of causality:

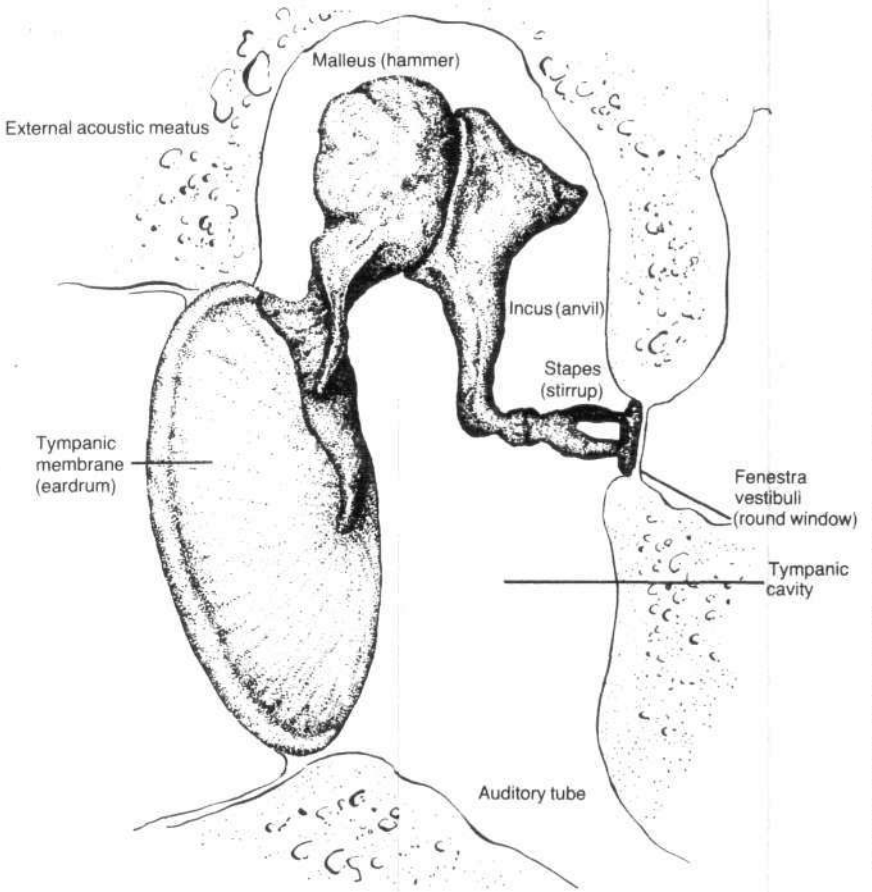
> The Law of Causation . . . is a mere hypothesis and not otherwise demonstrable. No previous uniformity can give proof of future uniformity . . . [but] without the Law of Causation there can be no thought. . . . Are we justified in thinking, and has our thought any meaning?[7]

Helmholtz believed that the relationship between the human mind and nature was statistical in character. It was from this philosophical standpoint that Helmholtz "discovered" an anatomical discontinuity in the middle ear's transmission of sound from the air to the fluid of the cochlea of the inner ear. Subsequent investigation proved this "discovery" to be a hoax.[8]

The Neoplatonic School of Physiology

Riemann, in contrast, stood in the Neoplatonic tradition of Augustine and Leibniz: The world is knowable to man because man can transform it in accordance with the potentialities of the Universe for self-development. This is natural law. Man is consubstantial with the Universe. Therefore, subjectively apparent harmony is actually a characteristic property of action in the Universe as a whole.

Riemann expressed exactly this idea when he wrote in his philosophical manuscripts that "our comprehension of the world is real . . . when the cohesion of our images corresponds to the cohesion of objects." In other words, if the mechanism of the middle ear projects the geometry of sound into the inner ear while preserving its essential qualities, then hearing is not "subjective." Riemann and his associates applied this method of projective invariance to dem-



Source: James E. Crouch, *Functional Human Anatomy* (Philadelphia: Lea & Febiger, 1965), p. 585.

Figure 1
CONSTRUCTION OF THE MIDDLE EAR

Shown here are the organs of the middle ear that were the issue of the controversy between Helmholtz and the Göttingen school. In response to sound, the eardrum on the left vibrates; this vibration is transmitted to the hammer that is attached to the eardrum; from the hammer it is transmitted to the anvil and stirrup, which transmits the sound to the fluid of the inner ear through the round window (fenestra vestibuli).

Eduard Weber (and later Riemann) argued that the known sensitivity of the ear required that the hammer and anvil vibrate as a single unit in transmitting the sound wave to the inner ear. Helmholtz maintained on the contrary that the hammer-anvil joint was loose, and that the two bones "clicked" in transmitting sound and added harmonics and combination tones to the original sound wave. On this basis, Helmholtz argued that harmonic relations were "subjective."

onstrate mathematically the principle of man's consubstantiality with nature and decisively refute Helmholtz.

Riemann begins with the known properties of the ear—its sensitivity, discrimination, and fidelity—and asks how the ear "solves the problem of the organ"; that is, what must be the properties of an organ with the performance of the ear? Riemann gives explicit instructions for discovering this:

> We must, as it were, reinvent the organ, and, insofar as we consider what the organ accomplishes to be its purpose, we must also consider its creation as the means to that purpose. But this purpose is not open to speculation, but rather is given by experience.

In approaching the "problem of the ear" in this fashion, Riemann collaborated with a Neoplatonic school of physiology based at Göttingen and Leipzig, whose leaders were among Riemann's closest friends: the three Weber brothers, Ernst, Wilhelm, and Eduard; Jacob Henle, the founder of the famous *Zeitschrift für Rationelle Medicin* in which Riemann's paper was published; and Gustav Fechner.

Ernst Weber, the senior member of the group, developed the approach toward anatomy that Riemann adopts in "The Mechanism of the Ear"—determining the role and even the specific anatomy of the individual parts of an organ on the basis of the function it performs. His brother Eduard was the first to argue that the joint between the hammer and anvil had to be rigid to account for the sensitivity of the ear.

Ernst Weber pointed out that in the case of the finer sense organs of hearing, vision, and touch, it is difficult to distinguish sensation from perception.[9] We do not feel sound waves pushing against our eardrums or producing waves in the inner ear. Rather, we hear the sound of a violin. Therefore, he argued, the unique property of the finer sense organs is that they establish continuity between the physical Universe and the human mind: Man is consubstantial with nature. Weber and Fechner demonstrated that this projection is logarithmic.

Therefore, for the scientist, "the problem of the organ," as Riemann writes, is to explain how this continuous projection is established. In the case of the auditory ossicles of the middle ear, the "problem of the organ" is to provide a perfect interface between the fluid of the air and the fluid of the inner ear.

To demonstrate this, Riemann made perhaps the first rigorous application of *the method of projective invariance* to biological systems. It is this aspect of his essay that is truly unique. Riemann postulated a physical quantity that must remain an invariant characteristic of the sound wave in its transmission from the air through the auditory ossicles to the cochlea if we are to account for what the ear accom-

plishes. Decisively refuting Helmholtz, he then showed that the invariance of this quantity required that the middle ear not introduce "distortion"—whether in the form of overtones or combination tones—into the sound wave.

The characteristic Riemann identified as the invariant was *timbre*, the quality of the sound ("die Klang, die Beschaffenheit des Schalles"), which he said had to be transmitted by the ear with sufficient fidelity to guarantee the preservation of the ratio between the tones and the harmonics of a sound. In his 1869 reply to the deceased Riemann, Helmholtz rejected the fact that this rigorously identifiable property of the sound wave is transmitted to the inner ear; instead, he regarded it as "subjective."

Timbre is a musical characteristic of sound. It provides the basis for distinguishing sources of sound, for distinguishing musical instruments from one another, or for communicating differences in intonation in reading poetry. The identification of this invariant shows that Riemann's musical or poetic sense informed his biophysics. Elsewhere, in his "Philosophical Fragments," Riemann had made it perfectly clear that he regarded physical processes as enlivened by the principles of life.

Riemann's argument on the physiology of the ear is suggestive of how the ear is able to detect sounds "below" the level of so-called quantum background noise in the acoustic medium, unlike the most advanced sonar equipment. Instead of performing a Fourier analysis—dissecting a sound into its pieces, individual tones and their harmonics—the ear may pick out a sound by its "internal geometry." Riemann wrote:

> If we take "timbre" to mean the quality of sound, which is independent of its intensity and direction, then this is evidently communicated by the apparatus with complete fidelity, so long as it transmits to the fluid of the inner ear *the variation in air pressure at every moment at a constant ratio of amplification*. . . .
>
> If the apparatus performed its task perfectly, the timbre curves of the inner ear fluid would completely coincide with the timbre curves of the air. Because of the sensitivity of the ear in the perception of sound, we consider it justified to assume that the timbre curve is altered only very slightly by the transmission. Hence the ratio between the synchronous pressure fluctuations of the air and of the inner ear fluid remains *virtually constant during a sound*. . . .
>
> Were the timbre curve noticeably altered, such sensitivity of hearing as indicated by, for example, the perception of slight differences of pronunciation, would seem to me scarcely conceivable. . . . Differences of timbre also serve in judging the distance of the sound source. From this difference of timbre we can reckon the mechanical origin; i.e., we can reckon the alteration of the timbre curve as the sound propagates through the air.

Ernst Weber and Gustav Fechner had demonstrated that the perceived loudness of a sound was proportional to the logarithm of sound intensity (or $L = k \log I$, where L is loudness and I intensity), and that the perceived pitch is proportional to the logarithm of frequency. Although it is well known that the range of human hearing stretches from the slightest sound to sounds four million times greater in intensity, Riemann argues, we do not actually perceive differences of that order, but rather the logarithms of such differences. It is the logarithm of sound intensity that is preserved in transmission to the inner ear, not the absolute intensity itself. He then defined the modern unit of loudness, the decibel. Today—following Weber, Fechner, and Riemann—biophysicists measure sound intensity in units of the logarithm of pressure.

One final "poem of hypothesis" from Riemann: The three ossicles together with the eardrum and the oval window of the cochlea comprise a hydraulic system that amplifies 20-fold to 30-fold the pressure that a sound wave makes against the eardrum. Riemann compared this action to that of an optical system: The middle ear focuses the vibrations of the broad eardrum down to the size of the stirrup footplate—which Riemann poetically calls "the lensbone"—and so amplifies sound waves by a constant ratio. The ligaments and connective tissue of the tympanic cavity adjust the ossicles'

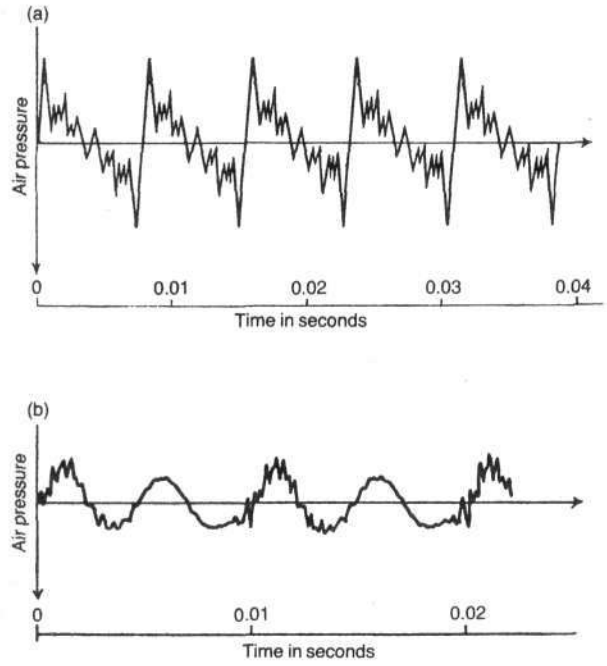


Figure 2
WHAT IS A 'TIMBRE CURVE'?

The waveform, the actual pressure fluctuations made in the air by repeatedly striking low C on a piano, is shown in (a). The jagged shape of the waveform shows the higher frequency but lower intensity harmonics of low C. Shown in (b) is the pressure fluctuation curve of the vowel sound "ee" in the word "see."

Riemann hypothesized correctly that the logarithm of this curve was transmitted perfectly from the air to the inner ear by the mechanism of the ear.

Source: Peter Ladefoged, *Elements of Acoustic Phonetics* (Chicago: University of Chicago Press, 1962), pp. 23 and 25.

positions in response to temperature fluctuation to maintain the perfect fit that must exist among the ossicles in order for the "lens" to focus sound waves.

Helmholtz Defends His Ear

Immediately after Riemann's death in 1866, Henle published "The Mechanism of the Ear" in his *Zeitschrift*. Helmholtz then immediately began to act out Riemann's characterization of him as the anatomist who, "occupied with the investigation of the individual components of the organ, feels obliged to ask of each part what influence it might have upon the activity of the organ." He embarked upon an extensive anatomical investigation in an effort to refute Riemann. This included the construction of three working models of the middle ear, one of which was—in Helmholtz's words—"particularly adapted to the production of [ossicle] tones." He presented his defense in two lectures on "The Mechanics of the Auditory Ossicles" before the Berlin Academy on July 26 and Aug. 9, 1867. In 1869, he published a 69-page essay in Pflueger's *Archive*, "The Mechanism of the Ossicles of the Ear and Membrana Tympani," which is entirely devoted to an attempt to refute Riemann.

He wrote in the introduction to this essay:

> [Riemann] says he will be obliged to oppose in many particulars the theory of the mechanism of hearing as developed by me in the Sensations of Tone. . . . In the description which I gave in [The Sensations of Tone], I adopted, in its most essential features, the theory of Eduard Weber. . . . It struck me that the chief difficulty in this theory lay in the existence of a joint between the hammer and anvil. According to Weber's description, the hammer and anvil constitute an immovable angular lever. . . . But how was the existence of a joint, surrounded by a weak and loose capsular membrane, allowing motion is all directions, possible in the midst of a lever whose vibrations must needs be of the greatest fineness and accuracy? . . .
>
> The solution of the difficulties was obtained by a closer investigation into the mechanics of the joints and attachments of the bones of the ear, and proved, in fact, to be entirely different from the one proposed by the celebrated mathematician [Riemann]. Besides, I must oppose his statement "that it is the task of the apparatus of the middle ear to transmit to the fluid of the labyrinth the changes in atmospheric pressure at every moment of time, with perfect accuracy and constant relative strength," because I consider this is nowise proven by the facts of the case. Accuracy in perception requires only that every tone of a given pitch should cause the same sensation, both in kind and intensity, every time that it is reproduced. It is a well-known fact that tones of a certain pitch produce an uncommonly strong impression upon the ear. We shall mention further on other new examples of abnormalities.[10]

The proof that Helmholtz's opposition to Riemann was not merely in the technical area of the physiology of hearing but represented a profound philosophical difference can be seen from his attack on Riemann's habilitation thesis, "The Hypotheses on Which Geometry is Based," in two lecture papers: "On the Facts on Which Geometry Is Based," presented to the Göttingen *Nachrichten* in 1868 and "On the Origin and Significance of Geometric Axioms," presented at Heidelberg in the same year.[11]

In a letter to Lipschitz in 1881, he characterizes Riemann as a "crank":

> I do not know how to meet (and this enrages me, often as I have sworn not to be annoyed about it) the calmness with which people, who are incapable of grasping the simplest geometrical statement, pronounce upon the most complex problems of the Theory of Space in the sure conviction of superior wisdom. . . . The individual, even if he be a Riemann, will always be regarded as a crank who is discussing unfamiliar matters as an amateur. . . . One must bestir oneself to see that the community of right-thinking persons increases gradually. At bottom it is the false rationalism and theorizing speculation that is the most crying evil of our German education in all directions.[12]

Riemann Confirmed by Contemporary Biophysics

Contemporary biophysics has since completely confirmed Riemann's analysis.[13] Ernst Wever, Merle Lawrence, and C.W. Bray showed that the middle ear transmits the sound wave to the inner ear nearly perfectly. Using a technique of recording the electrical potential at the cochlea's round window, they showed in experiments on various mammalian species that:

(1) "In most ears studied we were unable with the equipment available to detect any distortion" between sounds measured at the eardrum and measured at the round window of the cochlea.

(2) Otherwise, the ear generates harmonics and combination tones of the same relative intensities in response to pure tones whether the eardrum, hammer, and anvil are in place or not.

(3) Changes in air pressure inside the middle ear do not affect the ear's production of combination tones and harmonics.

(4) The locus of any "distortion" is in the cochlea, not in the middle ear.

It is amusing today to review how Riemann's tiny, 13-page article set off such a rage of denunciations from Helmholtz. Helmholtz's response, however, is appropriate if one understands the fundamental issue in the history of science in whose defense Riemann wrote "The Mechanism of the Ear."

Afterword

It is interesting to note that Riemann expanded the wave function concept of Fourier to include those series with infinite singularities. Such "arbitrary" curves can be analyzed by applying Fourier analysis; that is, by approximating the curve with an infinite series of trigonometric functions. Fourier, Riemann, LeJeune Dirichlet, Karl Weierstrauss, and Georg Cantor worked to discover methods by which the

original function, in this case, that of the physical process of sound production, could be recovered or studied from trigonometric descriptions of its image under projection. (Today, functions such as those represented in Figure 1, bear the names of Riemann and Weierstrauss.) It was out of this study that Cantor developed his theory of transfinite numbers.

At no time did Fourier and the Göttingen School claim that the Fourier analysis they invented and perfected bore anything approximating a correspondence to the actual physical process. However, this is precisely what Helmholtz asserted. In other words, Helmholtz completely discarded the transfinite character of sound, which had become a focus of mathematical physical investigation since Fourier's original work on the propagation of heat. At the same time he attributed properties to the inner ear that were physically and temporally impossible; namely, the ability to instantly carry out an infinite Fourier analysis.

This dispute boils down to that between Plato and Aristotle over the existence of universals in nature. Riemann's view was that the ear does not approximate the sound wave through some linear, additive decomposition, but rather that the ear directly (and "instantly") perceives its transfinite character as though it "decodes" an electromagnetic process that was "encoded" for its propagation through air.

Robert Gallagher is on the staff of the Fusion Energy Foundation in New York.

Notes

1. Uwe Parpart [Henke], "Riemann Declassified: His Method and Program for the Natural Sciences," *Fusion*, March-April 1979, p. 24.
2. Ernest Wever and Merle Lawrence, *Physiological Acoustics* (Princeton, N.J.: Princeton University Press, 1954), p. 145.
3. Wever and Lawrence point out in *Physiological Acoustics* (p. 147) that these two principles are contradictory: "If every tone is first subjected to distortion in the middle ear the simple representation [in the cochlea] indicated by the specific energies principle can no longer hold. . . . Consider, now, what must happen when the ear is presented with a musical chord containing the tone just mentioned and other tones of the frequencies of the overtones. In the cochlea this chord must excite exactly the same series of resonators as are excited by a single tone. The only difference between the second cochlear pattern and the first will be in the intensity relations among the responding elements. Yet Helmholtz's theory requires that we shall perceive the first pattern as simple and as representing only one pure tone and that we shall perceive the second pattern as complex and as made up of a tone and its series of overtones. This is hardly a specific energies theory, but a theory in which pitch perception depends upon a pattern of relative intensities. Such a theory can be maintained, and indeed is eminently reasonable, but it is not the theory presented by Helmholtz in his other discussions on this subject or the theory that has continued to be held and defended in his name."
4. H. Helmholtz, *The Mechanism of the Ossicles of the Ear and Membrana Tympani*, trans. Albert H. Buck and Normand Smith (New York: William Wood & Co., 1873), p. 8. This was originally published in Phleuger's *Archiv*, Vol. I, 1869.
5. Ibid, p. 50.
6. Leo Koenigsberger, *Hermann von Helmholtz* (New York: Dover, 1965), p. 227.
7. Ibid.
8. Helmholtz's detailed assertions are outrageous. For example, in his book *On the Sensations of Tone As a Physiological Basis for the Theory of Music*, (New York: Dover, 1954), p. 158, Helmholtz writes:

   "There are certain conditions which are peculiarly favourable for the generation of combination tones. First we have the unsymmetrical form of the skin of the eardrum itself. . . . But a more important circumstance . . . when the tones are powerful, is the loose formation of the joint between the hammer and anvil. If the handle of the hammer is driven inwards by the eardrum, the anvil and stirrup must follow the motion unconditionally. But that is not the case for the subsequent outward motion of the handle of the hammer, during which the teeth of the two ossicles need not catch each other. In this case the ossicles may click. Now I seem to hear this clicking in my own ear whenever a very strong and deep tone is brought to bear upon it, even when, for example, it is produced by a tuning-fork held between the fingers, in which there is certainly nothing that can make any click at all.

   "This peculiar feeling of mechanical tingling in the air had long ago struck me when two clear and powerful soprano voices executed passages in Thirds, in which case the combination tone comes out very distinctly. If the phases of the two tones are so related that after every fourth oscillation of the deeper and every fifth of the higher tone, there ensues a considerable outward displacement of the eardrum, sufficient to cause a momentary loosening in the joint between the hammer and anvil, a series of blows will be generated between the two bones, which would be absent if the connection were firm and oscillation regular, and these blows taken together would exactly generate the first differential tone of the interval of a major Third."

   In a letter to Gustav Fechner, as quoted in Koenigsberger, p. 227, Helmholtz writes:

   "A weak accompaniment of harmonic overtones is inevitably present, at least in all *strong* simple tones. They arise from the same law as combination tones, partly accidently outside the ear, partly in regular series within the ear, as often as the vibrations become so great that the elastic forces are no longer exactly proportional to the displacements. . . . the conditions for this are especially favourable inside the ear, so that there may even be a clashing of tones between the malleus and incus."
9. E.H. Weber, *The Sense of Touch* (New York: Academic Press, 1978), p. 150.
10. Helmholtz (1873), p. 8.
11. Koenigsberger, p. 254.
12. Koenigsberger, p. 267.
13. Wever and Lawrence, pp. 145, 152, 156, and 172.

    "Helmholtz located the distortion process in the middle ear, and especially in the actions of the drum membrane and of the joint between malleus [hammer] and incus [anvil]. He opposed the view expressed by Riemann that for the purposes of hearing the character of external sounds must be faithfully represented to the inner receptor processes. Riemann had argued that the middle ear apparatus is a delicate and precise amplifying mechanism that conveys the pattern of the external pressure changes with perfect accuracy and without any alteration in the intensity relations among its components. In other words, he assumed a linear relation between the external stimulus and its actions upon the ear.

    "Helmholtz maintained on the contrary, as we shall see in more detail presently, that every tone is subjected to distortion in its passage through the middle ear. For a suitable representation of the world of sound he saw no need for the strict correspondence that Riemann had postulated. For every tone to possess a certain perceptual identity it is only necessary, he said, that it have the same effect upon the ear every time it is presented. He accepted a nonlinear relationship because through it he was able to explain the production of overtones and combination tones. . . .

    "Dahmann in his experiments with powerful stimuli observed the relative motions between the ossicles that Helmholtz had spoken of. He reported that the amplitude of motion of the malleus was not fully transmitted to the incus, but some of this amplitude was lost on the resiliency of the joint. However, on theoretical grounds he supposed that when the stimuli were more moderate, and the displacements called for in the ossicles were not so great as to produce stresses in their articulations that exceeded the limits of yielding of the footplate in the oval window, the malleus and incus would vibrate together as a single mass. This, we will recall, is the view taken earlier by Eduard Weber and Riemann. . . .

    "Dennert objected to Helmholtz's theory of middle ear distortion on the basis of his observation that many persons without drum membranes, and some without the malleus and incus as well, are still able to hear the same combination tones that normal persons hear. Bingham examined a person who had lost the drum membrane and the two larger ossicles in both ears and yet was able to identify two different tones. . . .

    "These results support the conclusion already reached from our earlier experiments that the ear's distortion is produced in the cochlea and not in the middle ear. We can now carry this statement further and say that the distortion is largely in the final sensory processes, or at any rate is not in such mechanical processes of the cochlea as are closely coupled to the cochlear fluid. We can thus discount the frequent suggestions that distortion may occur in the stapedial [stirrup] movements, in the gross movements of the basilar membrane, or in the cochlear fluid itself, for distortion in any of these would be disclosed in the sounds passing out of the round window. These experiments support the view already expressed that the middle ear mechanism carries out its function of sound transmission with great fidelity."

The first English translation of Riemann's 1866 essay on the ear and the methodology of science.

The Mechanism Of the Ear

by Bernhard Riemann (1866)

Bernhard Riemann (1826-1866) and the frontispiece to his essay "The Mechanism of the Ear."

Mechanik des Ohres.

Aus dem Nachlass von **B. Riemann**[1]).

I. Ueber die in der Physiologie der feinern Sinnesorgane anzuwendende Methode.

Für die Physiologie eines Sinnesorganes sind ausser den allgemeinen Naturgesetzen zwei besondere Grundlagen nöthig, eine psychophysische, die erfahrungsgemässe Feststellung der Leistungen des Organes, und eine anatomische, die Erforschung seines Baues.

Es sind demnach zwei Wege möglich, um zur Kenntniss seiner Functionen zu gelangen. Man kann entweder vom Baue des Organes ausgehen und hieraus die Gesetze der Wechsel-

[1]) Der grosse Mathematiker, den ein früher Tod unserer Hochschule und der Wissenschaft entriss, beschäftigte sich, angeregt durch die von Helmholtz begründete neue Lehre von den Tonempfindungen, in seinen letzten Lebensmonaten mit der Theorie des Gehörorgans. Was sich darüber aufgezeichnet in seinen Papieren vorfand und hier mitgetheilt wird, berührt allerdings nur einen kleinen und minder wesentlichen Theil der Aufgabe; doch rechtfertigt sich ohne Zweifel die Veröffentlichung dieses Fragments durch die Bedeutung des Verfassers und durch den Werth seiner Aussprüche, wie seines Beispiels für die methodische Behandlung des Gegenstandes. Den ersten Abschnitt und den grössten Theil des zweiten hat der Verf. in Reinschrift hinterlassen; der Schluss des 2., vom ersten Absatze auf pag. 141 an, wurde aus zerstreuten Blättern und Blättern, in welchen R. seine ersten Entwürfe niederzulegen pflegte, zusammengestellt. Die Bemerkung, in welcher er sich gegen die Helmholtz'sche Theorie von den Bewegungen des Ohres erklärt, würde erst durch seine eigene Ausführung verständlich erwarten sein; Riemann's gesprächsweise Aeusserungen lassen vermuthen, dass die Verschiedenheit der beiderseitigen Ansichten erst bei dem Problem der Uebertragung der Schallschwingungen auf die Organe der Schnecke hervorgetreten sein würde, und dass R. das dabei zu lösende mathematische Problem als ein hydraulisches aufgefasst habe. Schering. Henle.

Zeitschr. f. rat. Med. Dritte R. Bd. XXIX. 9

EDITOR'S NOTE

This is the first English translation of Riemann's 1866 essay on the ear, which was first published as "Mechanik des Ohres" in Henle and Pfeuffer's *Zeitschrift für rationelle Medicin*, 3rd Series, Vol. 29, pp. 129-143. It later appeared in the collected works of Riemann, *Gesamelte Mathematische Werke und Wissenschaftliche Nachlass*, edited by Heinrich Weber with the assistance of Richard Dedekind (New York: Dover Publications, 1953), pp. 338-350.

The translators are David Cherry and Robert Gallagher, FEF staff members, and John Sigerson, president of the Schiller Institute. All footnotes and figures have been added by the translators, and translators' comments appear in brackets in the text.

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Introduction to the German Edition

The great mathematician Riemann, torn by premature death from our university and from science itself, was spurred by Helmholtz's new theory of the sensations of tone to devote the last months of his life to the theory of the organ of hearing. The material on this subject found among his papers and communicated here, of course, touches on only a small and elementary part of the problem. Yet the publication of this fragment is doubtless justified—given the stature of the author and the value of his dissertations—as his example of the correct methodology for the treatment of the subject. The first section and the greater portion of the second were left by the author in a fair hand. The close of the second, from [page 38, paragraph 2] onwards, was assembled from scattered pages and notes in which Riemann customarily set down his first draft. The remarks declaring his opposition to Helmholtz's theory of the ear's motions would only have become clear had he carried through on this work. Riemann's spoken views give us grounds to suppose that the difference between the two approaches would only have first come into focus over the problem of transmission of sound waves to the organs of the cochlea, and that Riemann thought that the mathematical problem to be solved was in fact a hydraulic one.

The Mechanism of the Ear

1. On the Method Applicable to the Study of The Physiology of the Finer Sense Organs

For the study of physiology of a sense organ, there are—aside from the universal laws of nature—two necessary special foundations: one psychophysical, the empirical determination of what the organ accomplishes; the other anatomical, the investigation of its construction. Accordingly, there are two possible ways of acquiring knowledge of its functions. Either we can proceed from the construction of the organ and from there seek to determine the laws of the mutual interaction of its parts as well as the result of external stimuli, or we can begin with what the organ accomplishes and then attempt to account for this.

By the first route we infer the effects from given causes, whereas by the second route we seek causes of given effects.

Following Newton and Herbart, we can call the first route synthetic, and the second analytic.

Synthetic Route. The first route is most familiar to the anatomist. Since he must concern himself with the investigation of the individual components of the organ, the anatomist feels obliged to inquire of each part, what influence it might have upon the activity of the organ. This route could also be taken with equal success with respect to the physiology of the sense organs, as well as the physiology of the organs of locomotion, provided that the physical characteristics of the individual parts of such organs could indeed be determined. But the determination of these characteristics from observation of microscopic objects is always more or less uncertain, and is, moreover, highly imprecise.

Therefore, in order to complete such an inquiry, we are compelled to resort to analogy or teleology, which unavoidably involves extreme arbitrariness; for this reason, the synthetic approach to physiology of the sense organs leads to results that are seldom correct and never all that certain.

Analytic Route. By the second route we seek to account for what the organ accomplishes.

There are three component parts to this business.

(1) The search for an hypothesis which is sufficient to account for what the organ accomplishes.

(2) Investigation of the extent to which this is a necessary hypothesis.

(3) Comparison with experience in order to verify or correct it.

I. We must, as it were, reinvent the organ, and, insofar as we consider what the organ accomplishes to be its purpose, we must also consider its creation as the means to that purpose. But this purpose is not open to speculation, but rather is given by experience, and so long as we disregard how the organ was produced, we need not bring into play the concept of final cause.

In order to account for what the organ actually accomplishes, we look to its construction. In our search for this explanation, we must first of all analyze the organ's task, the problem it must solve. This will result in a series of secondary tasks or problems, and only after we have become convinced that these *must* be solved, do we then look to the organ's construction in order to infer the manner in which they are solved.

II. Once we have arrived at a conception that suffices to account for the organ, we cannot fail to inquire about the extent to which that conception is necessary to account for it. We must carefully distinguish between those assumptions that are unconditional, or rather, are necessary by virtue of incontestable laws of nature, and those classes of conceptions that are completely interchangeable; whereas we must separate out all completely arbitrary, tacked-on notions. Only in this way can we counteract the detrimental consequences of the use of analogy in our search, and this also makes it considerably easier to test our explanation by reference to experience (i.e., by framing questions to be answered).

III. To test our explanation by reference to experience, we can in part draw upon what we have concluded from experience about what the organ accomplishes, and in part upon what that explanation presupposes as the physical characteristics of the organ's constituent parts. As for what the organ accomplishes, it is extremely difficult to precisely compare this with experience, and we must mostly confine our theory-testing to the question of whether the theory is contradicted by experimental results or observation. In contrast, conclusions about the physical characteristics of the constituent parts can have universal scope, and can give rise to advances in our knowledge of the laws of nature, as was the case, for example, with Euler's efforts to account for achromatism of the eye.

These two diametrically opposed investigative approaches, we might add, only correspond *a potiori* to the designations "synthetic" and "analytic." Purely synthetic and purely analytic research, when taken in the precise sense of these terms, is an impossibility. Every synthesis rests upon the results of a foregoing analysis, and every analysis requires a subsequent synthesis so that it may be confirmed or corrected with reference to experience. With the former, synthetic procedure, the universal laws of motion are simply the result of a previous, assumed analysis.

The first, chiefly synthetic procedure should therefore not be utilized for a theory of the finer sense organs, because the requirements for the applicability of this procedure are only incompletely met, and any attempted completion of these requirements via analogy and teleology, will remain completely arbitrary.

In the case of the second, chiefly analytic approach, we still cannot entirely dispense with teleology and analogy, but we are able to avoid their arbitrary use:

(1) We confine the application of teleology to inquiry into the means by which the organ accomplishes its tasks, but without raising the question of the utility of its individual components; and

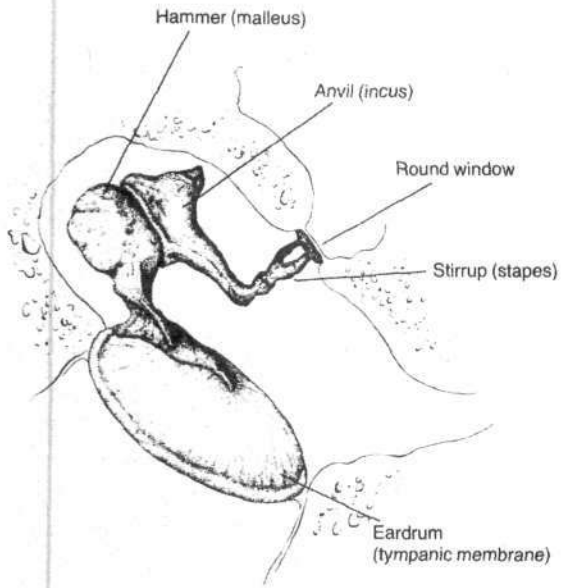
(2) We do not—as Newton proposes—completely reject the use of analogy (the "poetry of hypothesis"), but rather afterwards emphasize the conditions that *must* be met to

account for what the organ accomplishes, and discard any notions that are not essential to the explanation, but that have arisen solely through the use of analogy.

To begin with, our objective requires that we determine, in accordance with these principles, what the organ of hearing accomplishes. With what degree of discrimination, sensitivity, and fidelity does the ear mediate the perception of sound, its timbre[1] and tone, its intensity and direction? This we must determine with all possible precision by means of observation and experiment.

I shall assume a knowledge of these matters. In Helmholtz's *On the Sensations of Tone As a Physiological Basis for the Theory of Music*, we find assembled the latest advances in the extraordinarily difficult inquiry into matters involving the perception of tone, largely consisting of Helmholtz's own work.

Since I am frequently compelled to oppose the conclu-



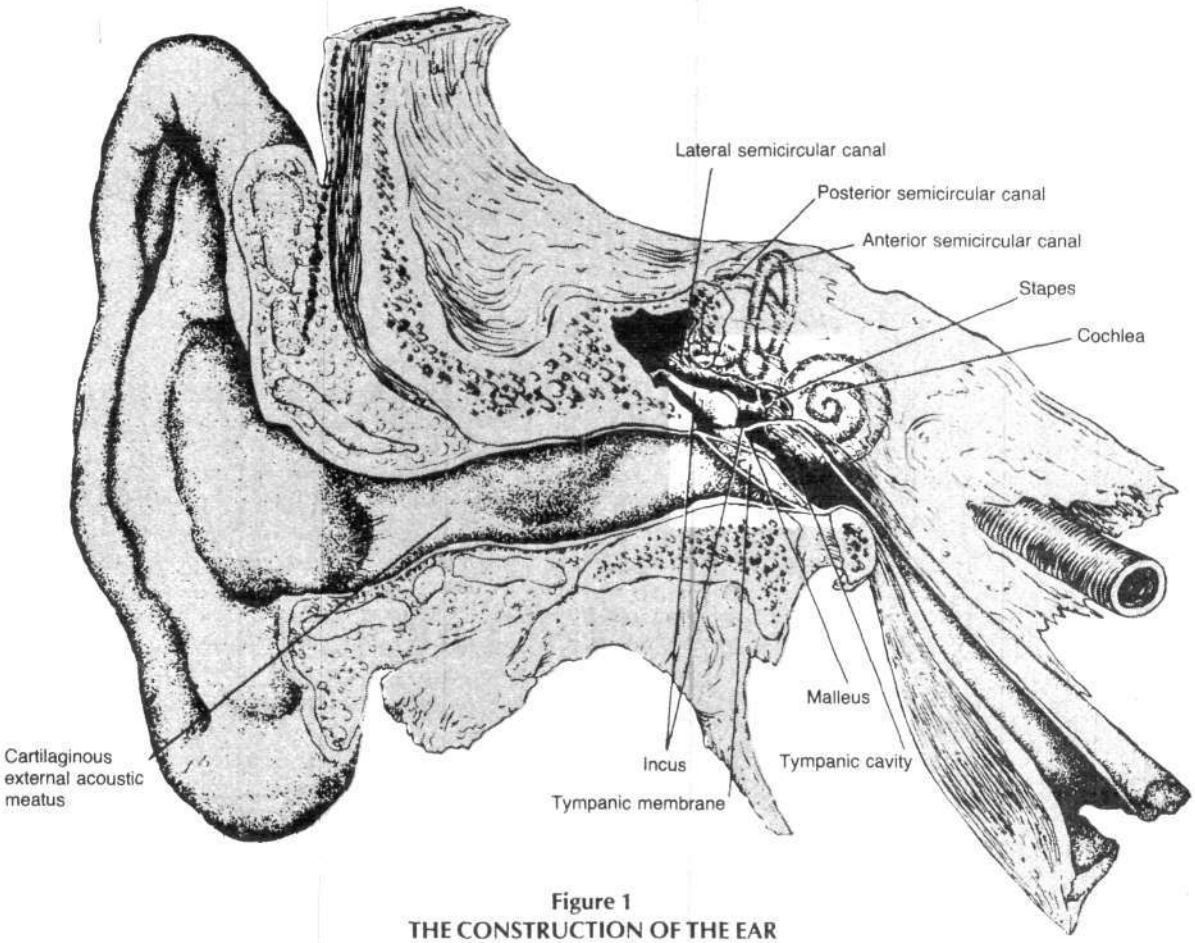


Figure 1
THE CONSTRUCTION OF THE EAR

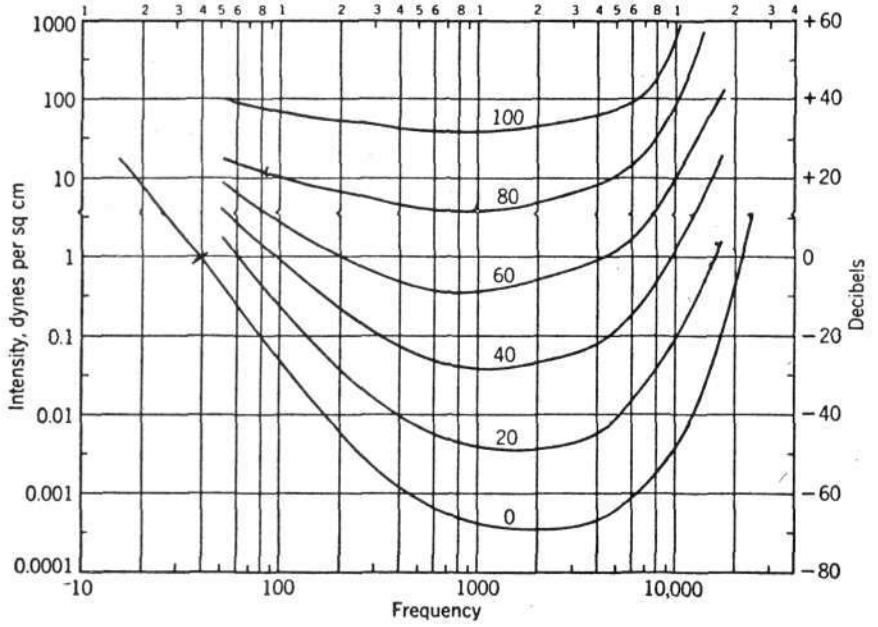
Shown is a section through the outer ear, the external auditory meatus, and the middle ear and cochlea. The inset shows the detailed construction of the hydraulic system of the middle ear—the eardrum, auditory ossicles, and the vestibular window.

Source: James E. Crouch, *Functional Human Anatomy* (Philadelphia: Lea & Febiger, 1965), p. 584.

Figure 2
EQUAL LOUDNESS CONTOURS

Sounds with the intensity and frequency combinations that occur along the solid curves in the figure are all heard as having the same level of loudness. The "gradual variation in the ratio" hypothesized by Riemann is shown as the gradual increases in intensity required to hear a sound at frequencies lower or higher than about 1,000 hertz.

These equal loudness contours were derived in 1933 by physiologists H. Fletcher and W. Munson, who verified Riemann's remarks that there may be "gradual variation in the ratio . . . between the synchronous pressure fluctuations of the air and of the inner ear" over a range of frequencies.



Source: Fletcher and Munson, cited in Theory of Hearing *by Ernest Glen Wever (New York: John Wiley & Sons, Inc., 1949), p. 307.*

sions that Helmholtz draws from his experiments and observations, I believe I am all the more obliged here to state how much I recognize the great merits of his work on our topic. These merits, however, are in my view not to be found in his theories of the motions of the ear, but rather in his improvement upon the empirical foundations for the theory of these motions.

I will also assume a knowledge of the construction of the ear, and ask the interested reader, if he finds it necessary, to make use of an illustrated handbook of anatomy. The latest findings on the construction of the cochlea and of the ear in general, can be found illustrated in the recent third printing of Volume II of Henle's *Handbook of Human Anatomy*.

My sole task here is to draw upon this anatomical data in order to account for the psychophysical data referred to earlier.

The parts of the ear that we must consider for our purposes are: the middle ear or tympanic cavity, and the inner ear, which consists of the vestibule, the semicircular canals, and the cochlea [Figure 1]. We proceed first by seeking to infer from the construction of these elements, what each element might contribute to what the ear accomplishes; then, for each individual element, we proceed from the task or problem it must solve, and seek the conditions that must be met for a satisfactory fulfillment of that task.

2. The Tympanic Cavity

It has long been recognized that the apparatus of the tympanic cavity acts to amplify and transmit variations in air pressure to the fluid of the inner ear.

In accordance with the principles developed above, we must now derive from the empirically known functions performed by the organ, the conditions which must be met in this transmission. This arises principally from the sensitivity of the ear in the perception of sound and from the ear's great discrimination—especially that of the unspoiled ear of the savage or desert-dweller. If we take "timbre" to mean the quality of sound, which is independent of its intensity and direction, then this is evidently communicated by the apparatus with complete fidelity, so long as it transmits to the fluid of the inner ear *the variation in air pressure at every moment at a constant ratio of amplification.*

It is safe to assume that this is the purpose of the mechanism, so long as we do not at the same time neglect to determine from the functioning of the ear, how far we are justified—i.e., compelled—by experience to presuppose the actual fulfillment of this purpose.

This we wish to do first before seeking a mathematical expression for the nature of the pressure fluctuation upon which timbre depends. The curve that shows the speed of pressure fluctuation[2] as a function of time, completely defines the sound wave except for its direction, and hence defines the intensity and timbre of the sound. If we take, instead of the speed, the log of the speed, or if one prefers, of the square of the speed, we obtain a curve whose form is independent of the direction and intensity of the sound, but which completely determines the timbre, and hence may be called the "timbre curve."

If the apparatus performed its task perfectly, the timbre curves of the inner ear fluid would completely coincide with the timbre curves of the air. Because of the sensitivity

of the ear in the perception of sound, we consider it justified to assume that the timbre curve is altered only very slightly by the transmission. Hence the ratio between the synchronous pressure fluctuations of the air and of the inner ear fluid remains *virtually constant during a sound.*

A gradual variation in this ratio [over a range of frequencies] is therefore quite consistent and probable. This would only result in a variation in the ear's estimation of the intensity of sound, a hypothesis not at all ruled out by experience [Figure 2]. Were the timbre curve noticeably altered, such sensitivity of hearing as indicated by, for example, the perception of slight differences of pronunciation, would seem to me scarcely conceivable. The immediate judgment of sensitivity of perceptions of timbre, and especially the estimation of the differences in the timbre curve corresponding to differences of timbre, is admittedly still quite subjective.

Differences of timbre also serve in judging the distance of the sound source. From this difference of timbre we can reckon the mechanical origin; i.e., we can reckon the alteration of the timbre curve as the sound propagates through the air.

We cannot pursue this subject further here, and will only demand that the transmission mechanism itself produce no gross distortions of timbre (although we believe that its fidelity is much greater than is usually supposed).

I.

The apparatus within the tympanic cavity (in its unspoiled condition) is a mechanical apparatus whose sensitivity is infinitely superior to everything we know about the sensitivity of mechanical apparatuses.

In fact, it is by no means improbable that it faithfully transmits sonic motions that are so small that they cannot be observed with a microscope.

The mechanical force of the weakest sounds detectable by the ear can, of course, hardly be estimated directly; we can show, however, by means of the law according to which the intensity of sound decreases with its propagation in the air, that the ear does pick up sounds whose mechanical force is millions of times weaker than that of sounds of ordinary intensity.

In the absence of other observations free of methodological errors, I refer to Nicholson's report that the call of the Portsmouth sentry is clearly audible at night at a distance of 4 to 5 English miles, at Ride on the Isle of Wight. When we consider the contrivances that Colladon found necessary in order to detect the propagation of sound through water, it will be conceded that we cannot speak of a substantial amplification of sound as it propagates through water; indeed, the mechanical force of sound in water is inversely proportional to the square of the distance from the source, and probably diminishes even more rapidly than that. Since a distance of 4 to 5 miles is approximately 2,000 times greater than a distance of 8 to 10 feet, the mechanical force of the sound waves reaching the eardrum is 4 million times smaller than at a distance of 8 to 10 feet from the sentry, and thus the motion of the eardrum is 2,000 times smaller. Admittedly, in measurements of sound perception, we find absolutely no mention of ratios on the order of 1 to 1 billion or 1 to 1,000. But in light of recent investigations of the relationship of psychological estimates of sound intensity to physical or mechanical measurement, this poses no obstacle to the conclusion we have just reached. This relationship of dependence is probably identical to how our estimate of the intensity or magnitude of the fixed stars is dependent on the mechanical force of the emitted light reaching us. As is well known, it has been concluded from the calibration of stars that the mechanical force of their light diminishes geometrically as their magnitude decreases arithmetically.

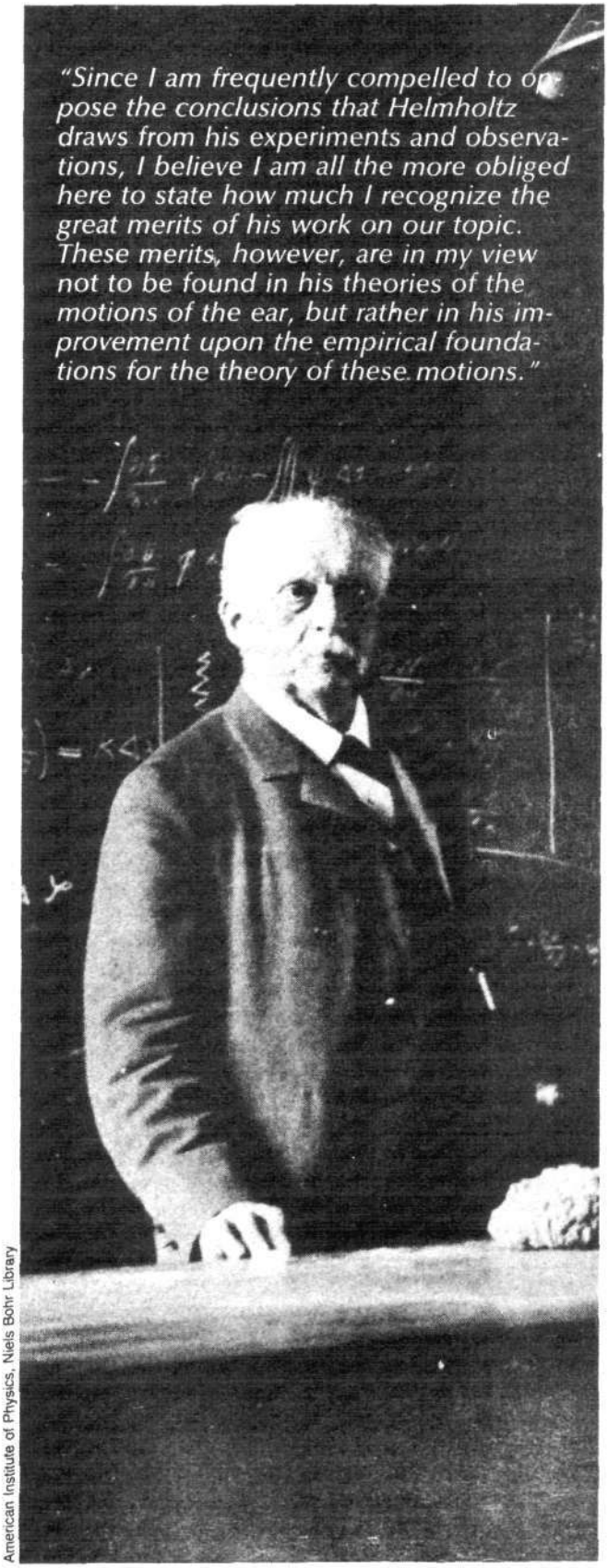
If, analogously, we divide sounds—from familiar intensity down to those barely perceptible—into eight magnitudes, then the mechanical force of a sound of the second magnitude would be about $1/10$, the third $1/100$, . . ., the eighth $1/10{,}000{,}000$—one ten-millionth the intensity of the first magnitude; whereas the amplitude of motion for sounds of the first, third, fifth, and seventh magnitudes would be in the ratios of $1 : 1/10 : 1/100 : 1/1{,}000$. In my foregoing considerations of the sound waves reaching the ear, I stopped with the eardrum, since some investigators assume a damping of the more intense sounds (because of the tension on the drumskin?). I must confess that this opinion strikes me as a completely arbitrary conjecture. It is possible, of course, that protective mechanisms do go into effect when a loud noise threatens to injure the membranes of the inner ear. But within the nature of audible impressions I find nothing whatsoever analogous to the eye's response to the degree of illumination of the visual field, and have no idea what a continuously variable reflex activity of *M. tensor tympani* is supposed to contribute to the exact comprehension of a piece of music.[3] In my view, there is no basis to assume that at a distance of 10 feet from the sentry, there exists a different relationship between the motion of air at the eardrum and the motion of the stirrup footplate (stapes), than at a distance of 20,000 feet; and even if a rather substantial variation in the tension of the eardrum is assumed, this would in no way alter our conclusions. If, at a distance of 10 feet from the sentry, the motion of the stirrup footplate is probably still just barely perceptible to the naked eye, then this motion would be just as perceptible at a distance of 20,000 feet with a 2,000-fold magnification.

II.

If the middle ear apparatus is to faithfully transmit the slight motions that experience shows it to do, the solid bodies that constitute it must fit perfectly at their points of effective contact, since obviously one body cannot transmit a motion to another if the distance separating them is greater than the amplitude of that motion.

Moreover, only a small portion of the mechanical force of the sonic motion is permitted to be lost through such additional work as the tensing of fibrous capsules and synovial membranes of the joints.

Such loss is minimized by the extremely small width of the free boundary of the membrane of the oval window or



American Institute of Physics, Niels Bohr Library

Hermann von Helmholtz (1821-1894)

fenestra vestibuli.[4] Were this boundary wider, the vibrations of the stirrup footplate would be almost entirely canceled out by the vibrations of this boundary, and would have only a slight effect on the cochlea and round window or fenestra cochlae.

Because of this membranous boundary's slight width, the effect of this boundary on the stirrup footplate will greatly vary with the various positions assumed by the stirrup footplate over the course of the sonic movements. Hence we must assume that the membrane's elasticity, if it is not to distort the timbre, is negligible, and that not this elasticity, but some other forces are involved in bringing the stirrup footplate into the correct equilibrium position.

III.

Since, if we are to account for the ear's empirically verifiable acuity, the components of the middle ear apparatus must constantly grab each other with better than microscopic precision, certain corrective mechanisms would seem indispensable to compensate for expansion and contraction of these bodies through the action of heat. Changes in temperature inside the tympanic cavity may be very small, yet they undoubtedly do occur. The temperature distribution in the human body, when the external temperature has remained constant for a sufficient length of time, approximates the law which states that the difference between the temperature of an arbitrary place in the body and the temperature of the brain is proportional to the difference between the external temperature and the temperature of the brain. This law is derived from Newton, along with the assumption that the thermal conductivity and the specific heat remains constant within the temperature range under consideration—an assumption that is probably very nearly satisfied. With this law, we can deduce the changes in temperature from the differences in the temperature of the tympanic cavity and the brain. Even if it may not be possible to determine the temperature difference between the tympanic cavity and the brain, there are still several reasons for concluding that a noticeable temperature difference is highly probable, *viz.*, the communication with the outside air through the exterior auditory canal or meatus and the eustachian tube, as well as the manner in which blood is supplied to the tympanic cavity.

By contrast, the pyramid bone[5] probably has a temperature very close to that of the brain, since it contains the carotid canal (*Can. caroticus*), and therefore we must assume that the inner lining of the tympanic cavity[6] is a very poor conductor and emitter of heat.

Regarding the other bones surrounding the tympanic cavity, it certainly cannot be claimed that their temperature is as high as that of the brain or the pyramid. Yet they do have certain significant sources of heat in blood vessels—large arteries and veins—and are, like the pyramid, protected by mucous membrane and periosteum from loss of heat to the tympanic cavity. Hence we may assume that their temperature is significantly higher than that of the tympanic cavity.

If the external temperature drops, then, in accordance

with the above-mentioned law, the difference between the temperature of the brain and everywhere else in the body will increase in the same ratio (1:2); the tympanic cavity will as a result cool noticeably, the surrounding bones will cool only very slightly, and the auditory ossicles will draw together noticeably, while the walls of the tympanic cavity remain nearly unchanged.

Our finding that the auditory ossicles draw together and cool down much more than the walls of the tympanic cavity with a drop in the external temperature is about all that can be established regarding the influence of temperature on the middle ear apparatus, given our total ignorance of the thermal properties of its components.

IV.

I will now attempt to determine the changes in the position assumed by the auditory ossicles as the external temperature drops, such that all contiguous parts of the apparatus continue to fit precisely. The part of the auditory ossicle system that is most firmly connected to the wall of the tympanic cavity is the anvil-drum joint.[7] All distances within composite, solid bodies become smaller with cooling; hence the distance between this joint surface and the anvil-stirrup joint becomes smaller. The upper handle is probably the part of the hammer that is subject to the most minimal displacement, at least parallel to the ring of the eardrum. Since with cooling the distance of the anvil-drum joint from the least mobile point of attachment of the upper handle of the hammer at the eardrum remains nearly unchanged, while the distances of these points from the anvil-hammer joint both decrease, the angle produced by the lines running from the anvil-hammer joint through these points must become somewhat smaller.

With these two changes in position of the auditory ossicles, the hammer is rotated slightly in the anterior-median-posterior direction, and simultaneously (in order to maintain the knob of the anvil[8]) more slightly in the anterior-superior-posterior direction. The long process of the hammer, as a result, would have to be moved at the fissure[9] upwards and medially, if it is to maintain one and the same position with respect to the handle and head of the hammer. By the action of cooling, however, its curvature increases and it draws closer to the hammer handle, so that during a change of temperature it probably only gradually draws a bit out of the fissure.

V.

We have now specified the conditions that are probably met by the positions of the auditory ossicles, such that they maintain precise articulation continuously and hence, neither at the edge of the vestibular membrane nor at the eardrum, produce any significant asymmetric tension. We now inquire into the *means* by which the auditory ossicles always achieve and maintain the correct position. (This is accomplished mainly through counterposed forces, which achieve a balance with the correct position of the ossicles and, if they become displaced, pull them back again.)

It is clear that these means must be sought in the two muscles regulating the position of the auditory ossicles, in the joint capsules, ligaments, folds of mucous membrane, and the two membranes with which the auditory ossicles are bound together. In this search for the origins of a specific effect upon the auditory ossicles, we are often presented with several ways to produce the same effect when the folds of mucous membrane are also considered. To identify the most probable of these various possibilities, it is first and foremost necessary to reach approximate conclusions as to the elasticity and tension of the ligaments, membranes, and so forth, on the basis of anatomical investigations using freshly prepared specimens. This is something I cannot do. But by carefully developing the consequences of the various hypotheses, we may hope to hit up against the improbable ones and weed these out.

For our present investigation, it is appropriate to distinguish between the alert ear, adjusted for precise hearing, and the nonalert ear, and—for certain questions—between the ear of the newborn and the ear of the adult. The distinction we make between the alert and nonalert ear is dependent upon whether or not the foot of the stirrup is pressed slightly against the inner ear fluid by tension of *M. tensor tympani*, so that the pressure at the inner ear fluid is slightly greater than that of the air in the tympanic cavity; in this way the parts of the solid bodies whose contact is to be ensured are pressed slightly against each other. Those who think that any such continuous tension of the mechanism is improbable (the eardrum perhaps excepted) might consider that, with variations in temperature, the auditory ossicles change their positions—through the effects of fastening ligaments and joint ligaments and the gradual variation of the contraction of muscles—without being pressed against each other. We have found, however, that only through tension is precise meshing of all parts of the mechanism assured.

Our investigation is thus valid for the alert ear—the ear deliberately prepared for precise perception, while it still remains possible that the ear (of the normally awake person?) is continuously adapted, if perhaps only to a lesser degree.

The apparatus of the auditory ossicles consists of a body composed of two parts (hammer and anvil), that can rotate about an axis and a stamper (the stirrup) with which it articulates, and which presses in upon the fluid at the oval window. One end of the axis of rotation, the short process of the anvil, is fastened by means of the anvil-drum joint to the posterior wall of the tympanic cavity; the other end, the long process of the hammer, surrounded only by soft tissue, projects into a gap between the anterior-superior end of the ring of the eardrum and the petrous bone, and rests in a furrow of this ring. (This is true at least for the ear of the newborn.)

The determination of the position of the auditory ossicles with respect to the tympanic cavity is made much simpler by means of Henle's procedure of considering the tympanic cavity rotated, so that the axis of rotation runs horizontally posterior-to-anterior, while the oval window stands vertically.

If, through an increase in air pressure, the handle of the hammer is driven together with the eardrum to which it is attached, the base of the stirrup is pressed against the membrane of the (oval) vestibular window and the pressure of the inner ear fluid increases, and thereby the membrane of the (round) cochlea window is driven outward.[10]

For the mechanism to be able to transmit to the inner ear fluid even the slightest changes in air pressure at a constant ratio of amplification, it is first and foremost necessary that *the pressure of the stirrup always act upon the inner ear fluid in precisely the same way.* To this end, it is necessary that:

(1) the pressure of the base always encounter one and the same surface, and the direction of motion always be the same;

(2) there can be no attachment of the stirrup to the wall of the vestibular window, at least none that could exert any noticeable influence on its position and motion;

(3) the stirrup never cease pressing against the membrane of the vestibular window.

As is readily apparent with a little reflection, the moment one of the above conditions is violated, variations in air pressure would either have scarcely any effect on the inner ear fluid, or else would act according to a completely changed set of laws.

In order to secure fulfillment of the third condition, the pressure maintained against the membrane of the vestibular window by *M. tensor tympani*, which draws the hammer handle inward, must always remain at such a level that it considerably exceeds the greatest variations in pressure that could ever be expected to occur in hearing. One effect of this pressure is probably registered at the cochlear or vestibular window, either as a tensing or a bending (stretching, variation in shape) of the membrane. Thus *M. tensor tympani* establishes the most favorable pressure for accurate hearing.

The pressure depends only on the position of the handle of the hammer, and to produce the required attitude of this handle, the tension of the muscle must be just enough to maintain a balance with the tension of the eardrum at this attitude. Whether the resulting tension of the eardrum is more or less, is of no consequence; it is only necessary, as we shall now show, that the tension remain so great that only a very small part of the mechanical force of the waves striking the ear is lost to the air within the tympanic cavity.

When a stretched membrane in the open air is struck by a sound wave, an oscillation of the membrane is generated, as well as a reflected air wave and a continuing (refracted) air wave. How the mechanical force of the sound wave is distributed among these three effects, depends upon the tension of the membrane. If the tension is very slight, the first two effects are very weak, and the sound wave proceeds onward, nearly unchanged. If, on the other hand, the membrane is so taut that its movements are only very small in comparison with the vibrations of the air particles of the sound wave striking it, it can impart to the air beyond it only very small movements, and hence can modify its pressure only slightly, and nearly the entire variation in pressure on the front of the membrane is absorbed by the tension of the membrane. In addition, when the membrane is stretched out *in the open air,* a reflected wave is produced.

Thus the position of the lensbone[11] relative to the vestibular window cannot remain invariable; but by rotation of the anvil about its point of attachment (the drum-joint), the lensbone can only be displaced parallel to the long axis of the vestibular (oval) window, and thus only in this direction is a rotation of the stirrup about the center of the anvil joint surface necessary to maintain the stirrup footplate at its position. Since it is only for this direction that a mechanism (*M. stapedius*) is available to freely rotate the stirrup with respect to the knob of the anvil, but not for the perpendicular direction, one may therefore reasonably assume that such a latter mechanism is not required, since the knob is already being maintained at an unvarying height.

VI.

A counterbalance for the tension of the tendon of *M. tensor tympani* is maintained by the attachment of the handle of the hammer to the eardrum, and of the eardrum to the *sulcus tympanicus*. The attachment of the eardrum to the handle of the hammer reaches only slightly higher (according to Tröltsch and Gerlach) than the point of insertion of the tendon, and its terminus itself lies higher than the terminus of the *sulcus tympanicus*.

Obviously, therefore, the fastening of the eardrum at the *sulcus tympanicus* to *M. tensor tympani* cannot by itself maintain a balance. Much more is necessary for this balance of the hammer: there must be equally large and contrary torques for the part that lies above the point of insertion, and for the handle that lies below it. We can look for this force necessary to establish a balance:

(1) either in the binding of the drumskin to the superficial layers of skin of the exterior auditory canal,

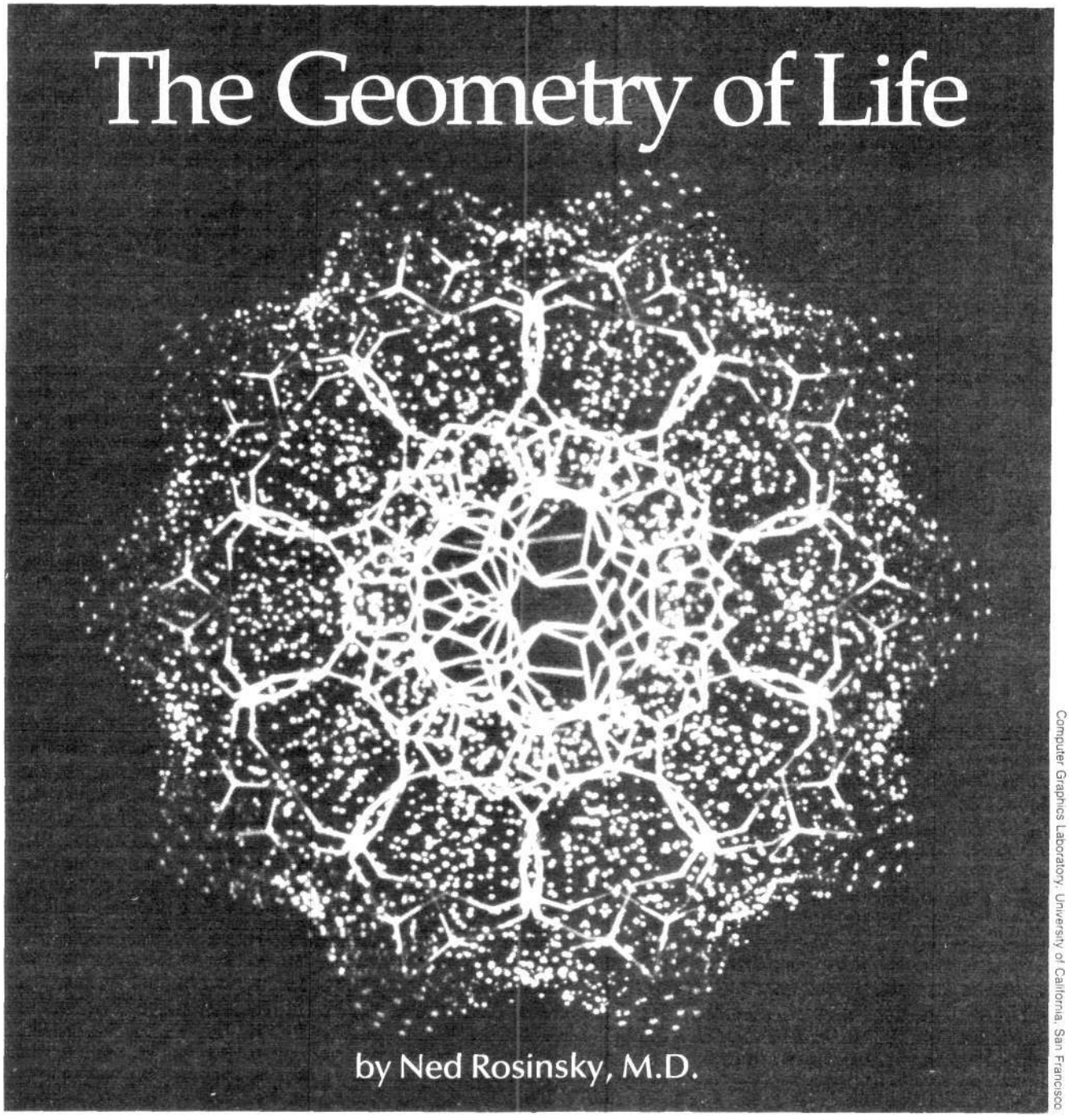
(2) or in the effect of the posterior fold of the eardrum,

(3) or perhaps in the combined effect of the attachments of the hammer head to the wall of the tympanic cavity by the anvil on the one side, and by the *Lig. superior Arnoldi* on the other. These attachments form an angle extended somewhat toward the vertex of the short process and, when under tension, press this vertex against the eardrum.

Notes

1. Riemann defines "Klang" as "die Beschaffenheit des Schalles" (the quality of the sound), which derives from "the mechanical origin" of the sound. Therefore, we translate Klang as timbre, which refers to the relationship between a tone and its harmonics as produced by a specific sound-source.
2. The speed of pressure fluctuation simultaneously captures both the frequencies and intensities of a sound.
3. This refers to one of Helmholtz's instructions to concert goers.
4. Riemann here refers to the annular ligament attaching the stapes to the oval window.
5. The stapedius muscle is attached to the pyramidal eminence or pyramid and to the neck of the stapes.
6. A mucous membrane.
7. The short process of the anvil is bound to the bony walls of the tympanic cavity or "drum." Riemann uses the image of the tympanic cavity as a drum, the eardrum as the drumskin, and the ossicles as the mechanism that drums against the oval window.
8. Its short process.
9. Between the edge of the eardrum and the petrous pyramid bone.
10. Riemann's draft ends here.
11. That is, the stapes footplate.

The Geometry of Life



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by Ned Rosinsky, M.D.

The most powerful experimental tool in modern biology is the study of spectra, the patterns of absorption and emission of light and other frequencies of electromagnetic radiation by biological substances. It is by resonating that absorption and emission presumably occur; therefore, the spectrum is an indication of the specific frequencies at which a biological or other process is capable of resonating. These resonant frequencies, in turn, define the modes of work of which a process is capable. A "frequency" is usually thought of as some sort of a back-and-forth oscillation motion, but in fact such motion is actually always rotational in character, and this rotational motion is potentially capable of doing work; that is, forcing useful transformations (Figure 1). It is these transformations or *work functions* that are the clues to biological processes and our ability to change these processes when they have harmful effects, such as the growth of cancerous tissue.

The broad gamut of electromagnetic frequencies, from the low-frequency radiowaves up to the very high-frequency gamma rays, can do work on a wide range of phenomena (Figure 2). During the course of this century, chemists and physicists with a reductionist orientation have used data garnered from some variations of this technique (X-ray crystallography, for example) to produce the currently accepted models of molecular biology, including the double-helix picture of DNA. What has emerged from this work is a body of science—molecular biology—that aims to explain biology as a glorified version of chemistry and physics. This

reductionist approach has a fundamental weakness, which comes out most clearly in the question of evolution: It ultimately treats biological evolution, including the evolution of man, as a random statistical event. Since we know that this cannot be true, this absurdity undercuts the entire framework of molecular biology.

Recently, several new areas of electromagnetic spectrum studies of substances such as DNA and chlorophyll have opened up a more hopeful approach, based on the notion that biology—life—fundamentally consists of processes of change or transformation and that there are specific types of such changes characteristic of life. In particular, these studies emphasize the idea of *biological work*, as useful transformations.

These studies are unique because they are looking at biological entities using parts of the spectrum that in certain respects have been largely ignored; namely, the radiowave to microwave region. It is understandable why these findings are new: First, until recently it was extremely difficult to do some of the work because of technical problems. Second, the interpretation of the data requires a methodological approach diametrically opposed to the usual chemistry notions, emphasizing coherent activity over long ranges rather than breaking up action into smaller and smaller independent components. Radiowave and microwave frequencies are appropriate to study these kinds of phenomena in biology, because the lower frequencies correspond to smaller quanta or packets of work potential, which are typical of the electromagnetic fields involved in long-range coherence in DNA, proteins, water, and so on. (The smallest division of electromagnetic energy is called a quantum, and its size is proportional to the frequency; thus low frequencies correspond to smaller quanta.)

The currently accepted usage of these frequencies is itself interesting: Current theory associates some bands of microwave absorption with such action as changes in rotation of molecules and inversion of left/right-handedness of certain dysymmetric substances, such as nitrogen compounds containing three different groups. Radiowaves are associated with changes in the rotation of nuclei and electrons and the consequent magnetic field effects. The more controversial use of this part of the spectrum involves lasers (microwave lasers or masers), pulsing the energy of radiowaves, and observations of possible radical upshifts in emitted frequencies compared to absorbed frequencies.

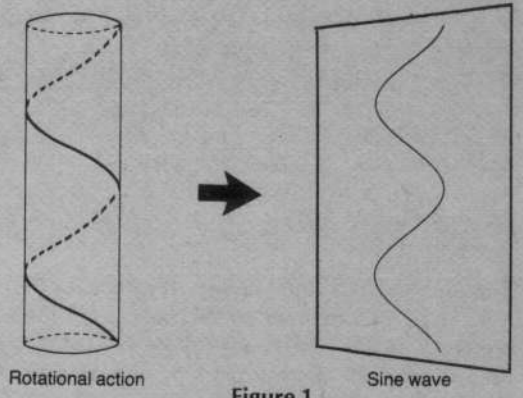


Figure 1
PROJECTION OF A CYLINDRICAL SPIRAL ONTO A PLANE

A cylindrical spiral (rotational action) projected perpendicular to the axis of the cylinder onto a plane forms a sine wave. This suggests that rotational action, which we know to be the primary form of work, may appear under certain circumstances as a simple oscillation, like that of electromagnetic waves.

These latter techniques bring out new and higher-order coherent effects that challenge the current reductionist dogma of biochemistry and point toward the new approach outlined here. The various areas are termed *nonlinear spectroscopy* because of the highly self-ordered nature of the coherent effects implied by the data.

The ultimate aim in this approach is to define what makes life unique, what makes it qualitatively different from chemistry and physics. Once we have done this, we will be in a much better position to go on to an improved understanding of a host of biological questions, including the problems of cancer and aging of tissues.

The Radiowave and Microwave Experiments

The intense study of coherent microwave effects on biological tissue began in the early 1970s with the improvement of microwave lasers. The cardinal finding during those years was that *lased* microwaves at very low intensities (in the range of milliwatts per square centimeter), for periods of seconds to hours, could cause changes in the functioning of living organisms, such as increases in specific enzyme activity and increases in bacteria and yeast cell division rates. All these effects occurred with no measurable change in temperature, as the level of radiation was extremely low.

Another intriguing finding was the existence of a threshold for each effect such that if the power of the input was below the threshold, there would be no measurable effect. As soon as the power reached the threshold, the effect occurred; raising the power further gave no increase in the effect. This "either/or" condition, together with the low total energy required, suggested that some sort of phase transition was going on, rather than a more continuous quantitative change. In addition, in nearly every case of this type of finding, the effect occurred only if the input was of a very specific frequency, thus implying that there was some sort of resonant uptake of the wave. The idea of resonance implies that a specific geometry is involved in the uptake of the specific frequency and also that the geometry is somehow changed as a result of the uptake (Figure 3).

This line of research paralleled an interest in using pulsed radiowaves to study the structure of water, work that had been going on slowly since the early 1950s in the form of a technique called nuclear magnetic resonance, or NMR. The usual use of radiowaves as a diagnostic technique in organic chemistry involves very fine-tuned frequency measurements with continuous input, and by the usual theory the absorptions and emissions correlate with magnetic spins of molecules. However, another use of radiowaves is in a pulsed mode. In this procedure, the test material is placed in a strong constant magnetic field, which, according to

theory, aligns the hydrogen protons of water and other substances. Then a second alternating magnetic field at radiowave frequencies is imposed as a pulse of a broad band of radiowave frequencies. The absorption, and particularly the time of reemission of this second field, is closely related to the degree of periodicity of hydrogen protons (how regularly they are arranged in some notion of space).

For example, in ice, in which the crystalline structure is highly periodic, the reemission occurs rapidly, while in water it is slower; in the more amorphous steam it is slower still. Since the reemission depends on the periodicity of the substance over a long distance, the reemission presumably is a product of some sort of coherent activity. The most interesting finding here is that the NMR of the water in living cells, the water of the cytoplasm, shows much more structure or periodicity than would otherwise be expected, and the water in cancer tissue is less structured, by NMR measurement, than the water in normal tissue (Figure 4).

These two strong indications, from radiowave and microwave effects, of some form of higher geometric ordering in living tissues set the stage for the third and most intriguing effect: Certain biological substances such as chlorophyll and probably DNA can absorb microwaves at specific frequencies and then reemit the waves at higher frequencies. The significance of this finding from a geometric perspective, as evidence of biological "work" of a very basic sort, will be explored below. The technique by which these experiments are done is shown in Figure 5.

There is just a handful of researchers working in the abovementioned areas of coherent effects from radio and microwaves, and the models they use to explain these effects come generally from solid state physics. For example, Earl Prohofsky, a leader in the field working at Purdue University, has taken the double-helix model of DNA and looked at all the various ways in which it could "resonate" in response to input of energy.[1] Given the complex model used, which is like a very complicated "slinky" toy, the vibrational modes are numerous and appallingly complicated in their interactions (Figure 6). Nevertheless, by assuming that there

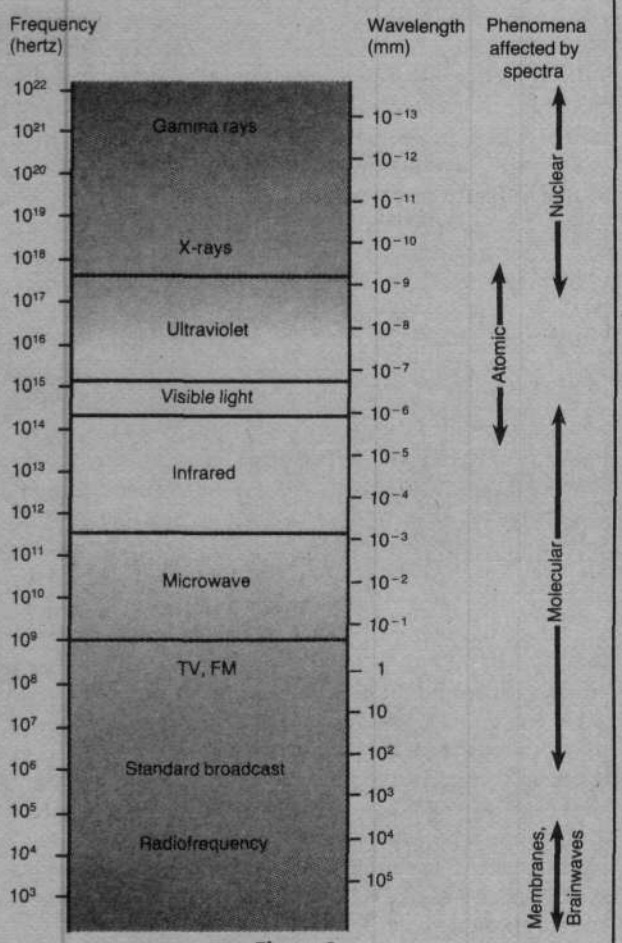
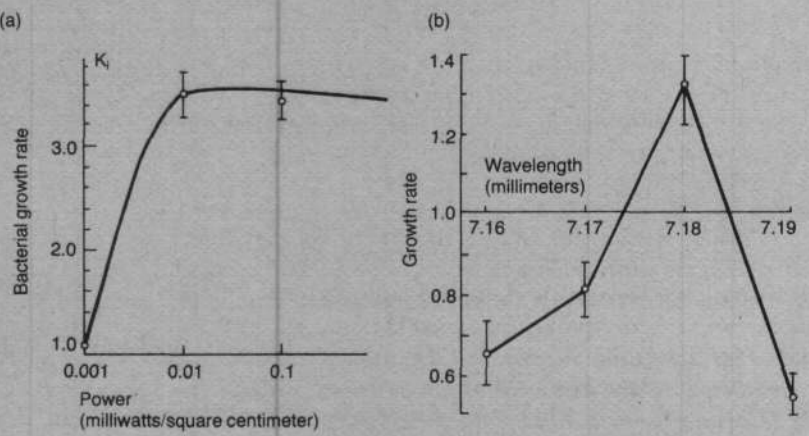


Figure 2
THE ELECTROMAGNETIC SPECTRUM
Electromagnetic waves range in frequency from extremely low radiowaves, to visible light, to the very high frequency gamma rays. Each frequency band has characteristic effects when absorbed, as shown.

Figure 3
EFFECT OF LASED MICROWAVES ON BACTERIAL GROWTH RATE
Bacterial growth rate is unaffected by lased microwaves until the power reaches a critical threshold; at that point the rate increases in almost a stepwise fashion, with no more increase as the power is further increased (a). The power at the step-point is below the amount required to perceptibly heat the bacteria. In (b) the frequency of the microwave input is varied, and the increase in growth rate occurs only at a narrow frequency range, implying a resonant uptake of the wave in producing the effect.



Source: A.Z. Smolyanskaya and R.L. Vilenskaya: "Effects of Millimeter-band Electromagnetic Radiation on the Functional Activity of Certain Genetic Elements of Bacterial Cells," *Sov. Phys. -Usp.*, Vol. 16, No. 4 (1974), p. 571; N.D. Devyatkov, "Influence of Millimeter-band Electromagnetic Radiation on Biological Objects," *Sov. Phys. -Usp.*, Vol. 16, No. 4 (1974), p. 568.

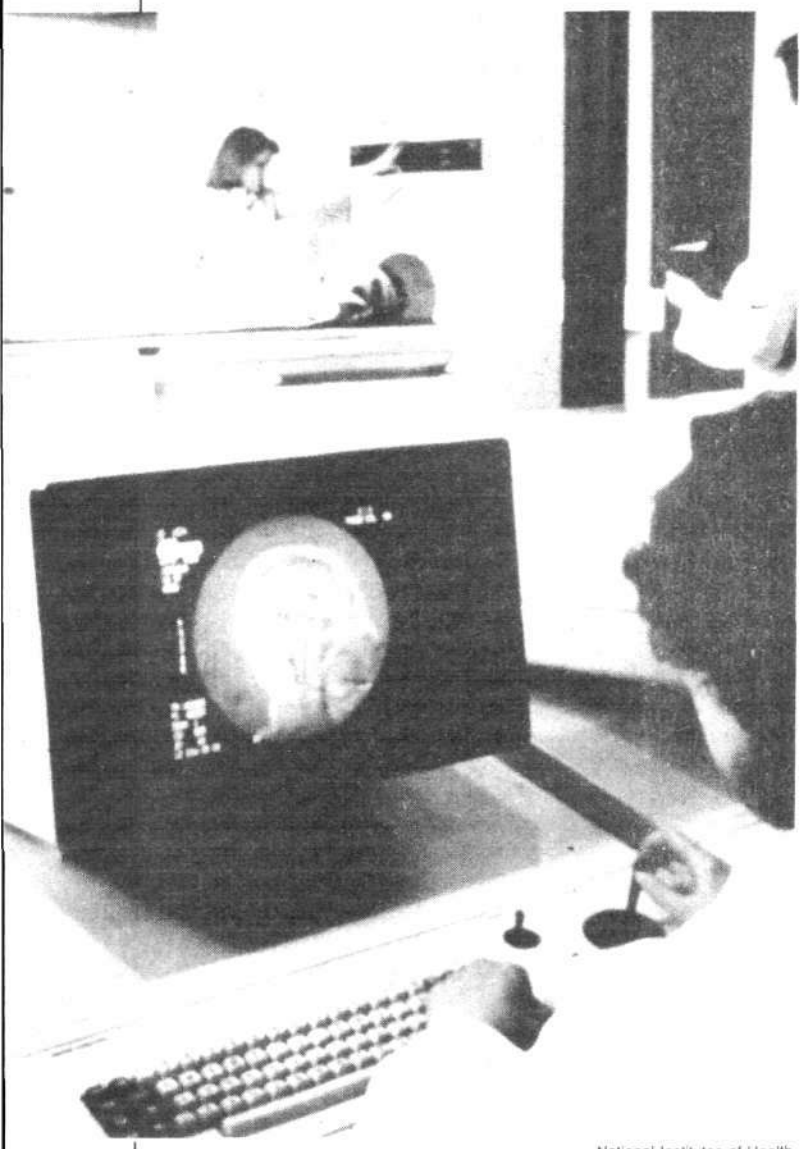


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Figure 4
NUCLEAR MAGNETIC RESONANCE
On the screen is an NMR scanner image of a sagittal section of the brain, a view that is a unique capability of the NMR Technology. In the background is an NMR scanner. Notice the extreme detail possible with this technique, especially the details of the soft tissues which usually are invisible with standard X-rays.

REEMISSION OF RADIOWAVE FREQUENCY IN MAMMARY GLAND TISSUE

Tissue and number of samples	T_1 (sec)
Pure water	3.1
Tumor (5)	0.920 ± 0.047
Nodule (5)	0.451 ± 0.021
Normal pregnant Mammary gland (5)	0.380 ± 0.041

Source: C.F. Hazlewood et al., "Distinction Between the Preneoplastic and Neoplastic State of Murine Mammary Glands," *Proc. Nat. Acad. Sci.*, Vol. 69:6 (June 1972) pp. 1478-1480.

Shown are the times of reemission of a pulse of energy at radiofrequency bands in mammary gland tissue and water. All samples are placed in a strong constant magnetic field. Then a second alternating magnetic field in a radiowave band is imposed and the energy is absorbed and then reemitted. Normal pregnant mammary gland tissue reemits faster than a premalignant nodule, which in turn is faster than a cancer, which in turn is faster than pure water. By making use of these differences in the states of water, NMR researchers can visualize a cancer deep within the body.

is long-range coherence and then following the development of the interaction by computer analysis, Prohofsky has been able to accurately predict the major resonant uptake frequencies of DNA in the microwave region (Figure 7).

Prohofsky is currently including the effects of water around the DNA to enhance the accuracy of his model, and he is having the same success there. Many of these theoretical predictions are also being confirmed in experiments by Mays Swicord of the Bureau of Radiological Health in Rockland, Md.[2] Prohofsky has further predicted that the long-range phase-coherent action he is modeling determines the major changes in DNA in the course of its functioning in the production of RNA for protein synthesis, as well as its own replication with cell division (Figure 8).

Although Prohofsky has been successful using models from solid state physics, there are still major gaps in the predictions, and he is unable to explain the findings of large upshifts in the emitted frequencies. James Frazer, who works at the Texas Medical Center in Houston, originally found this upshift in chlorophyll in 1969, but his line of research was aborted by the general cutoff of research funding with the collapse of the NASA program. Frazer, a close follower of Prohofsky's work, is currently replicating this using DNA.[3]

Diagnosing and Treating Cancer

Frazer is also one of the early pioneers of NMR spectroscopy, with a particular interest in using the study of the state of water as a diagnostic tool for understanding pathological processes such as cancer. An NMR scanner aided by computer image reconstruction can visualize a cancer located deep within the body more accurately in most cases than can a computerized tomography or CT scanner, and certainly better than a usual X-ray. The cancer "lights up" because of the change in the state of water and other metabolic conditions, compared to normal tissue.

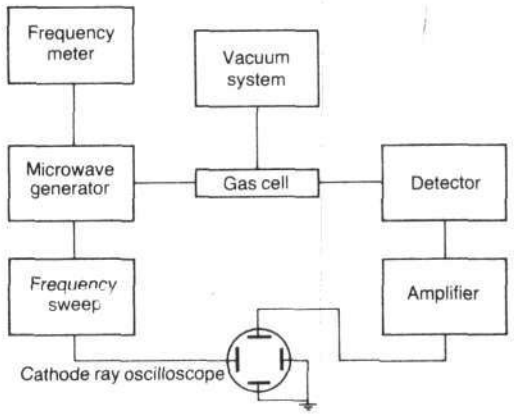


Figure 5
MICROWAVE SPECTROMETER
A diagram of a simple apparatus used for measuring microwaves. Microwaves are transmitted by a generator through the specimen container, in this case a low pressure gas for measuring inversion transitions. A crystal detector picks up the microwaves, its signal amplified by a broad band amplifier. A cathode ray oscilloscope visualizes the results. If there are rotation or inversion transitions present in the frequency region sweep, the signal level at the detector decreases, and the spectrum lines appear on the oscilloscope.

Once the cancer is in view, the power of the NMR machine can be turned up to increase the energy input, which raises the temperature of the tumor and kills it. The temperatures involved go up to approximately 119 degrees Fahrenheit (with some cancers other frequencies are used, and sometimes ultrasound is used as well). Frazer has used this technique, termed *hyperthermia*, on more than 130 animals during the past six months (since January 1984) with 100 percent tumor destruction and no recurrence of tumor so far.[3] Frazer has also treated scores of human cancer patients during this time, patients who have failed all currently used treatments (chemotherapy, radiation, and/or surgery), and he has produced shrinkage of the tumor in more than 60 percent of the cases so far. The heat treatment can also increase the effect of chemotherapy by up to 30-fold. "If you want to eradicate cancer, this is one way to go," Frazer recently stated. Since the cancer takes up radiowaves and microwaves differently from normal tissue, Frazer is attempting to find frequencies that will affect only the cancer, thus even further reducing the risk of the treatment to normal tissue.

In addition to the impressive effects the treatment has on the tumor directly, Frazer has found that after destroying a large mass of tumor, other metastatic tumors located at distant areas of the body that have not been directly treated sometimes tend to shrink. He has postulated that the immune system, which is known to be adversely affected by cancer, improves with the destruction of the main tumor mass and is then in a better position to fight against the rest of the cancer. Measurements of the immune system response to the destruction of a large tumor are now under way to test this hypothesis. Frazer also thinks that the hyperthermia treatment does not directly harm the immune system, which is in contrast to the damaging effects most chemotherapy and radiotherapy have on the immune system.

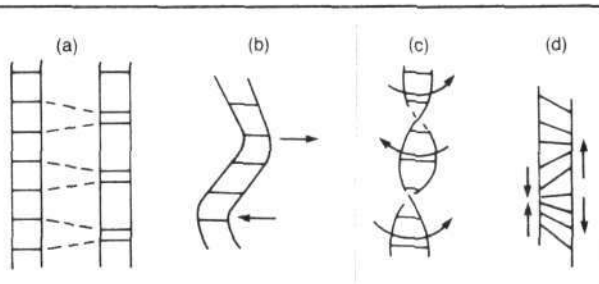


Figure 6
DNA MOLECULAR OSCILLATION MODEL
The DNA double helix is treated in this simple model as a flexible ladder or "slinky" with recurring distortions possible. Several modes of distortion are shown: (a) a longitudinal mode, (b) a transverse mode, (c) a torsional mode, and (d) an optical mode, in which the two backbones move in opposite directions.

Source: E. Prohofsky, *Biopolymers*, Vol. 20, (New York: John Wiley and Sons, 1981), p. 833.

A Geometric Approach to Resonance Findings

Although Prohofsky and Frazer have made outstanding contributions in their areas, the approach of using solid state physics to model living processes is at bottom no better than the simpler statistical notions of chemistry. We end up with a model that looks like a "slinky" toy (based on

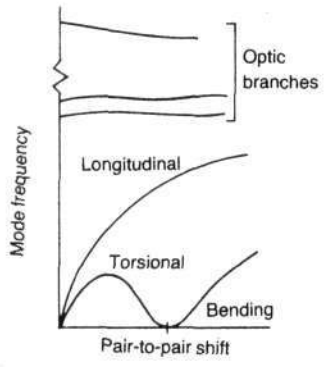


Figure 7
DNA MICROWAVE SPECTRUM
The microwave modes are related to the degree of shift from DNA subunit to subunit (the "steps" in the ladder of Figure 6). The large number of modes testifies to the complexity of the overall spectrum.

Source: E. Prohofsky: *Biopolymers*, Vol. 20 (New York: John Wiley and Sons, 1981), p. 833.

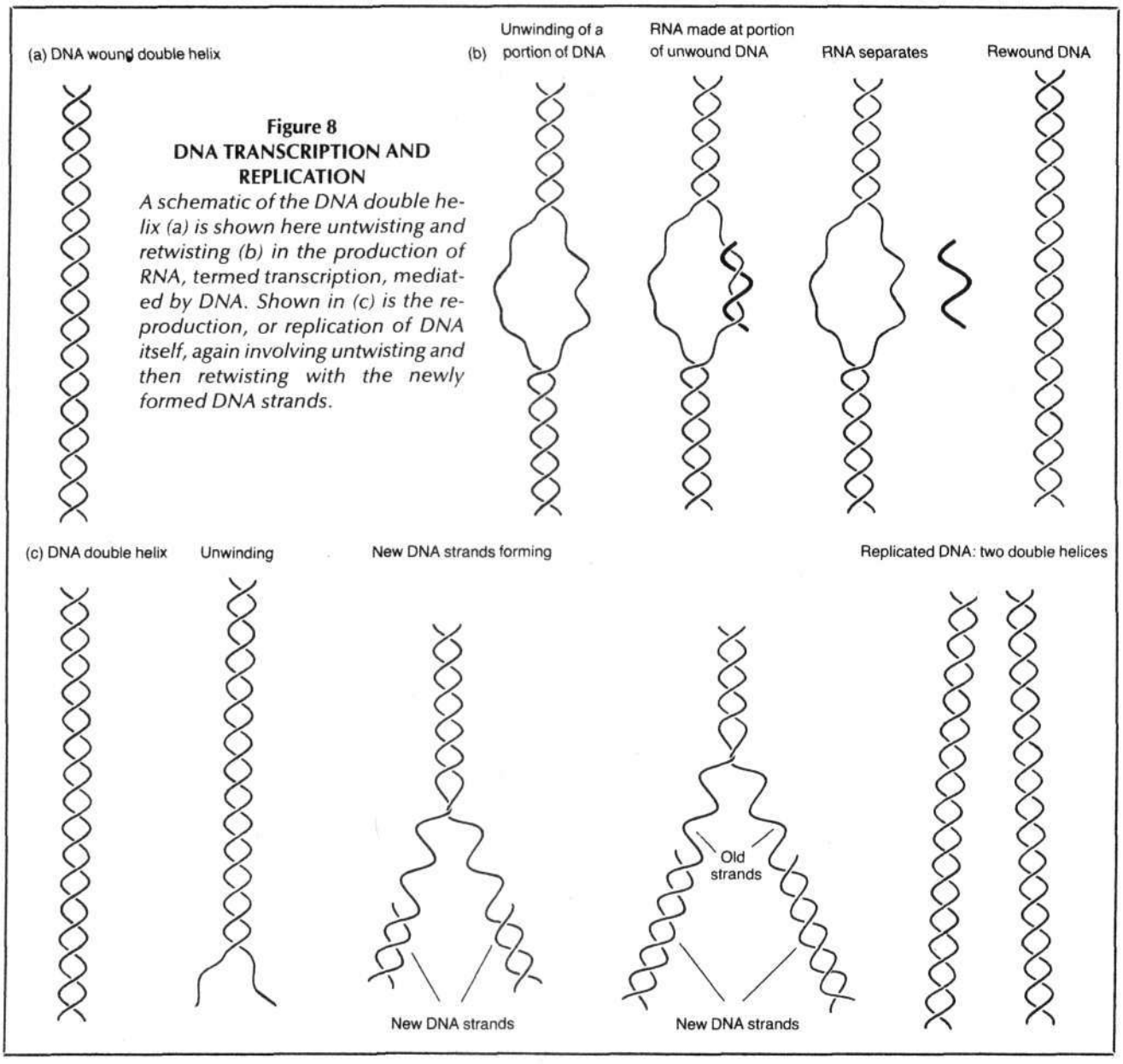


Figure 8
DNA TRANSCRIPTION AND REPLICATION
A schematic of the DNA double helix (a) is shown here untwisting and retwisting (b) in the production of RNA, termed transcription, mediated by DNA. Shown in (c) is the reproduction, or replication of DNA itself, again involving untwisting and then retwisting with the newly formed DNA strands.

interacting or coupled simple oscillators) whose various contortions do not have the aspect of qualitative development upon which we know life must be based. We need an entirely new perspective from which we can frame hypotheses. The wealth of interesting and potentially life-saving findings in biological resonance effects demands it.

We outline here an approach based on a rigorous geometrical orientation to the idea of work in general and further modified by geometric considerations peculiar to life. If they are to make sense of the data from resonance experiments, scientists in the relevant fields of research must use this approach, although the specific elaborations will vary with the experimental subject.

We begin with a rigorous notion of "work" as the basis for all action, biological or not. Let us start with the idea that the simplest form of action is rotation, and that work is a change in the speed or frequency of rotation.[4] The geometry we use to represent this situation is a spiral on a torus: The torus defines the least quantum of action (we know that quanta of action exist empirically) as an increase of the spiral by one turn as it makes one complete revolution around the torus (Figure 9a).

Since much of Prohofsky's work centers on DNA, and also since the currently accepted biochemistry hinges on DNA as well, we will focus on DNA here, but the discussion could apply as well to other aspects of living tissue.

Now let us look at DNA more closely. It is in some sense a double helix. How can this be related to the idea of a work function? As a first step, let us hypothesize that this double helix may be simply a projection of a torus with a single helix on side view, producing what appears to be a double helix (Figure 9b). This implies that, if the DNA is functionally a double helix, then the two strands should be functionally antiparallel, as they are geometrically antiparallel in the

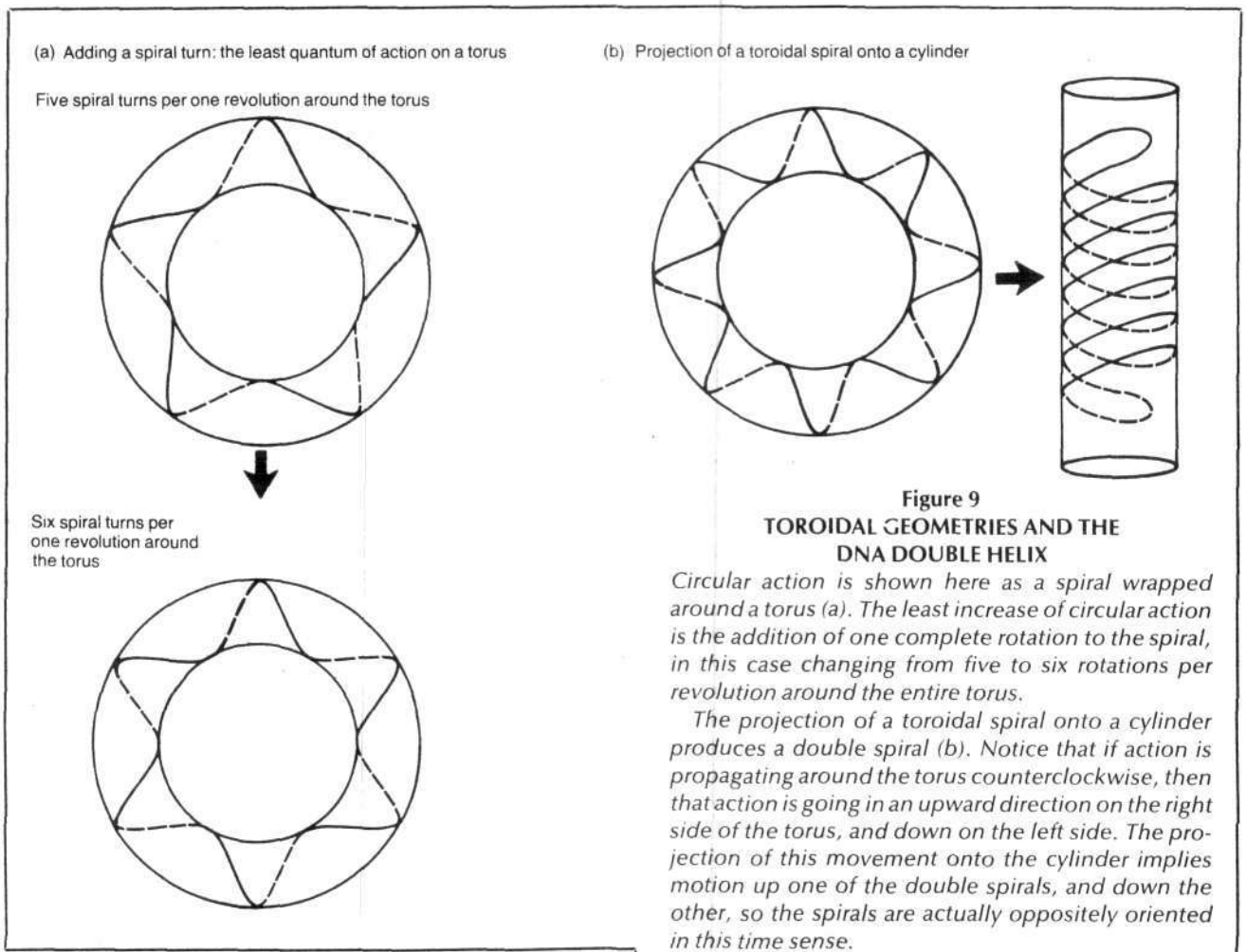


Figure 9
TOROIDAL GEOMETRIES AND THE DNA DOUBLE HELIX

Circular action is shown here as a spiral wrapped around a torus (a). The least increase of circular action is the addition of one complete rotation to the spiral, in this case changing from five to six rotations per revolution around the entire torus.

The projection of a toroidal spiral onto a cylinder produces a double spiral (b). Notice that if action is propagating around the torus counterclockwise, then that action is going in an upward direction on the right side of the torus, and down on the left side. The projection of this movement onto the cylinder implies motion up one of the double spirals, and down the other, so the spirals are actually oppositely oriented in this time sense.

A detail of the DNA double helix (c), showing that the two strands are oppositely directed in terms of the orientation of the ribose sugar subunits, although both strands are right-handed in position.

figure. In fact, they are known to be antiparallel in orientation, so there is some initial confirmation of this hypothesis (Figure 9c).

Biology and Work Functions

We can then look at biological action more generally: Biological action, such as growth, is not only associated with the notion of work as rotation, but also with the idea of qualitative advancement. This advancement or development in biological organisms has the form of being self-similar, as any geometrically growing process is. The most efficient representation of this idea of rotation with self-similar growth is a conical logarithmic spiral (Figure 10). Growth of the spiral represents development as work is done. The self-similar aspect of this spiral connects directly to the idea of biological work, since living organisms are characteristically self-similar in their morphology. This consideration, therefore, takes us beyond the inorganic realm.

Living processes are self-similar because biological growth proceeds geometrically, while inorganic growth proceeds arithmetically, by adding. This distinction must be understood in the qualitative sense; a dead crystal may grow in a self-similar fashion, say, remaining cubical and getting symmetrically larger, but there is no qualitative change as the crystal grows, only simple accretion. In contrast, biological growth occurs as an increase in the overall organism as a unified entity, and in that qualitative sense there is self-similarity. Thus the shapes characteristic of biology are those related to self-similarity, most prominently the logarithmic spiral and the golden mean.

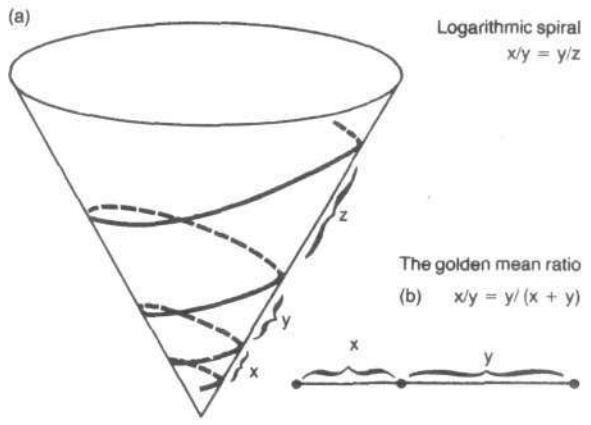


Figure 10
LOGARITHMIC SPIRAL ON A CONE AND THE GOLDEN MEAN RATIO

The logarithmic spiral (a) is a self-similar function: Each turn is identical to the preceding one except for a constant size-proportional factor. *If each turn represents a qualitative advancement in a developing process, then the function correctly models the underlying dynamic of biological growth.*

Another geometric characteristic of biological growth is the golden mean, the ratio of division in which the smaller part is to the larger as the larger is to the whole (b). This ratio reappears throughout living anatomy because of the self-similar nature of biological growth; in the human, for example, the waist divides the body height into golden mean proportions.

While a single logarithmic spiral on a cone represents a work function, a more elaborated picture is the action of one work process on another, in which one spiral is "running down" in the process of expanding the work potential of another spiral (Figure 11). The intersection of this double cone defines double conical action as the basis for useful work.

If the cone is changed so that the sides become parallel, the figure changes into a cylinder in which the diameter does not enlarge as the spiral propagates. We can use the cylinder to indicate the propagation of work potential at a steady rate, without the increase or decrease of that potential. This type of cylindrical spiral function is characteristic of the propagation of light. In Figure 11, a cylindrical function takes a conical form as it begins to do work. A second cone is acted upon, has its work potential increased; then it goes on to propagate that new potential on a larger cylinder than the first.

Now to return to DNA and its double helix: DNA has an apparently cylindrical spiral form, but could this come about as some sort of projection of a conical work function? Exploring this hypothesis, look at the region of Figure 11 in which the two cones intersect. This is shown enlarged in Figure 12, and then projected onto a cylinder. This suggests the hypothesis that the cylindrical double spiral appearance of DNA arises as a projection onto a cylinder of this region of the double-spiral work function. The double conical region represents what we term a *singularity* in the transformation process.

Can we identify the double spiral of DNA with the double spiral of the work function as in Figure 12? Not necessarily; it may not be so simple. Let us look more carefully at the notion of double spiral action. We are dealing with a sin-

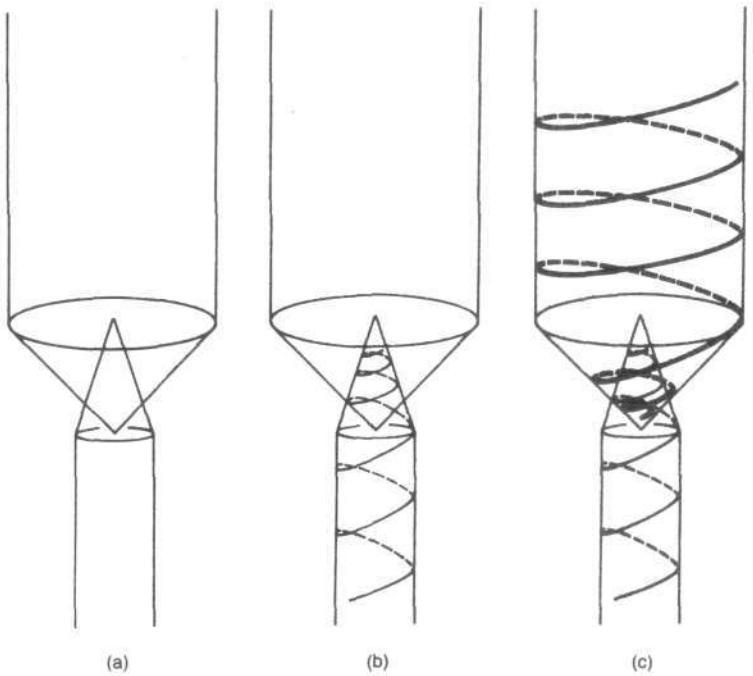


Figure 11
DOUBLE CONICAL WORK FUNCTION

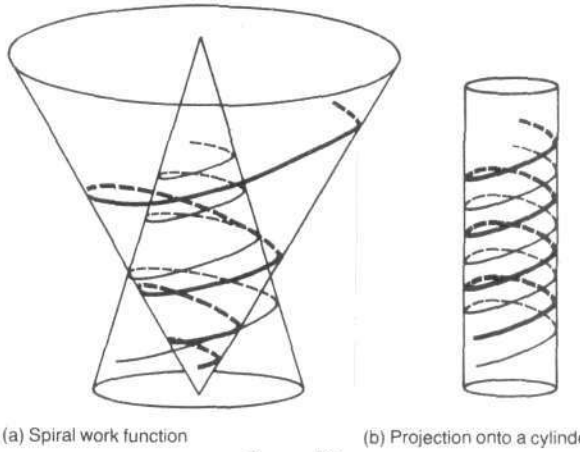
A narrow cylinder ending in a cone that overlaps the cone of a larger cylinder is shown in (a). A spiral on the narrow cylinder (b) represents an energy propagation function, in which the width of the spiral is not changing. The spiral then enters the cone and becomes narrower, losing its work potential. This narrow cone is coupled to the larger cone (c), driving the production of a spiral work function on the larger cone, which then goes on to propagate on the larger cylinder. Overall, there has been an upshift of frequency or energy density in the process. This is the elementary form of work, and its simplest representation is as a double conical function.

gularity, a qualitative transformation process. Thus, what we are looking for is a radical shift in the ordering principle of the geometry, not simply a quantitative shift in some isolated "parameter."

The best model of this kind of shift comes from Bernard Riemann in his work on shock waves as an elaboration of the spiral work function. Riemann showed rigorously that the propagation of a nonlinear wave results in a shock developing after a finite distance, similar to a sonic boom (Figure 13). A sonic boom shock wave arises because of the motion of a jet plane through air at supersonic speed. The air can propagate waves only up to the speed of sound, but the jet is moving through the air faster than the speed of sound because its motion is based on an action different from sound waves; in fact, it is based on the rapid expansion of gas burning in its engine. Thus, there are really two different rates of propagation involved, which occur in what we may term two *submanifolds*, the sound waves in air and the propagation of the jet. Although these two submanifolds have different maximum velocities of propagation, they are linked to one another, or coupled, so that one, the jet plane, can drive or push the other, the air waves, to their maximum velocity and beyond.

At this point the shock occurs, as shown in Figure 13. This creates a discontinuity in the pressure and actually changes the quality of the air at the shock front. Since neither of the two submanifolds can propagate work potential infinitely fast, we say that the potential is *retarded* as it propagates, and thus there is a degree of *retarded potential* associated with each submanifold. The retardation of potential propagation indicates that a certain amount of time is required to organize the medium to allow the propagation to occur. This difference in retarded potential allows one submanifold to drive the other to its limit, creating a singularity.

The notion of a double spiral connected to the process of generating a singularity, therefore, suggests that each spiral in the figure (not necessarily in the DNA) is in some sense a work function with a distinct degree of retarded potential; in fact, it is the difference in retarded potentials that generates the possibility for a shock wave as the smallest unit of qualitative work. Look again at DNA from this perspective and notice certain aspects that are relevant. In searching for submanifolds of DNA that have differing propagation rates for work potential, we begin by looking at the simplest topological distinction in a cylinder: There is an outside and an inside. Therefore, the simplest qualitative action for a cylinder, from a topological standpoint (topological meaning a geometric quality not associated with measurement), is the separation of the outside from



(a) Spiral work function (b) Projection onto a cylinder

Figure 12
PROJECTION OF THE DOUBLE CONE ONTO A CYLINDER

The conical intersection area from Figure 11 is shown here enlarged (a). This double conical geometry is then projected onto a cylinder (b), creating a double cylindrical spiral suggestive of the DNA geometry. Although the spirals are projected from oppositely oriented cones, they are both right-handed.

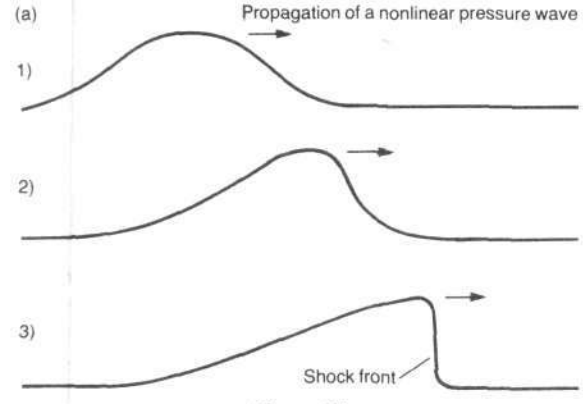
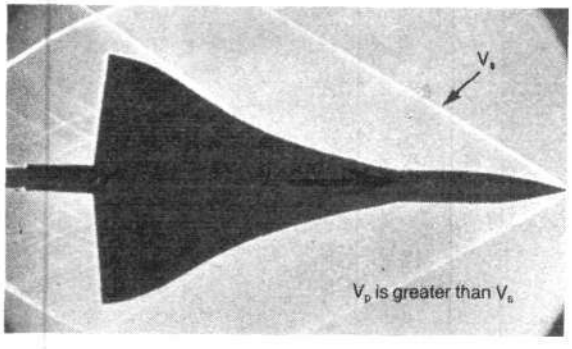


Figure 13
SHOCK WAVES

The progression of the shape of a nonlinear pressure wave as it travels (a). It is termed nonlinear because the higher pressure area moves forward faster than the lower pressure area. It tends to lean forward, similar to an ocean wave beginning to break at the beach. However, in this case the wave forms a sharp front that has a "shock" effect if it hits an obstacle.

The formation of a sonic boom wave at the front of a jet plane traveling at supersonic speed is shown in (b). The jet, moving faster than the speed of sound, "piles up" the air in front of it, creating a pressure situation similar to the shock in (a).

(b) Formation of sonic boom shock wave



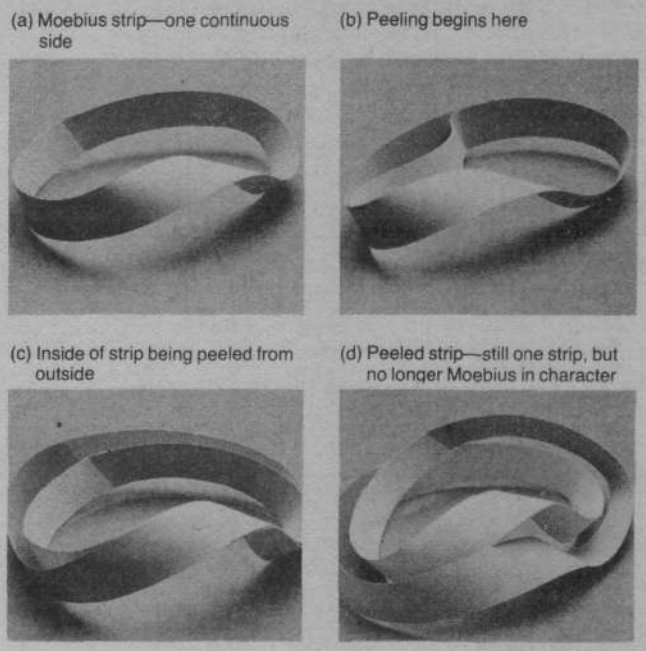


Figure 14
PEELING A MOEBIUS STRIP

A Moebius strip is a closed loop of ribbon or paper that has a half-turn before reconnecting. The two original sides or surfaces (the back and front surfaces of a ribbon) are thus connected together, so there is only one continuous "side" in the strip, as in (a). You can verify this by tracing one side of the ribbon around the strip; you should come out on the other side after making one complete revolution around the ribbon.

If the Moebius strip is peeled into two layers (c), the resulting figure is not two strips, but one. However, as shown in (d), the new strip has two half-turns (or one whole turn all together). Therefore, one side is not connected to the other as it was before and the strip is no longer Moebius in character. This demonstrates that an additional turn in a closed loop can result from the topological change of separating its outside from its inside.

the inside, in some sense. So we start looking for evidence of differing propagation rates of work potential on the outside versus the inside of the DNA, where the result of such propagation differences would be the opening up of the cylinder in some sense.

DNA 'Unpeeled'

As we get a more differentiated idea of what we are looking for from a rigorous methodological standpoint, we can expand our overview of the relevant data. The outside of DNA is, in fact, radically different in its potential propagation characteristics from the inside. The outside is highly electrically polarized, containing periodically occurring negatively charged phosphate groups that are associated with water, divalent positively charged metal ions such as calcium and zinc, and numerous multiply charged proteins, as well as potassium and sodium and other ions. The actual physical condition here is poorly understood, but one thing is certain: It is not at all approximated by any usual notion of chemistry, most emphatically not by any usual notion of the chemistry of water as separate self-evident molecules. Whatever the form of the action in this submanifold, it has an overall gross propagation rate of work potential differing significantly from the core of the DNA.

The core is largely formed by polycyclic purine and pyrimidine rings, which are overall in gross measure much less polarized than the outside of the cylinder. This change in degree of polarization results in a change in potential propagation rates. Prohofsky has predicted that these differences in propagation rates can cause separation of the two DNA strands, opening up the cylinder. DNA in some sense does open up and separate as part of the ongoing function of the cell in transcription of RNA for protein synthesis, as well as for replication of new DNA in cell division (Figure 8). This opening and closing of the double helix involves untwisting, followed by retwisting as in Figure 8, which is reminiscent of the change in number of cycles we referenced above as the hallmark of work.

How is the notion of separation of inside from outside related to the generation of increased frequency? As a first approximation, the topological change suggests a Moebius strip whose outside is continuous with its inside; the separation of these sides, by peeling the strip apart into two layers, generates additional turns in the strip (Figure 14).

This line of thought focuses us more specifically on the actual period of rotation of the DNA, the amount of DNA contained in one complete 360-degree revolution of one of the spirals, the DNA "wavelength" unit. To begin with, we can make use of the overall dimensions of the unit of rotation of the DNA: As depicted in Figure 15, one turn is 34 angstroms long (measured in the direction of the central axis), and the width of the double helix is 20 angstroms, to the nearest angstrom (1 angstrom is one 10-billionth of a meter). This gives a ratio of length to width that is equal to the golden mean, within the stated margin of error. The portion of DNA contained within one revolution of the double helix can be thought of as a "golden cylinder," similar to the idea of a golden rectangle whose sides are of the ratio of the golden mean.

The occurrence of the golden mean alerts us to look for other instances of this ratio, which is associated with self-similar processes generally. For example, the pentagon shape is characteristically found only in biological contexts, presumably because of its close relation to the golden mean (Figure 16). Looking again at the DNA, we note that each of the helices contains repeating phosphate groups, alternating with ribose, a five-carbon sugar. The sugar is in the form of a closed pentagon, and phosphorus is also characterized by a pentagonal geometry in that it has the capacity, in some sense, for five "chemical bonds" (though, again, we want to avoid the usual notions of chemistry at this stage).

Now taking the phosphate-ribose combination as a sub-

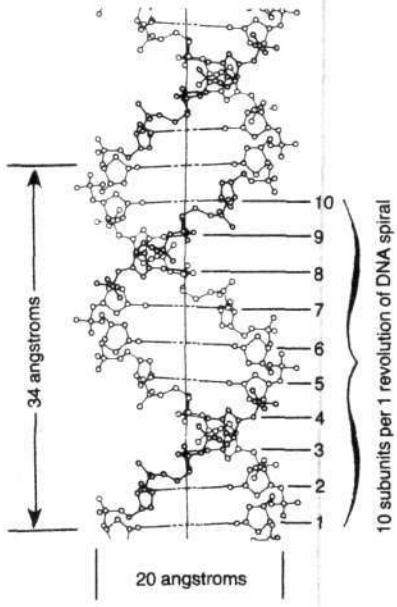


Figure 15
SIZE OF ONE DNA TWIST

One 360-degree turn of DNA measures 34 angstroms in the direction of the axis. The width of the molecule is 20 angstroms, to the nearest angstrom. These lengths, 34:20, are in the ratio of the golden mean, within the limits of the accuracy of the measurements.

Source: W. Fuller et al., *Progress in Biophysics* (New York: W. A. Benjamin, Inc., 1969), p. 122.

Figure 17
DNA PERIODIC SUBUNITS

Each DNA strand contains periodically recurring phosphate and sugar subunits. There are 10 such phosphate-sugar groups in each full 360-degree revolution of the DNA spiral. Thus the amount of rotation of each of these subunits around the DNA cylinder is 360 degrees divided by 10, or 36 degrees. This is exactly half the pentagon rotation, showing a close relation of the DNA subunit to the golden mean.

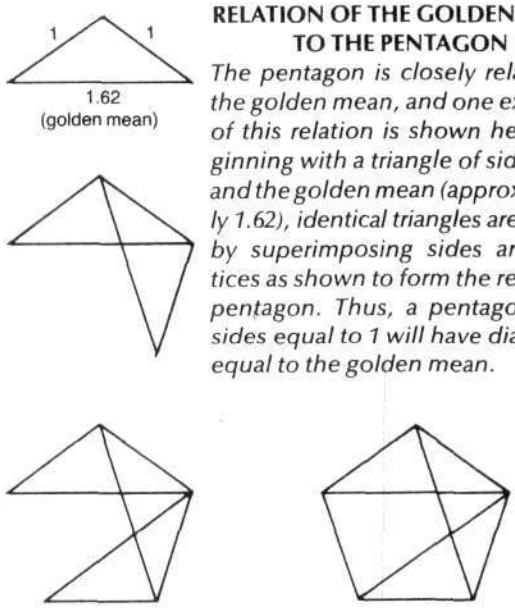


Figure 16
RELATION OF THE GOLDEN MEAN TO THE PENTAGON

The pentagon is closely related to the golden mean, and one example of this relation is shown here: Beginning with a triangle of sides 1, 1, and the golden mean (approximately 1.62), identical triangles are added by superimposing sides and vertices as shown to form the resulting pentagon. Thus, a pentagon with sides equal to 1 will have diagonals equal to the golden mean.

unit, we note that there are 10 such subunits per 360-degree rotation of each helix (Figure 17), forming a decagon on end view, which is also based on the golden mean since it contains the pentagon (see front cover photo).

How can we put together this apparent abundance of golden mean proportions? There are many possible hypotheses about their specific significance, but we will suggest only one at this time. Each of the subunits turns one-tenth of 360 degrees, or 36 degrees. This particular amount of rotation is prominent in the construction of a second pentagon by drawing all the diagonals of a given pentagon (Figure 18). The second pentagon is rotated by one-half the circular division of a side of the pentagon, or 36 degrees. If the process is repeated a second time, the next pentagon is again rotated 36 degrees, and its vertices now line up with the original figure. Thus the characteristic displacement angle of the phosphate groups in DNA, which themselves are in some sense pentagonal (and as well the pentagonal sugar groups), is the same angle as the rotation of pentagons in their creation from one another, as shown in Figure 18.

What about the change in the size of the pentagons in this construction? We do not see this change in size in the DNA, but rather than interpret size here as linear measurement, we may associate size with the work function and hypothesize that the change in size indicates a change in magnitude of work potential. In the figure, each time a new pentagon is constructed, the length of its side increases by the golden mean squared, or by a factor of approximately 2.62. Since there are 10 such rotations within one turn of DNA, the change in work potential per turn is 2.62 raised to the 10th power, or approximately 15,000. We would look for an increase in frequency in the spectrum of approximately this size, 4 powers of 10, as evidence for this hypothesis. Frazer has preliminary indications that microwave input into DNA will result in coherent output of infrared wavelength, which is, in fact, a difference of 4 orders of magnitude. This is parallel to Frazer's above-mentioned 1969 experiment using chlorophyll.[5]

This hypothesis based on one rotation of the DNA may imply that the same upshift should continue through the entire molecule, and since there may be millions of rotations in a single long DNA molecule, how can these be brought into the hypothesis? The answer again is not to look at the geometry too simplistically. When we say one rotation, we mean one functional rotation. If there is something akin to long-range coherence of action along the DNA, then each full rotation may be in coherent activity with the next, so the DNA as a whole may be thought of as functionally consisting of only one full rotation. The data of Mays

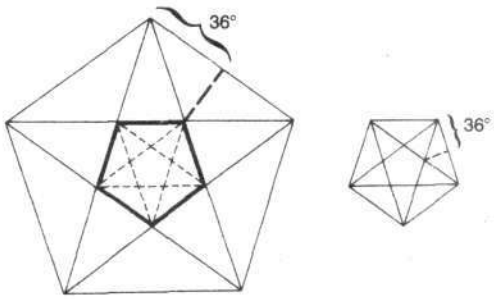


Figure 18
PENTAGONS GENERATED FROM PENTAGONS
If all the diagonals of a pentagon are drawn, as shown here in the large pentagon, their intersection forms another pentagon (heavy lines). Notice that the position of the vertices of the new, smaller pentagon is turned to be halfway between the vertices of the larger pentagon. Because the pentagon vertices are 72 degrees apart, this turning is 36 degrees. If the vertices of the smaller pentagon are again connected (dotted lines), a third pentagon is created, again rotated 36 degrees, so it now lines up exactly with the original pentagon figure.

The shrinking size of the pentagon side with each construction is equal to a factor of the golden mean squared, or approximately 2.62.

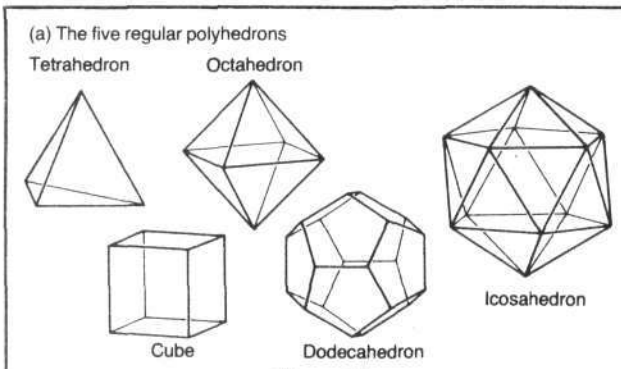
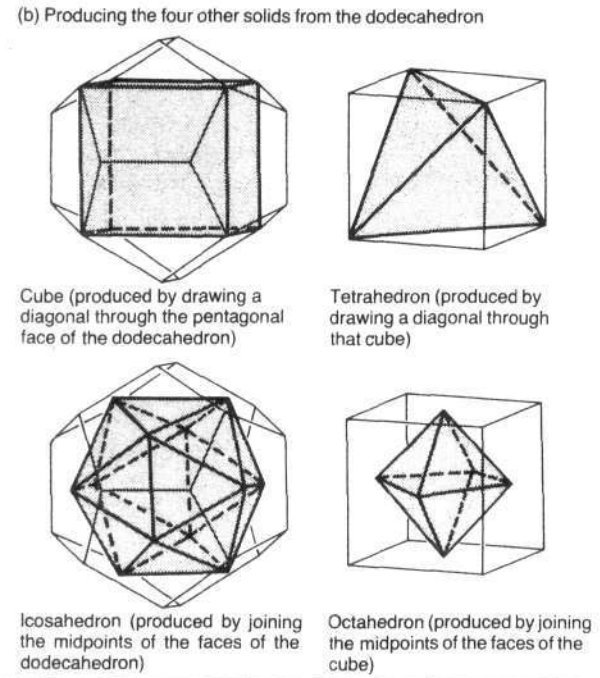


Figure 19
THE FIVE REGULAR POLYHEDRONS
The five regular polyhedrons, the three-dimensional figures whose faces are all the same regular polygon (a).

The dodecahedron can be used to construct the four other polyhedrons (b). Because it is unique in this respect, the dodecahedron is central in synthetic geometry approaches to physics and biology.



Swicord, implying long-range phase coherence in DNA, suggest something along these lines.

We can expand on the series of hypotheses generated so far with one more excursion. Kepler, like Plato, viewed the regular polyhedrons as crucial starting points for understanding the process of continuous creation in the universe. Among the five regular polyhedrons, the dodecahedron is considered the crucial one, because the other four can be constructed directly from it alone (Figure 19). The dodecahedron is composed of 12 regular pentagons, and we would be interested to see if there were a relation of the DNA period to the dodecahedron.

We begin by taking 10 pentagons, each representing one 36-degree turn of the helix, and attaching them to one another in the overall form approximating a horizontal sine wave (Figure 20a). Since the sine wave is actually a projection of a circular process, we take the series of pentagons so arranged and start to perform rotational action on them, around the vertical axis (Figure 20b and c). As the figure becomes curved around a vertical axis, it begins to suggest a spiral on the horizontal axis. Continuing the rotation, the pentagons ultimately meet one another, and form exactly into a dodecahedron (Figure 20d). This is a surprising result, since we started with only 10 faces, but notice that two faces are missing from the final figure. However, they are missing only in a certain sense, because the other faces define the boundaries of the missing surfaces, and therefore actually create the missing polygons with their edges.

Since the missing faces are opposite one another, the resulting topology is a torus. Thus, we have actually wrapped the DNA period around a torus, in fact twice, to arrive at this figure. This brings to the fore the relation of the pentagons in one helix to the pentagons of the other, just as the double-winding in the figure interdigitates exactly to form the regular polyhedron. This has implications for the characteristic spectrum expected from DNA, further defining the retarded potential expected in the region of the DNA surface.

The Origins of Life and the DNA Work Function

If the spiral work function has a wide and general significance, we would like to relate this idea to other fundamental questions in biology, and none is so basic as the riddle of the origin of life. The usually accepted notion of how life

(a)

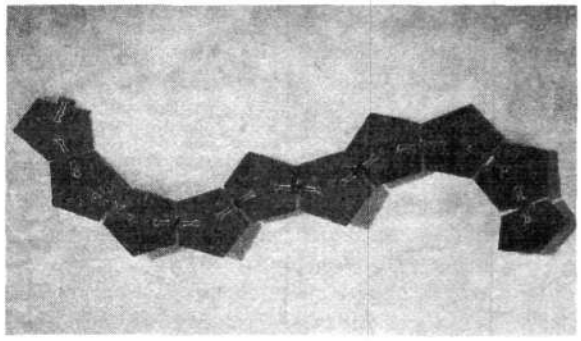
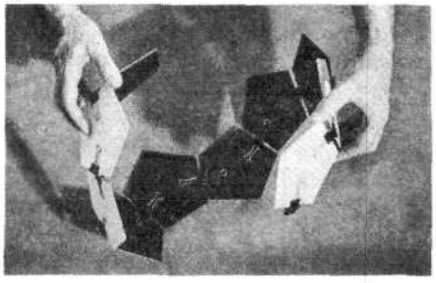


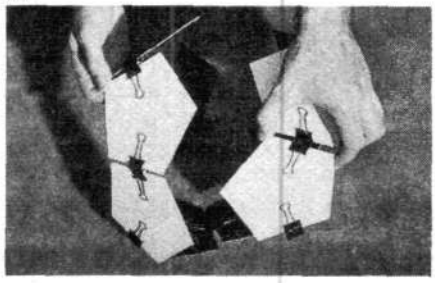
Figure 20
10 PENTAGONS AND THE DODECAHEDRON

Ten pentagons are attached roughly approximating the shape of a sine wave (a). This flat figure is progressively folded with an overall rotational motion, (b) and (c). Initially this produces an approximation to a spiral in three dimensions. Then, as the rotation continues, the pentagons meet one another and form a dodecahedron (d), but with two faces missing on opposite sides. (The space of the missing upper face is visible at the top of the pentagon in the photo; another face is missing at the base.) These faces are actually formed, however, by the edges of the neighboring pentagons, thus completing the figure.

(b)



(c)



(d)

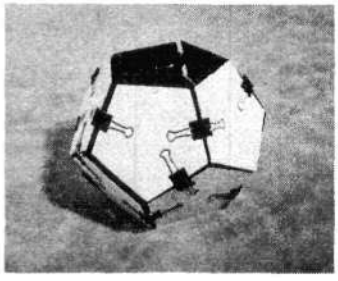


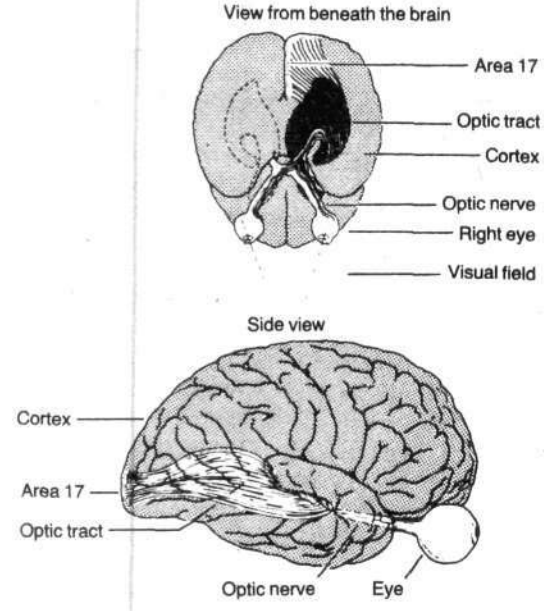
Figure 21
MAPPING OF RETINA TO THE CORTEX

The retina connects to the brain through a nerve fiber bundle (a). This fiber bundle maps the retina surface to the brain surface, much like a fiber-optic bundle carries a picture. However, this bundle redistributes the relative location of its fibers as the bundle grows back from the eye to the brain in the development of the embryo, causing a distortion of the proportions of the image it carries. This distortion is shown in a grid mapping (b).

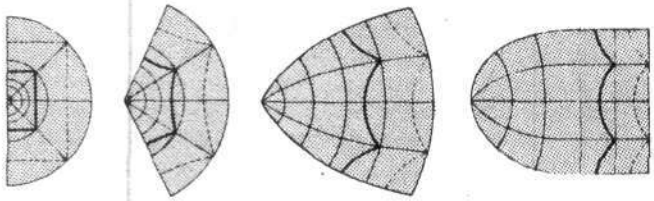
If a target-shaped grid image is on the retina, that image will distort to a nearly rectangular grid on the cortex. This distortion is caused by the shifting of the fiber bundle. It changes the shape of the image and provides an invariant shape on the cortex if the shape looked at gets symmetrically larger, such as the half-rectangle shown. This is extremely useful in depth perception, where shapes get symmetrically larger or smaller as they move toward or away from the viewer.

This mapping is actually a logarithmic function in two dimensions. The shifting in the fiber bundle during embryological development can be shown to arise as a result of the boundary conditions through which the bundle grows, much like a fluid distorts as it flows through pipes whose shape changes. The evolution of the vertebrates, from fish to primate, which produced this mapping, did so through successive changes in precisely these boundary conditions. Thus the visual physiology of depth perception, the embryological determination of the growth, and the evolution are all aspects of the same logarithmic work function.

(a) **The retino-cortical pathway**



(b) **Mapping of a square image to cortex**



Solid line is a small square
Dotted line is a symmetrically enlarged square

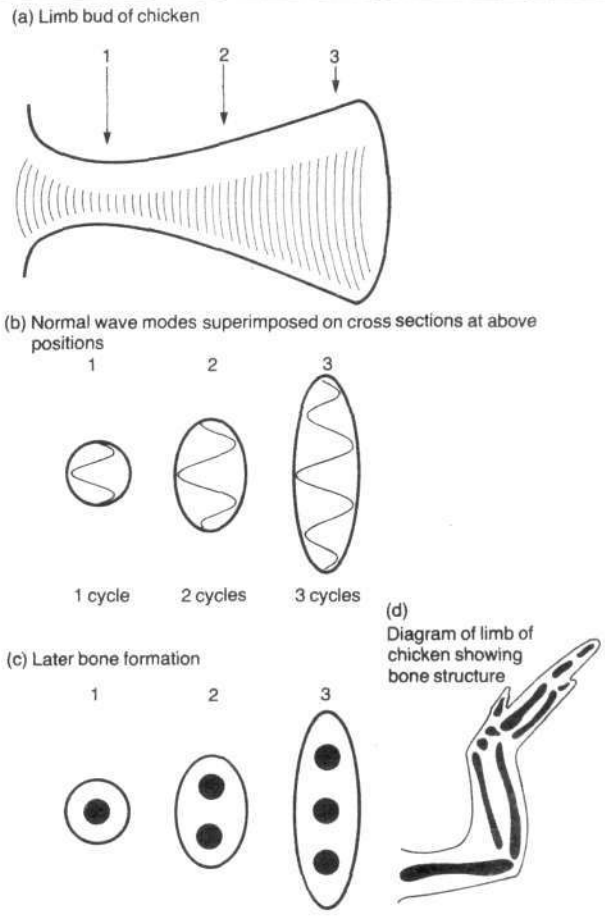


Figure 22
DIFFERENTIATION OF THE LIMB BUD

The wing of the chicken begins embryological development as a limb bud (a). The shape in cross section is round near the body, then progressively flatter farther out, ending in a flattened pad. The number of bones are similar to the human, one in the upper arm, two in the lower arm, and five in the hand.

How is this differentiation carried out? Looking at the cross-section shapes, a wave in the form of a usual sine wave could be fit into the outlines with one, two, and three cycles respectively (b). If these waves determine the future bones, then the number of bones is simply determined by the overall boundary shape (c) and (d). This, in fact, seems to be the case. Not only is this an extremely efficient way to grow the embryo, but it means that evolution could proceed rapidly simply by changing the shape of the limb bud to produce a change in the number of toes in an animal, as is known to have happened repeatedly in the evolution of the grazing mammals. Here again, we have a self-similar work function determining the physiology, embryology, and evolution in an efficient form, similar to the case in the visual system.

Source: S.A. Newman and H.L. Frisch, "Dynamics of Skeletal Pattern Formation in Developing Chick Limb," *Science*, Vol. 205 (1979), pp. 662-68.

began consists of some sort of improbable statistical event that brought together DNA as the genetic element (which alone could self-replicate), protein enzymes to catalyze metabolic reactions, and possibly a photosynthetic pigment, the predecessor of chlorophyll; and they all worked together to form a living organism.

However, consider the following hypothesis: DNA originally served all three of these functions (including self-replication) as different elaborations of the same basic work function. There are some data in support of this hypothesis. First, the temperature of the Earth for the first 2 billion years was more than 70 degrees Celsius, a condition that would destroy the functioning of any known enzymes, but not DNA, which is stable at temperatures approaching 100 degrees Celsius. Second, DNA's first cousin, RNA, is known to function in a sense as an enzyme in the form of ribosomal-RNA, which composes the ribosome, the organelle in the cell that produces proteins; and other RNA's are also known to function as enzymes. Third, sunlight reaching the Earth's surface during the first 3 billion years consisted largely of ultraviolet waves, because of the lack of oxygen in the atmosphere and the consequent lack of a protective ozone layer (which we now have). DNA absorbs heavily in the ultraviolet range, so it would have been a good candidate as a photoreceptor for early life. This notion must also take into consideration that ultraviolet light can destabilize DNA as well, but the DNA involved in replication and enzyme activity may have been separate from the DNA involved in light capture.

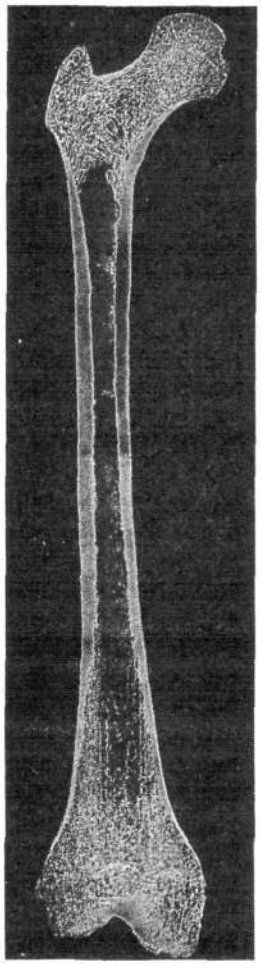
The main argument, however, for the wider function of DNA in early life is the compactness and simplicity of such a living organism; if you were to build one, it would be an efficient way to do it. And it would not be surprising to find DNA in these various contexts, since they are all ultimately based on the identical spiral work function. We have already discussed replication and electromagnetic wave capture; enzyme activity in catalyzing metabolic reactions generally functions to vastly speed the rate of the reactions—by a million times or more—and is crucial for maintaining the high rates of activity needed for life to function. Since this activity has the character of an electromagnetic resonance, it should follow the same general geometric form that we have been describing for other instances of work.

This last DNA hypothesis is not meant to exclude the importance of other factors, such as water or membranes, but to highlight the broad-ranging significance of the type of work function we have been exploring in determining many seemingly disparate biological processes.

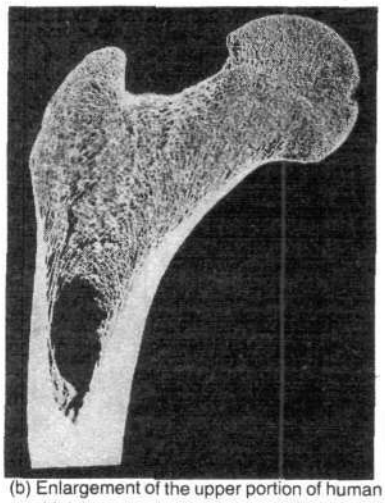
Geometry and Tissue Organization

The fight against cancer and aging requires that we extend our work-function approach to better understand the overall geometry of functioning tissue. Since cancer involves a progressive loss of specialization or differentiation of the tissue involved, with the most virulent cancers tending to a generalized undifferentiated condition, it makes sense to first get a firm understanding of normal differentiation and then go on to explore the changes in cancer from this perspective.

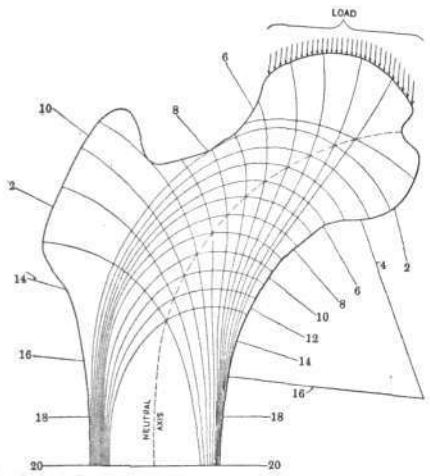
As in the case of DNA, we need to approach tissues as



(a) Cross section of the human thigh bone



(b) Enlargement of the upper portion of human thigh bone



(c) Stress lines produced by normal use of the leg

Figure 23
POLARIZATION AND BONE SHAPE

Stress on a bone causes the production of electromagnetic fields, which then determine the growth of future bone. The direction of spicules of calcium crystals, which make up the bone, lines up parallel to the direction of stress on the bone. A cross section of the human thigh bone or femur is shown in (a). An enlargement of the upper portion is shown in (b), and the directional pattern of the spicules is evident. The stress lines produced by normal use of the leg in support and walking are shown in (c).

Note the close similarity between the spicule pattern and the stress lines. The growth and development of the bone is determined by fields set up through the entire tissue, not simply by individual cell genetic programming.

Source: H. Gray, *Anatomy of the Human Body* (Philadelphia: Lea and Febiger, 1959), pp. 276-78.

based on geometric work functions. Several embryological tissues strongly suggest this approach, in that they have self-similar proportions as the basis of their activity. For example, the shape of the nerve connection between the eye and the brain is logarithmic, and this self-similar shape can be shown to be related to the dynamics of vision activity, to the action of embryological development of the visual pathway, and even to the question of the evolution of the visual system itself (Figure 21). Similarly, the pitch of sound is carried to the brain logarithmically. The logarithmic form of this neuroembryology and similar findings in the embryology of other organs such as the heart and the limbs (Figure 22) are an immediate avenue for tracing the spiral work function in animal development.

This is not a new idea: Leonardo da Vinci dedicated a major portion of his life's work to identifying the golden mean as the characteristic invariant in anatomical proportions.

Once the self-similar functions of the embryological geometries are mapped out, the next step is to define the metabolic transformations of the tissues, the specific work done by the tissues, as particular states of polarization in the sense implied by the NMR data, and then to trace out the progressive development of this polarization as each tissue differentiates. The electrical polarization of bone is a simple case, but it indicates the direction we are aiming at (Figure 23).

Once we have a firmer understanding of the elaboration of the spiral work function in creating and maintaining the healthy state of tissues, we will be in position to map out crucial experiments to determine what goes wrong to cause the broad variety of diseases of aging, including cancer and the accompanying breakdown of the immune system. We will then have the tools to greatly extend the human life span, possibly indefinitely.

Ned Rosinsky, a physician, is on the staff of the Fusion Energy Foundation.

Notes

1. W.N. Mei, M. Kohli, E.W. Prohofsky, and L.L. Van Zandt, "Acoustic Modes and Nonbonded Interaction of the Double Helix," *Biopolymers*, Vol. 20, (1981), pp. 833-852.
2. M.L. Swicord, "Microwave Absorption of DNA Between 8 and 12 GHz," *Biopolymers*, Vol. 21, (1980), pp. 2453-2460.
3. Personal communication, June 10, 1984.
4. This concept is discussed by Jonathan Tennenbaum in "How Man Transforms the Laws of the Universe," *Fusion*, May-June 1984, p. 19 and "Why I Must Attack Albert Einstein," by Lyndon H. LaRouche, *Fusion*, July-August 1984, p. 41.
5. A.W. Boddie, Jr., W.S. Yamanashi, J. Frazer, C.M. McBride, and R. Martin, "Field Focusing and Focal Heating Patterns Using a Hybrid Radiofrequency Hyperthermia System of Novel Design," *Medical Instrumentation*, Vol. 17, (1983), pp. 358-364.

AN INTERVIEW WITH DR. ROBERT JASTROW

The Anti-Beam-Defense Arguments Are 'At Variance with the Facts'

Dr. Robert Jastrow founded the theoretical division of NASA at the Goddard Space Flight Center in 1958. The director of the Goddard Institute of Space Studies since 1961, Jastrow is now adjunct professor of earth sciences at Dartmouth College in New Hampshire. Although he trained as a nuclear physicist, Jastrow is known for his work on astronomy. He is the author of Red Giants, White Dwarfs *and several other works. He was interviewed by FEF staff member Robert Gallagher.*

Question: What are your views on the feasibility of a defense based on lasers and other directed energy technology, and how early could we deploy such a defense?

The estimate is that it would take some years of research to decide which is the best way to go, but no fundamental scientific or technical obstacles stand in the way of a defense against a Soviet nuclear attack on the United States, according to the qualified people who worked with Dr. Fletcher on a study of that question. [James Fletcher, former NASA director, headed the commission of scientists appointed by President Reagan to review beam defense technologies.]

You asked about how long it would take: Five years is the time allotted by the administration to research on this matter. Around 1989, the experts feel that it should be possible to choose the best technologies and build a system around them that could be deployed for the defense of Americans in the 1990s.

Question: Last year, Dr. Teller made a statement that a partial ABM defense based on the X-ray laser could be constructed and deployed within five years.

I think that that's generally considered to be about the right estimate. And it would of course require renegotiation of the ABM treaty, but that's a bridge we don't have to cross for a number of years.

Stuart Lewis

"No fundamental scientific or technical obstacles stand in the way of a defense against a Soviet nuclear attack on the United States."

Question: Why do you think so many well-known members of the scientific community are opposed to this program? I'm thinking of people like Hans Bethe and Richard Garwin.

That's a question for a psychologist rather than a scientist! I don't understand why nominally competent physicists like Bethe should lend their names to statements by this group of scientists [the Union of Concerned Scientists] about the technical feasibility of a defense against Soviet missiles—statements which turn out on close examination to be full of errors and seriously misleading.

Question: In April 1983, Garwin circulated a petition for a ban on weapons in space that was signed by 30 or 40 scientists, some of whom are serious people. Many astronomers were involved, for example. Why do scientists get trapped into this kind of thing?

There is a striking similarity in the language of the Soviet draft treaty submitted to the United Nations on the ban of so-called weapons in space, and the draft treaty or petition that was drawn up by this group of scientists. I think that the reason for all this well-intentioned activity is an implicit assumption that the United States is the greater menace to world peace, and that it is our efforts that spur the arms race. It's a feeling that I think is completely at variance with the facts.

Question: What do you think the major problem is in U.S.-Soviet relations today?

I think that the Soviet Union depends on its nuclear missile arsenal in a fundamental way as a main prop for its superpower status, and so it is most unlikely to give up any element of that arsenal except under heavy pressure. It's a country with an economy that is strikingly unproductive, a people with a lower life expectancy than any country in the Western world including Japan, to my knowledge—I believe it's 63 years for Russian males—and a country with a high infant mortality rate. And there is a lot of alcoholism.

It all suggests that it is a miserable

place to live, and it's been commented that the Soviet Union would not even be respected as a superpower if it weren't for this fearsome arsenal of weapons. So, that's obviously a plus for the Soviet leaders—the only thing they've got behind them, and a stimulus to the further expansion of their nuclear destructiveness.

Question: The litany against beam weapons includes the argument that as soon as they are deployed, or about to be deployed, this in itself will provoke the Soviet Union to start a war. Now of course this is coming directly out of Moscow, so it's not very credible. . . .

Well, it also comes from Carl Sagan, you know, because he said that to me on the Brinkley hour [ABC-TV]; we discussed this matter in public. And I think the answer to it is that the technical problems involved in building an operating system for missile defense are substantial, and the pace of movement toward deployment is almost glacially slow, because it involves almost five years of research before we decide which way to go.

Because of this, there's no reason for the Soviet Union to feel threatened suddenly. And as we move in that direction, thanks to the President's initiative [the new strategic doctrine announced March 23, 1983], the Soviet Union is and will be moving as fast as it can in the limits of its own technology, so that as we are ready to deploy they will be also, which will result in the joint uselessness of these weapons as the endpoint the President desired and hoped for.

Question: I've spoken to a lot of scientists and engineers who actually believe that there's a big question as to whether or not this is possible. What do you think about that?

I think that the people involved are mostly nuclear or ex-nuclear physicists whose world experience has been shaped by the nuclear bomb that their profession helped to create. It has dominated their thinking, and a certain amount of lack of imagination or inflexibility has prevented them from embracing the full implications [such as] newer technologies of the computer that led to the smart warhead and the even more accurate antiballistic missile that can shoot down an enemy missile without using nuclear weapons itself. That development makes President Reagan's proposal feasible, and its import is not fully grasped by the technicians themselves who are offering this criticism.

Question: Richard Garwin objected that it is impossible to pop an X-ray laser up into space upon warning of an attack in time to intercept ballistic missiles in their boost phase, because the curvature of the Earth makes the pop-up distance too great for a rocket to carry the X-ray laser there before the boost phase ends.

I think that's a fatuous remark on Garwin's part, because at this juncture in 1984, no one has any idea whether the pop-up X-ray laser is the best way to go or lasers deployed in space are better, or whether chemical lasers are better than X-ray lasers in the 1990s, and so on. None of those matters are worked out. That's what five years and $26 billion have been allotted for, to settle those questions.

"There's no reason for the Soviet Union to feel threatened suddenly. . . . As we are ready to deploy, they will be also, which will result in the joint uselessness of these [nuclear] weapons as the endpoint the President desired and hoped for."

Question: What's your evaluation of the Union of Concerned Scientists report?

It makes the most serious errors on the fundamental issues—in alleging, for example, that calculations show a fleet of thousands of laser-equipped satellites is necessary to provide a defensive screen against Soviet missiles. Whereas defense scientists who have been studying this question, this very question, for more than 10 years, have found, always, at the end of their calculations that the correct number is less than 100: No more than 100 are needed. And just the significance of that difference, between thousands of satellites and less than 100, is the difference between a practical program and an impractical one: Each satellite will cost about as much as a Trident submarine, and if thousands were needed, the total cost would be many trillions of dollars, but if only 100 are needed, then one can develop and deploy the system at a cost averaged out, spread out, which is well within the present level of expenditure today for strategic defense.

Question: Are you talking about the chemical laser system that Max Hunter of Lockheed has worked on?

Yes, [this is] the basic technology that is the closest to realization, the least exotic of the exotic technologies: the chemical laser fueled and fired in orbit, and directed from orbit at a hypothetical simultaneous launch of the whole Soviet arsenal, 1,400 Soviet missile silos. I myself looked into that matter [of how many satellites are required] with a globe and some pieces of string and then some more elaborate calculations later, to convince myself by rough estimates that the result of less than 100 is correct. I arrived at a number between 50 and 100, and there's no question but that that's the right answer. And there's no excuse whatsoever for a group of nominally competent scientists [the Union of Concerned Scientists] to make such large errors, an error in this case by a factor of 20.

Question: At the meeting of the American Association for the Advancement of Science in May, you and Richard Garwin had an argument about the weight of shielding required to protect a missile from lasers. What impact would the shielding required have on the ability of the missile to get off the ground with the desired payload?

Garwin stated at that meeting that 660 pounds of material would be adequate to protect a Soviet missile against our lasers, and the correct number is 4.8 tons. When I announced this figure, he said that I had made an error in forgetting that when the first stage of the rocket burns out, you throw it away

together with everything on it. But that's not true, because when the first stage burns out, the velocity that the missile has achieved at that point is determined by the mass of the empty shell and everything that sits on top of it; that controls what is called the mass ratio and the burnout velocity.

To maintain that burnout velocity and maintain the range of the missile, which are an absolute essential, you must keep the mass ratio and the final mass of the empty shell constant. So if you smear some weight on the outside of the casing of the skin of the first stage, then you must subtract that weight from what sits on top of the first stage, which includes the payload of warheads. I was so shocked at Garwin's error that I burst out in public and said, "Dick, you've made a terrible error," and it is in fact the case that he did.

Question: So he said that it would only result in a 660-pound decrease in the payload, and you . . . .

Yes, and the right answer was 4.8 tons for the layer of material about half an inch in thickness, which is what is needed. And that's interesting because 4.8 tons is 60 percent of the 8-ton payload of the SS-18, which means that if the Russians actually implemented Dr. Garwin's suggestion, they would be losing 60 percent of the destructiveness of the most fearful weapon in their whole arsenal, the monster SS-18. And I would say that's a pretty good return from American science for the President's appeal to make these dreadful missiles impotent and obsolete.

Question: Do you have any other comments on specific points of the Union of Concerned Scientists report?

Yes, one other, a criticism of that report that also applies to the Office of Technology Assessment report authored by Ashton Carter. Both reports stress the fact that the X-ray laser, which is one of the most promising technologies at this stage, can be defeated by a rocket which burns out very quickly in the lower atmosphere where the density of the air is thick enough to block the laser X-rays from penetrating. And it works out that the rocket must burn out below about 40 or 45 miles, which means it must burn out within 50 seconds to do that. But at the present, the time that the Soviet arsenal takes before burnout—that means all the SS-17s, -18s, and -19s, all 820 of them, with their terrifying complement of 5,000 destructive, accurate warheads—their burnout time is no less than 300 seconds. So every one of the missiles that's now out in their silos, in the Russian missile fields, is entirely vulnerable to an X-ray laser.

And if you ask whether the Russians might develop a newer and faster-burning missile in time to counter our defense, I will remind you that the next generation of missiles, which the Soviets don't even possess yet, is represented by the MX, and *its* burn time is

"The only surprise is that anybody in this country believes these fellows."

180 seconds. So the MX generation of missiles is still terribly vulnerable to an X-ray laser defense. And a kind of missile that would burn out in 50 seconds will not be available in *this* country, according to informed estimates, until the end of the century, and the Soviet Union is thought to be a generation behind us in this kind of development; it will not have such a missile until the first years of the 21st century at the earliest. So the whole present generation of Soviet missiles, and the generation after that, are vulnerable to an X-ray laser defense. And I will say again, that's a pretty good response by American scientists to the President's call for making these missiles impotent and obsolete.

Question: Let me mention to you that their calculation on the pop-up distance is wrong.

I wouldn't be surprised. I picked three examples from my analysis that were especially easy to understand and to check reliably, but that paper is just rife with technical errors.

Question: Do you have any specific comments on the questions that were raised in the Office of Technology Assessment (OTA) report?

The OTA report, or the report *to* the OTA by Dr. Carter, does not have as misleading or exaggerated a set of claims as the Union of Concerned Scientists report but the exaggerations are still quite substantial, because, for example, that report says that as many as 500 satellites would be needed in a defensive screen to counter the Soviets; and the right answer, again, is less than 100.

And on the X-ray laser, it doesn't make the mistake that these fellows make in regard to the ablative covering and such matters—it's less fatuous in these respects—but it makes the same mistake in its unwarranted optimism about the ability of the Soviet Union to deploy a fast-burn booster and defeat our X-ray laser defense.

Question: Ashton Carter asserts in the report to the OTA that 1 gram of ablative material per centimeter squared of missile surface is all that is required to shield a booster from a laser. You calculated 4.8 tons total ablative material required. How much is that per centimeter squared?

The ablative covering has to be at least 2 grams per square centimeter thick, to protect against the presently planned U.S. [chemical] lasers.

Question: One countermeasure against lasers that's been proposed is to spin the missile during the boost phase so that the beam must dwell on the target longer to kill it.

That's another fatuous suggestion. At most it gains a factor of π, which is roughly three. At this stage the definition of the brightness of our lasers is up in the air and factors of three are a very modest increase; that would not be an effective defense at all. But even if the Russians were foolish enough to go to the trouble of trying to spin their missiles, which would require a complete retrofit, by the way—it would be a rather elaborate job for them to rebuild their silos to do that—if they did, we would simply concentrate our laser energy in a pulse that caught the spinning rocket at one point of its spin, so to speak.

I'll tell you what another one of these fellows mentioned in their report: to shine up the rocket so that it would reflect the laser beam. But you know the reflection would have to be really perfect; if even a fraction of 1 percent of the laser energy got in, it would destroy the perfection of the shine, degrade the surface, and even if it did so just a little bit it would let more of the energy get in and that would degrade the surface even more and you would end up with a positive feedback that would quickly eliminate the shine and the rocket altogether.

Question: E. P. Velikhov at the Kurchatov Institute in Moscow has been directing work there that has been oriented toward nuclear pumping various types of systems for applications from energy production to lasers and particle beam devices. *Aviation Week and Space Technology* magazine has independently reported recently that there is a full-blown Soviet program to develop a nuclear pumped X-ray laser, and that they are testing a device at Semipalatinsk—with Lebedev providing the guidance on lasing and Kurchatov on nuclear pumping. Yet, this is just part of the story. I know from Rand reports issued over the past 10 years that there has been an intense effort in the Soviet Union for at least that long to develop an X-ray laser pumped by electron beams. At the same time that he is doing this, Velikhov is running around the U.S. lying to Americans about what he's doing and about what other Soviet scientists are doing and saying that a beam defense is not feasible and would be dangerous if ever achieved.

In the Soviet defense structure there's something, a branch with a name like Ministry of Strategic Deception, headed at one time by the famous Ogarkov, that has mounted this procedure for firing missiles at night in missile tests so that our satellites cannot photograph the tests. And it's interesting that Ogarkov was also the Soviet military representative at the SALT talks. So I'm not surprised to hear you say that what they tell us is completely contrary to what they're doing. One of the major weapons in their arsenal is deception, according to their own command structure.

The only surprise is that anybody in this country believes these fellows.

The Young Scientist

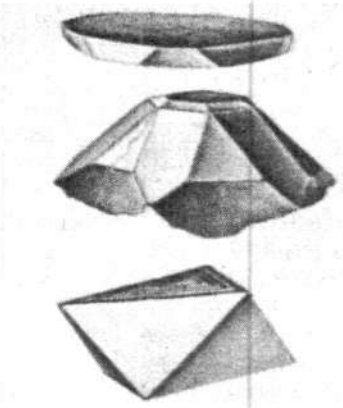
Experiment

Crystals: An Ordering Principle For Solid Matter

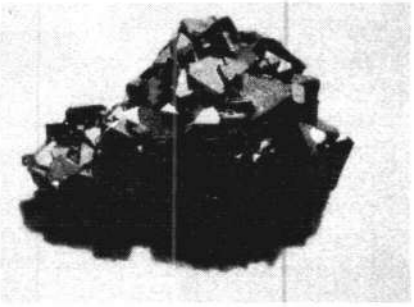
by Rod Huth

Which of these things do you think are made up of crystals: steel, tin, salt? If you answered only "salt," you have a lot more to learn about crystals. All three are crystals and, in fact, crystals are the rule rather than the exception for all inorganic matter.

Crystals represent a self-ordering capacity of solid matter. Most all inorganic matter found in nature organizes itself around a repeating geometric pattern—or crystal. If you put steel or tin under a microscope, you would see the crystals. Metals look and feel smooth because their crystals have a particular ability to slide along one another so that they lock into a smooth surface.



Above: Sketches of hematite crystals. Hematite, or ferrous oxide, is the major ore of iron. Below: Purple chrome alum crystals formed around a button in the method described here.



Aluminum is the most prevalent metal in the world. It is perfect for aeronautics: It's light, withstands high temperature, and does not rust. In combination with oxygen and often silicon dioxide (SiO_2) aluminum forms the basis of the most beautiful gems—sapphires, rubies, and other precious stones. These gems are crystals made in nature under conditions of extreme temperature and pressure, but you can make crystals that are related to them and to aluminum from a common, inexpensive material called alum.

Here are the materials you will need:

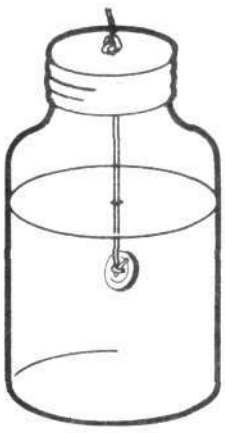
10 tablespoons of alum

2 cups of water (distilled water is best)

1 quart jar and lid
plastic measuring spoons
long wooden spoon
piece of string
plastic button (about ½ inch)

Making Crystals

It takes from 10 to 20 hours to make beautiful clear crystals in the shape



Jonathan Pearl

Examining a seed crystal (right); A button suspended in a jar of supersaturated solution.

of octahedrons (eight-sided solids with faces that are equilateral triangles).

First, take the quart jar and fill it with two cups of distilled water. (If you cannot get distilled water, boil some tap water and then filter it through paper filters like those used in a coffee maker.)

Place the jar in a pan of water on the stove, and heat the pan. Add the alum, one tablespoon at a time, stirring continuously with a wooden spoon until a little bit of the alum stays on the bottom and won't dissolve. The solution is now *saturated*.

As you continue to heat the pan, you will find that more alum will dissolve. Continue to heat and add more alum, but do not allow the water in the pan to boil, or the jar may break.

As you add the last of 8 tablespoons of alum, you will reach another point where no more alum will dissolve. The solution is now *supersaturated*.

When the solution is cooled, remove the jar from the pan and put it in a room where the temperature will not change very much in the next 24 hours.

Within 10 to 20 hours, perhaps overnight, crystals will begin to form on the surface of the solution and drop to the bottom of the jar. If you are able to monitor this process closely, as soon as the crystals form, take a plastic spoon and scoop them out. Dry them on a paper towel and set them aside to be *seed crystals*. Each crystal may be as large as ½ inch to 1 inch in width.

Save the supersaturated solution in the jar.

Seed Crystals

Take the best-formed crystal and *tie a piece of thread or string around* it. This seed crystal will provide the pattern around which you can build even larger crystals.

Now put the jar with the supersaturated solution in a pan of water on the stove again. Add 2 more tablespoons of alum to the solution in the jar and heat the pan of water until the alum is dissolved.

Remove the jar and again set it in a place where the temperature remains fairly constant. Then, when the jar has reached room temperature, suspend your seed crystal in the solution. (To do this, make two holes in the jar lid. Take the two ends of the thread around the seed crystal, pull them through the holes in the lid, and tie a knot.)

Overnight you should have a crystal at least 2 to 3 inches across.

If you are not able to monitor the initial crystal-forming process, you can skip making the seed crystal and instead suspend a string with a ½-inch plastic button on the end about one-quarter of the way up from the bottom of the jar. A necklace of octahedron crystals will form in about 10 to 20 hours.

Colored Crystals

Now try making colored crystals using the same method with other materials. Be careful not to allow the solution to boil, or you will force the evaporation of the water molecules that are part of the crystal. The more solution you use, the more perfect the crystals will be. Use these proportions of material for each 8 ounces of water:

Name of material	Amount	Color	Shape of Crystal
Chrome alum	5 ounces	purple	octahedron
Cupric sulfate	3 ounces	blue	rhombohedron

Perfect Crystals in Space

In 1781, the French minerologist Abbe Hauy discovered that crystals were reoccurring geometric patterns found in almost all solid matter. Years later, Louis Pasteur and Marie and Pierre Curie discovered the *piezoelectric* effect, the process by which crystals amplify or increase electric current passing through them ("piezo" is from the Greek word "piezein," to press). Since then, crystals have played an increasing role in advancing technology, especially in electronics where crystals are used for transistors and crystal chips are used for hand calculators.

Now the space program has begun to study how to make more perfect crystals. Recent Space Shuttle efforts included a crystal project, making crystals outside the pull of the Earth's gravity and the constant vibrations here on Earth. Perhaps one of the first products of future lunar orbiting factories or lunar colonies will be cheap, mass-produced crystals for an expanded electronics industry that is just now reaching its ascent in the "age of the transistor."

For Further Reading

To learn more about crystals, I recommend *Crystals and Crystal Growing* by Alan Holden and Phylis Morrison (Cambridge, Mass.: MIT Press, 1982).

Professor von Puzzle

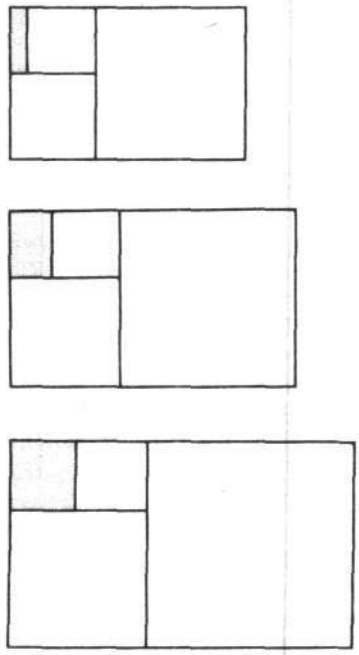
Building Golden Rectangles

In the last puzzle, we examined the growth of a rabbit population and saw that it followed the simple ratios of the Fibonacci series: 1, 1, 2, 3, 5, 8, 13, 21. . . . We get this series by starting with 1 and 1, and adding terms. Each term is the sum of the previous two (for example: $2=1+1$ and $13=8+5$).

Then we saw that this series can be developed by geometry. We start with a square. Build another square on one side of the first square, producing a 2×1 rectangle. Then, build a square on the long side of this rectangle, and keep repeating this procedure.

The ratios of the long to the short sides of the rectangles that are produced are ratios of successive numbers in the Fibonacci series (2/1, 3/2, 5/3, and so on). As we follow out this series, we see that the ratios converge on the ratio of the *golden section*, which is approximately 1.618. The rectangle that has this golden section ratio of length to width is called the *golden rectangle*. The figure we build by starting from a square and always adding a square onto its longest side very quickly becomes a *golden rectangle*.

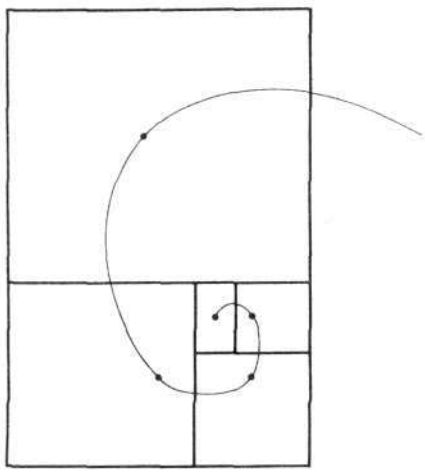
We asked *you* to figure out what would happen if we started with a rectangle of *any* shape and followed the procedure of always building a square on its longest side. In case you haven't already done it, here's what happens:



We took three rectangles (shaded): (1) a long skinny one, (2) a medium-proportioned one, and (3) the rectangle which has the same length as width—also known as a square. You see that when we build a square on the longest side and repeat this several times, all the figures turn into rectangles of the same proportion. They are all approximately golden rectangles. The more times we repeat the procedure, the closer they come to golden rectangles.

Plants—and animals too—grow in the golden section ratio. Just as with the rectangles, it is a way of growing that permits the plant or animal to grow in size, but always maintain a similar proportioning throughout its life. You might wonder what the golden rectangle has to do with a plant or an animal: What animal looks like a rectangle? Well, none that we know of. But, with a small change in the way you construct your golden rectangles, you can produce a shape that should remind you very much of one animal, and of the parts of many plants and animals.

Start again with some rectangle, and build a square on its longest side. Keep repeating this procedure, but this time, be sure that you always move around the figure in one direction as you build on new squares. Now put a dot at the center of the starting rectangle and at the center of each new one that you build on. Then connect the dots with a smooth curve. See what you get?



You can find this shape almost everywhere in nature. Try collecting some examples. Last night I saw one trillions of miles away, in my telescope.

—Laurence Hecht

TFTR Demonstrates Better Scaling

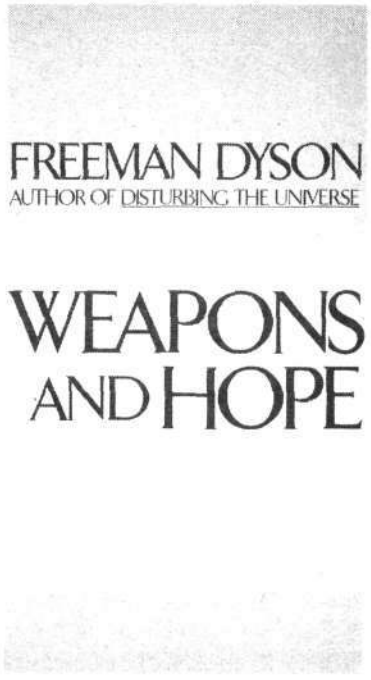
Continued from page 15

demonstrated only for low-temperature plasmas that are ohmically heated. Plasmas heated with neutral beams, which approach the temperatures needed for fusion, generally had been found to have degraded energy confinement. Although even this degraded confinement was sufficient enough to project designs for workable reactors, improving the energy confinement time will lead to far more economic models.

Last year on the West German Asdex tokamak, it was found that if the plasma was cleansed of nonhydrogen impurities, such as carbon and oxygen, and if the plasma temperature and density distributions were carefully controlled, neutral-beam heated plasmas could be made to follow the good ohmic-heated tokamak scaling laws. Over the past year, experiments throughout the United States—the PDX at Princeton, the Doublet III in San Diego, and several other tokamaks—have replicated the good scaling results achieved by the Asdex.

Freeman Dyson: Master of Deceit

Weapons and Hope
Freeman Dyson
New York: Harper & Row Publishers
1984, $17.95



The question for patriotic Americans today is not so much to identify the traitors on the right and the left who are bent on turning the country over to the Russians. The question is: How did they get into position to do this? Reading *Weapons and Hope* will not provide the answer directly, but it is an interesting case study on how these traitors operate.

It is clear that the Vietnam War was a turning point for the nation; it was the first war we ever lost, but, more important, the worst war we ever fought. The policy of indiscriminate napalm bombing of Vietnamese civilians was evil, and this helped to turn a whole generation of youth into cynical hedonists.

What is not so well understood is the fact that the men who authored the policy decisions that got us into the war and kept us there, and kept us from winning the war, were the same men who were then—and are now—engineering the peace movement from behind the scenes. Also not understood is that the policy failure represented by the Vietnam War had its seeds in the capitulation to the British by President Roosevelt during World War II, when he tolerated their murderous incendiary bombing of the German civilian population.

Who Is Dyson?

Freeman Dyson is a liar, and his book is a clever but deceitful attack on President Reagan's strategic defense initiative. He pretends to be presenting a balanced view between the peace movement and the proponents of military buildup, but his veneer of objectivity is pathetically thin.

He is one of the authors of General Danny Graham's "Rube Goldberg" High Frontier, which is merely a sophisticated attack on the President's Strategic Defense Initiative—saying that the development of advanced laser and beam defense technologies is unnecessary and that we can make do with incompetent off-the-shelf alternatives.

Yet Dyson's support even for Graham's proposal is curious, for Dyson believes that it will be useful to have nonnuclear ABM systems only *after* we have unilaterally disarmed and the Soviets have followed suit. Then such ABM systems will function as a way of policing disarmament.

He says: "If I were running the United States as an absolute monarch, I would choose nonnuclear resistance as my policy. It is risky, it is hopeful, and in my heart I know that it is right. I would accept the risks of leaving the Soviet Union as the only major nuclear power in the world."

"Fortunately," he continues, "I am not an absolute monarch and do not have to take this responsibility. So long as the United States is a constitutional republic, nonnuclear resistance will not be adopted as national policy unless it has the support of the military establishment. To persuade a majority of soldiers to support it will take a long time and a revolution in military thinking."

Dyson, like all of the architects of the nuclear freeze movement, is also an apologist for Soviet aggression. The program he advocates in *Weapons and Hope* would leave us with neither weapons nor hope. Like his other associates in the nuclear freeze movement, he wants what amounts to unilateral disarmament of the United States. While he pretends to be for "defensive" rather than "aggressive" weapons, he would postpone the development of *any* antimissile program in the United States into the indefinite future, and give the Soviets a decisive margin of advantage in any future war.

Apologist Dyson writes: "Because of the divergent views of American and Soviet strategists concerning the nature of nuclear war and the possibility of technical assurance, American and Soviet strategic objectives are strictly incommensurable. It is natural for Americans to believe that the American objective of deterrence is more reasonable or more modest than the Soviet objective of victory." He dismisses the importance of the Soviet army with the cavalier assertion that the memory of World War II has conditioned the Soviet view of war so that, "Russians when they think of war, think of themselves not as warriors but as victims."

Dyson never bothers to explain why the peace-loving Soviets have systematically refused to accept President Reagan's offer to negotiate joint development of beam weapons, but instead castigate President Reagan as more evil than Adolf Hitler. Since Dyson aims to unilaterally disarm the United States, he brushes aside the documented evidence of Soviet violations of the SALT treaty as unimportant.

He writes: "We read about giant Soviet lasers and particle beam experiments, and we are supposed to be duly frightened. Fortunately, we can rely upon photographic reconnaissance from space to give us timely warning if ever any of these alleged superweapons reaches the stage of serious deployment." In other words, according to Dyson, we should wait to develop beam weapons until after the Soviets have an ABM system in place.

Dyson has so low an opinion of his readers, that he gives two contradictory sets of standards, one for the Soviets and one for the United States,

without even commenting on the discrepancy. He says about the Soviet defense weapons and civil defense programs (p. 26): "It is absurd for Americans to oppose the building of active defenses against nuclear bombardment because of an assumed incompatibility between defense and deterrence of nuclear war." But then he denies this right to the United States (p. 93), "So long as our land is loaded with nuclear weapons, serious shelter-building is ethically unacceptable."

A Hitler Supporter

Dyson's connection to the peace movement dates from his school days. He tells us in *Weapons and Hope* that while he was attending Winchester Public School (an elite British private school), and even after the war started, he was a supporter of Bertrand Russell's pro-Hitler Peace Union. He actively organized for the Union, distributing leaflets that urged the revival of Neville Chamberlain's policy of appeasement.

Although he says that he realized by and by that this was not a correct position, incredibly, he still publicly endorses his racist, antisemitic views of that time. Thus he writes: "Our self-confidence was sustained by the knowledge that, if our program did not make sense in terms of immediate practical politics, the idea of fighting World War II in order to save the Czechs or the Poles, or the European Jews made sense even less. We could see clearly that however badly we might suffer in the coming war, the Czechs and the Poles and the Jews would suffer worse. In this, as in many of our judgments of that time, history has proved us right."

Dyson was a fellow of Bertrand Russell's Trinity College, Cambridge until 1950, although he came to the United States in September 1947, after a period in Germany where he studied the effects of starvation on the population. He then enrolled in Cornell University, where he began a continuing collaboration with current nuclear freeze advocate Hans Bethe. He became a U.S. citizen in 1960 in order to regularize his position, although he admits that throughout his residence here he was privy to defense secrets to which British scientists were offically denied access.

Trinity College was the center of the Philby-Blunt spy network, as well as a large, open Communist apparatus. Like his friend Robert Oppenheimer, Dyson sports interesting Communist connections. His closest boyhood friend at school was the Communist fighter in Spain, Frank Thompson. At Cornell, he worked with the scientist accused of being a Soviet spy in the Oppenheimer investigation, Rossi Lomanitz.

Dyson is still at it today. Like Richard Garwin and Hans Bethe, Freeman Dyson is a physicist who uses his credentials to operate as a major spokesman for the nuclear freeze movement—at the same time that he acts as a consultant on weapons questions for the Defense Department and for the Arms Control and Disarmament Agency. And he uses this "double agent" quality to advertise his wares as special. He is the man who, so he says, can see both sides of the issue. To maintain credibility under these conditions is a special talent.

Dyson's Big Lie

Dyson is a slick operator. In *Weapons and Hope*, he works to confuse and bemuse the reader; however, he makes one major slip. In establishing his so-called credentials as a weapons specialist, he admits that he served on P.M.S. Blackett's strategic bombing survey, temporarily giving up his fascist, pacifist sympathies to join the British war effort, a move he now deplores.

His dishonesty is shown by the fact that while he pretends to attack the British policy of bombing civilian populations in Germany, he actually covers up the fact that the British deliberately created fire storms throughout Germany, and in particular over the German city of Dresden, just 12 weeks before the end of the war—a raid that deliberately incinerated more than 100,000 people.

This is no paradox. Dyson and his collaborators in the nuclear freeze movement today are vehement advocates of population reduction. Their opposition to President Reagan's defense policy does not prevent them from advocating limited, so-called conventional wars against those developing sector nations that fall behind on their debt payments. These people are quite open in their support of Bertrand Russell's infamous prescription for limiting black and Hispanic populations through war, famine, and plague.

Dyson brags that his posting at the headquarters of British Bomber Command gave him special access to information: "I was in a highly privileged position at Bomber Command. I knew much more than most of the operational officers about the general course of the campaign. I knew much more than the cabinet ministers in London about the details of our operations. I was one of very few people who knew what were the objectives, and how expensive this was for us in money and lives." If this is true, then his account of the British atrocity at Dresden is a pure-and-simple lie.

He writes: "Nobody understands to this day why or how fire storms begin. In every big raid we tried to raise a fire storm, but we succeeded only twice, once in Hamburg and once two years later in Dresden. Probably the thing happens only when the bombing releases a preexisting instability in the local meteorology. The big slaughter in Hamburg and Dresden was not the result of a political decision to attack those places in any special way. It was a technological accident. Berlin and the Ruhr cities received many more attacks of the same size as Dresden's but never had a fire storm."

British Planned Genocide

Contrary to Dyson's "technological accident" explanation, the British carefully planned the fire bombing of Dresden, where 100,000 Germans were killed over the space of one day—facts that are available to any informed person. For example, British Cabinet Minister Richard Crossman wrote about the bombing in the *New Statesman* May 3, 1963: "In Dresden the fire storm, which had unexpectedly engulfed Hamburg and Cassel was for the first time deliberately created. For this purpose the first incendiary raid at 19:10 PM struck the old city which contained no important factory, no bridge, and not one of Dresden's 18 railway stations."

Today, since the bombing of Hiroshima and Nagasaki, and the napalm bombing of the people of Vietnam and Cambodia, the fire-bombing of Dresden has been forgotten and with it the origin of this evil policy of making warfare against innocent civilians. Yet, more people were killed in Dresden

than were killed in either Hiroshima or Nagasaki.

The British have offered many justifications for their fire-storm policy, but the truth is that they wanted to obliterate the German nation and they used Hitler to accomplish this. They financed Hitler and helped him to stay in power. They countenanced his aggression—as long as it did not threaten their island. Yes, the Hitler project was not merely or even primarily a British conspiracy, but British sympathy with Hitler before the war and their Nazi-like genocidal policies against Germany during the war were merely two sides of the same moral rot that had festered since the British Empire took shape.

Despite Dyson's lying assertion that the raid on Dresden was accidental, a mere freak of nature caused by unusual weather conditions, the British deliberately deployed to create the fire storm, just 12 weeks before the end of the war. They chose a city bursting with refugees who were fleeing the Soviets, a hospital center filled with the sick and the wounded. Dresden's population had doubled during the last days of the war, because it was believed to be safe. The city, one of the most beautiful in Europe, was not even a military center, much less a military target.

By the time of the Dresden firebombing, not only were German fighter planes suffering from a severe oil shortage, but the German early warning system had been knocked out.

The British try to justify their war policy by saying that it was expedient. They claim that at the beginning of the war they had difficulty in hitting planned targets. Yet by the end of the war they had a demonstrated capability for precision bombing. They also justified the policy as a way of shortening the war by weakening civilian morale. This too was a lie.

By the end of the war, the British had killed about 400,000 civilians in bombing raids, one third of whom died in the fire storms of Hamburg and Dresden. Despite the fact that 63 German cities were reduced to rubble, industrial production continued to rise throughout the war, since factories were left intact. Airplane production, for example, rose steadily from 2,518 in 1939 to 40,593 in 1944. Only in 1945, was there a slump.

Predictably, deliberate British bombing of nonmilitary targets merely strengthened the average German in his or her conviction that there was no feasible alternative to the Nazi oppression under which they suffered.

The Deal

I am discussing the fire-bombing issue here in some detail because I think it exemplifies the British colonial mentality, Dyson's mendacity, and the "big lie" behind the nuclear freeze leadership.The Yalta summit conference in 1945 is ordinarily thought to be the occasion where the division of Europe was agreed upon with the Soviets. But in reality, the die was cast in January 1943, when once again, at Casablanca, the second (Western) front was postponed. It was then, at the Casablanca conference between Winston Churchill and Franklin Roosevelt, that the United States finally capitulated to the British on the question of strategic bombing, in place of establishing a beachhead in France.

This was not U.S. policy for its own bombing missions. U.S. planes flew in daylight in order to do precision bombing of military targets. Nonetheless, the U.S. government accepted the British policy of genocide. The seeds of Hiroshima, Nagasaki, and Vietnam lay in this unprincipled capitulation.

The deliberate destruction of German residential areas while leaving industry intact was in accord with the Allied agreement, known as the Morgenthau Plan, which was to strip Germany of its industry, more than 20 percent of which would be shipped off to the Soviet Union. Although the Soviets demanded a second front to ease the pressure on them, in the long run the delay of a continental invasion worked to their advantage. They were able to occupy Eastern Europe and half of Germany.

The Policy

The British policy of bombing defenseless civilian populations was formulated in outline by 1935, and according to the head of the Bomber Command, Sir Arthur Harris, it was adopted in 1940. In fact, it was the British who initiated the policy of bombing residential areas, not the Germans. Hitler repeatedly warned that he would be forced to retaliate. Finally, after three straight days in which residential areas in the city of Berlin were bombed,

Erich Andres, Hamburg

Miriam Dyson

Dyson: Proposals that would leave us with neither weapons nor hope. . Above: Dresden, 1945.

Hitler initiated the Battle of Britain.

This is substantiated by P.M.S. Blackett, Dyson's boss in World War II, in an article published in Vol. 5, 1948 of the quarterly journal of the British Association for the Advancement of Science: "The stated [German] intention was to reserve terror attacks to be used only as reprisals," Blackett wrote. "The heavy area attacks on British cities, which started early in September, were announced as reprisals for British air attacks against German cities. A full history of these events, by which to judge finally the legitimacy of this claim is not available, but it will be shown later that the available evidence does, on the whole support this."

This is further corroborated by military historian Liddel-Hart in the book *The Revolution in Warfare*, published in 1946: "Hitler, during the time when he had immensely superior bombing

power, was remarkably reluctant to unleash it full against his opponents' cities, and repeatedly sought to secure a truce in city-bombing during peak days of his power."

It was only at the end of the war, as President Roosevelt neared death and may be presumed to have been less able to assert an independent policy from the British, that the United States reversed its opposition. British authors such as J. M. Spaight, former principal assistant secretary to the British Air Ministry, are quite open about British responsibility.

In his book *Bombing Vindicated,* Spaight proudly admitted: "Because we were doubtful about the psychological effect of propagandist distortion of the truth that it was we who started the strategic bombing offensive, we have shrunk giving our great decision of May 11th, 1940, the publicity it deserves. That surely was a mistake, it was a splendid decision."

This British Nazi brazenly continues, "There was no certainty, but there was a reasonable probability that our capital and our industrial centres would not have been attacked if we had continued to refrain from attacking those of Germany."

Fire Storm Success

Head of the Bomber Command Arthur Harris described in his book how the British got the idea of creating fire storms. The British observed German raids in London and Coventry at the start of the war, and they noted that it was the incendiary markers rather than the high explosives that caused the greatest damage. Therefore, they reasoned, it should be possible to reverse the ordinary bombing procedure and drop incendiary bombs after high explosives had made targets more potentially inflammable.

It should be possible to create a fire storm from this fire-bombing, they reasoned, by concentrating the placement of incendiary charge both in space and in time. For this purpose, explosive charges were used to take the roofs off buildings in order to create better surface conditions for the ignition of fires on a massive scale.

On Jan. 27, 1945, Harris was given instructions to create a fire storm in Dresden. American planes participated in the attack, by doing precision bombing of transportation centers by day. On Feb. 9, 1945, American bombers deliberately created a fire storm in Tokyo. Casualties here and in Dresden were higher than those in Nagasaki, and on a par with Hiroshima.

The Pugwash Movement

The same British policies that led to the unnecessary and wrong use of nuclear weapons in Japan at a time when the Japanese had already indicated their willingness to surrender have governed postwar policy. It was the Dyson crowd that formulated the doctrine of mutually assured destruction. The leading person in this regard was perhaps the most evil man of this century, Bertrand Russell, father of the Pugwash movement.

Russell's policy at the end of the war was to wage preemptive war against the Soviets at the point at which the United States had stockpiled sufficient nuclear weapons, under the pretext that the Soviets would not accept enforced international control of nuclear energy. Dyson writes that his good friend Robert Oppenheimer was the secret author of the Baruch Plan, which specified this international energy agency.

By the middle of the 1950s, Russell realized that since the Soviets now also had a nuclear capability, it would be necessary to come to an accord with them, which would mean the sacrifice of the continued existence of the United States as the superpower. He therefore formed the Pugwash conference, whose purpose was to cement a deal with the Soviets. Their strategic superiority would be assured through various treaties such as SALT, later negotiated by Pugwash conferee Henry Kissinger.

The Oppenheimer Story

Dyson writes at length about Robert Oppenheimer in his book, as a person with whom he identifies. And of course, the Oppenheimer case has remained a cause celèbre in the scientific community. Less known is the fact that Oppenheimer, like Russell and Dyson, pretended to be a crusader against war, yet he personally, as the head of the Manhattan Project, urged dropping the bomb on Hiroshima and Nagasaki.

In the book *The Flying Trapeze: Three Crises for Physicists* (London: Oxford Press, 1964), Oppenheimer explained that he urged dropping the bomb in order to set the stage for the creation of a world federalist government.

Dyson comments about this: "Nuclear weaponry was then a new and revolutionary factor in human affairs. Here, if anywhere, was a chance to create a new international order before national rivalries in the possession and deployment of nuclear weapons would have time to develop. The initial impetus behind the idea of international ownership of nuclear facilities came from the physicists Niels Bohr and Robert Oppenheimer, who had worried together about the future of nuclear weaponry while they worked on the bomb project at Los Alamos."

Dyson describes how these Pugwash networks operate: "After the war, Oppenheimer persuaded Under Secretary of State Acheson and other leading figures in the American government to make a serious effort to achieve international control of nuclear energy. Oppenheimer was not as great a physicist as Bohr, but he was a more skillful diplomat. The result of his diplomacy was the Baruch Plan, the formal American proposal to place all nuclear facilities under international ownership. The Baruch Plan was placed before the United Nations in 1946. . . ."

Dyson then lets the cat out of the bag: "Conceivably, if the International Atomic Development Authority had been set up with the powers envisaged in the plan, the unprecedented renunciation of national sovereignty in the area of nuclear weaponry might have gradually been extended, as Bohr had originally hoped, to a renunciation of national sovereignty over other kinds of armaments, and ultimately to a renunciation of the sovereign right of nations to wage war."

Dyson became an American citizen some years after World War II, but his loyalties have clearly remained with the British Empire. He would destroy nations to reimpose British-style colonialism on a global scale—only now he would let the Soviets in on a piece of the action.

The question to ask is how this incompetent self-avowed traitor remains an advisor on defense policy.

—*Carol White*

The New Race for Space
James E. Oberg
Harrisburg, Pa.: Stackpole Books
1984, $14.95

Is the Soviet Union building its own space shuttle? Were the cosmonauts on last year's Soyuz T-9 mission really stranded in space? Will the Soviets use the super booster they are readying for a manned mission to Mars?

Aerospace engineer James Oberg is one of the few space experts who can answer these questions with both technical accuracy and political aplomb, and he does so in *The New Race for Space*.

For both the technologist and the layman who is trying to keep informed about the Soviet space program, Oberg's latest book is a meaty update. Unlike his other books on space, such as *Mission to Mars* and *New Earths*, however, this book does not have a single theme. This makes it a little more difficult to follow, as Oberg summarizes the state of the art in both the U.S. and Soviet programs and outlines the possibilities for the future.

'Wealth and Power'

The future race for space that Oberg describes is not concerned with space spectaculars or "glory or curiosity," but with wealth and power. This wealth and power, he says, will be economic, based on the exploitation of space for manufacturing and industry and using the infrastructure and technology that have been developed over the past 25 years.

As Oberg notes, this "space race has no finish line."

Oberg is one of the world's foremost experts on the Soviet space program. His *Red Star in Orbit*, published by Random House in 1981, exposed the secrecy and outright lying of the Russians about their space failures and even about their successes.

U.S.-Soviet Cooperation

Therefore, it is certainly with both eyes open that Oberg makes the recommendation that we resurrect the joint U.S.-Soviet space missions over the next decade, based on the unique technologies of each existing national program. A joint U.S.-Soviet mission would be technically feasible as well as politically productive, he says.

In the next few years the Space Shuttle is likely to continue to be the world's only manned, reusable launch vehicle, and the Salyut will be the world's only space station until 1992, when NASA plans its first manned space station. These capabilities could be productively combined.

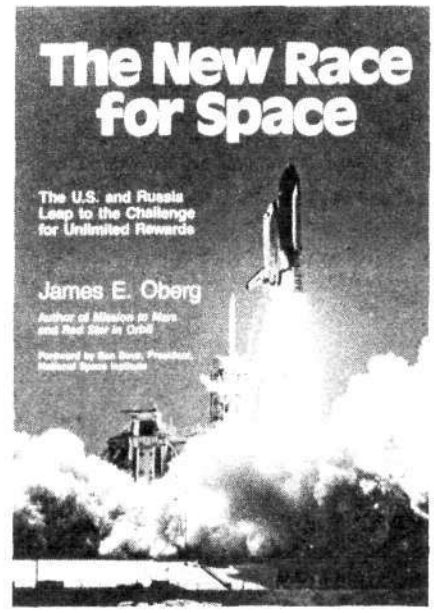
For example, the manned Soyuz capsules that return cosmonauts to Earth have very limited cargo capability and cannot bring back large pieces of equipment or broken satellites. If the Soviet cosmonauts wanted to send something large back to Earth, the Shuttle could make the pickup and delivery.

From the U.S. side, Shuttle scientists might have experiments that they would like to leave in orbit for more than the 10 or so days the Shuttle can stay up there. They could drop them off at the Salyut space station for later retrieval.

The benefit of having Shuttle/Salyut compatable technology to transfer space travelers from one ship to the other is obvious in the case of space rescue attempts, and the political payoff would outweigh even the scientific benefits, according to Oberg.

Spaceships of the Future

Oberg's chapter on spaceships of the future explores some of the most imaginative concepts that have been advanced recently for nonchemical space propulsion systems for future manned planetary missions.



One of the ideas he discusses was put forward by Dr. Franklin Chang, a physicist and a Space Shuttle astronaut. Called the Hybrid Plume Plasma Engine, Chang's concept uses a high-temperature plasma generator coupled to a nozzle system. The nozzle injects an inert gas around the plasma, creating a plume. The combined plume then pours out of the rocket nozzle, "generating much more thrust than the plasma jet would have alone."

Oberg reports that with the help of a graduate student at the Massachusetts Institute of Technology, Chang hopes to test his hybrid plume concept by 1985. After that, there could be an orbital demonstration of the engine attached to a platform in the Shuttle's payload bay. As Oberg points out, since Chang is still in his early 30s, he "may help build them—and ride them."

The recent presidential and congressional support for the space station has once again made it possible for people such as those described in Oberg's book to plan and design and dream about the things they could be doing into the next century. *The New Race for Space* is a look at an optimistic future.

—Marsha Freeman

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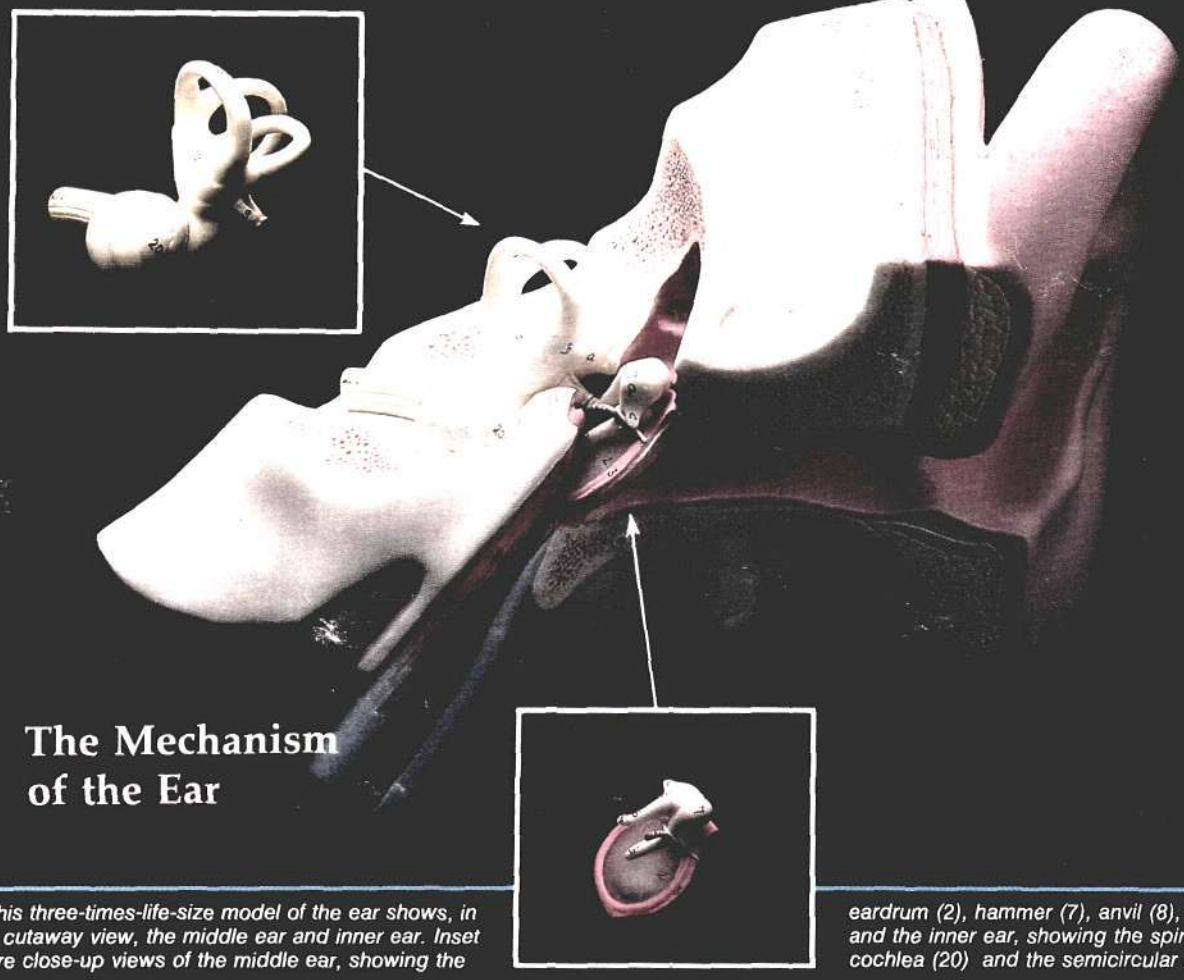


Somso Model from West Germany, courtesy of Kilgore International, Coldwater, Mich.

The Mechanism of the Ear

This three-times-life-size model of the ear shows, in a cutaway view, the middle ear and inner ear. Inset are close-up views of the middle ear, showing the eardrum (2), hammer (7), anvil (8), and stirrup (9); and the inner ear, showing the spiral-shaped cochlea (20) and the semicircular canals.

RIEMANN PROVED RIGHT IN 100-YEAR CONTROVERSY

The little bones in the middle ear (see inset) were at the center of a hotly contested scientific battle in the mid-19th century between mathematical physicist Bernhard Riemann and scientist Hermann von Helmholtz. One hundred years later, as two feature articles in this issue discuss, modern biophysics has proved Riemann and his Neoplatonic approach correct, and Helmholtz and his Aristotelian approach wrong.

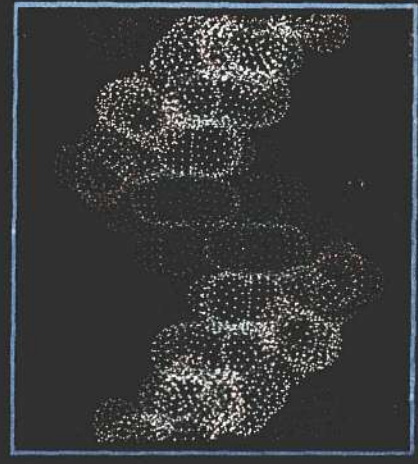
The ear picks up sounds whose mechanical force is millions of times weaker than sounds of ordinary intensity. How is this possible? Like a systems analyst, Helmholtz looked at all the various parts of the ear and tried to guess how they fit together. Riemann approached the problem by asking the questions: What does this life process accomplish? What problem must it solve? Riemann proposed that new physical principles were necessary to understand the extraordinary sensitivity of the ear, and to this end he formulated new hypotheses.

In a feature article accompanying the first English translation of Riemann's essay "The Mechanism of the Ear," Jonathan Tennenbaum likens Riemann's solution to the mechanism of the ear to a kind of laser, focusing a tiny amount of action, a sound wave, that draws energy from the medium and amplifies itself in the course of its propagation to the brain.

A GEOMETRICAL APPROACH TO UNDERSTANDING BIOPHYSICS

In the "Geometry of Life," this issue's cover story, author Ned Rosinsky explores a geometrical approach to biophysics and discusses the latest research in the study of spectra, the patterns of absorption and emission of electromagnetic radiation by biological substances. If such resonances are considered as spiral motion, or biological work functions that transform living processes, Rosinsky hypothesizes, this provides us with clues for understanding—and changing—the processes that lead to cancer, or aging in general.

Computer Graphics Laboratory, University of California, San Francisco



A computer-generated model of a DNA molecule is shown from the side. (The front cover graphic shows an end-on view.) The simulation depicts two-thirds of one revolution of the DNA helix. Red represents oxygen; blue, nitrogen; green, carbon; and yellow, phosphorous. Hydrogen is not shown.