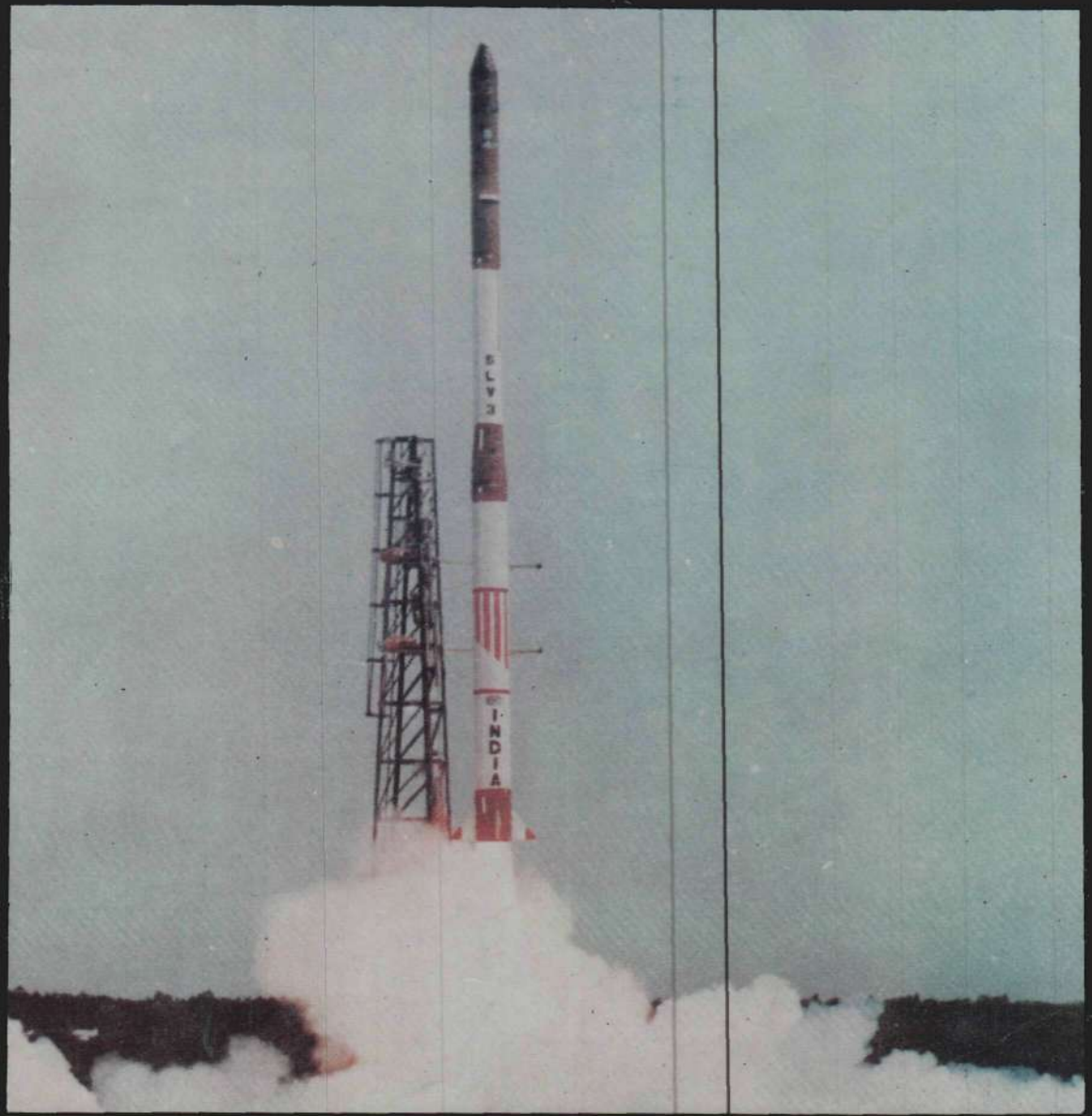
KRA CANAL MUST BE BUILT! Conference Report

FUSION ASIA

SCIENCE • TECHNOLOGY • ECONOMICS • ENERGY

January 1985 Vol. 2 No. 2



INDIA'S SPACE PROGRAMME BOOSTING INDUSTRY

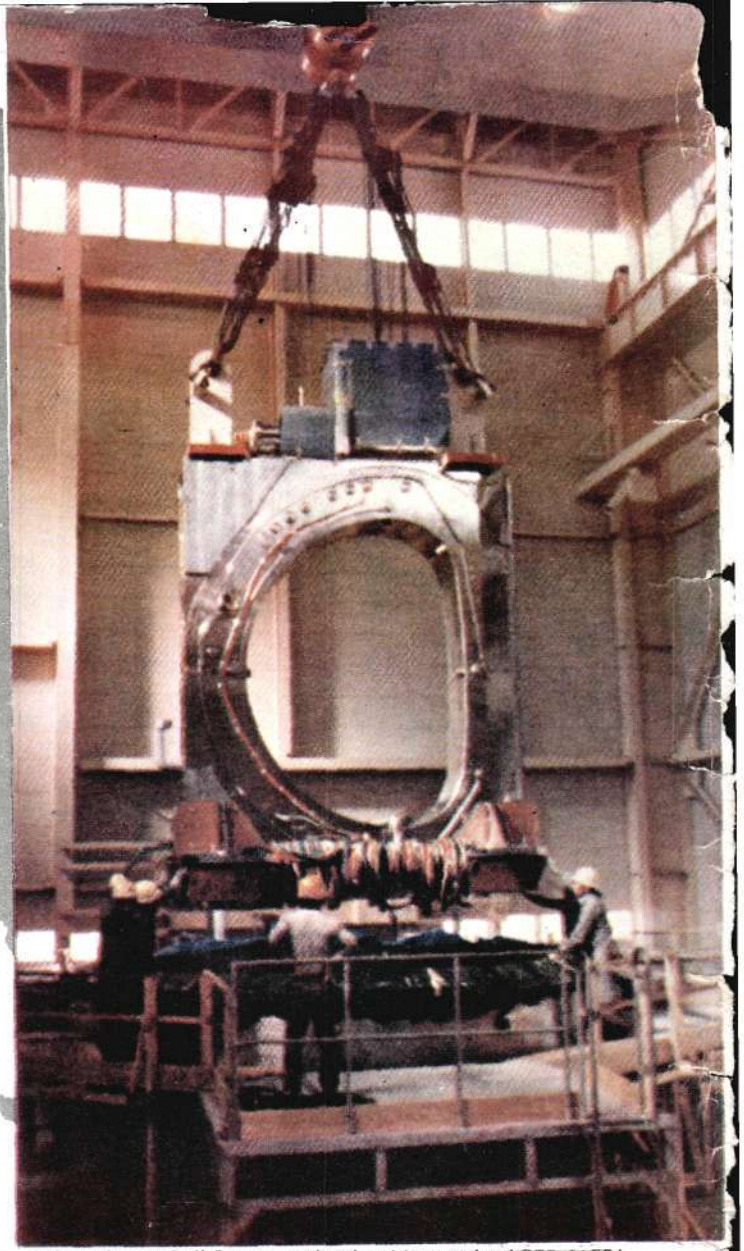
Stay out in front !
Read

FUSION ASIA

A Quarterly Journal of

- SCIENCE • TECHNOLOGY
- ENERGY • ECONOMICS

FOR AND ABOUT ASIA



Japan's Large Coil Superconducting Magnet for LCTF, JAERI

Please enter my subscription to

FUSION ASIA

Name_____

Address_____

Make drafts payable to Fusion Asia. Address all enquiries to
Editor, Ramtanu Maitra, C-9 Nizamuddin East, New Delhi- 110013 India

Subscribe!	Annual!
Australia, New Zealand	A$ 18.0
Bangladesh	Tk. 120
Burma	K. 40.
China	U.S.$ 15.0
Hong Kong	HK$ 80
India	Rs. 50
Indonesia	Rp. 9000
Japan	Y. 5000
Malaysia	M$ 35.0
Pakistan	Rs. 50
Philippines	P. 250
Republic of Korea	W. 8000
Singapore	S$ 35.0
Sri Lanka	Rs. 100
Taiwan	NT$ 450
Thailand	B. 300
U.S. and Europe	U.S. 20.0

Advertise!*

Full page : 40 X annual subscription
Half page and Quarter page accordingly
Inside covers : 160 X annual subscription

* **Detailed ad information available upon request**

Vol. 2, No. 2 January 1985

FUSION ASIA

FUSION ASIA is published quarterly and dedicated to providing accurate and comprehensive information on advanced energy technologies and policies. FUSION ASIA is committed to the scientific and technological advancement of all developing nations. FUSION ASIA coverage of the frontiers of science focuses on the self-developing qualities of the physical universe in such areas as plasma physics—the basis for fusion power—as well as biology and biotechnology, space science, laser physics, solid state physics, cryogenics, and includes studies of the historical development of science and technology.

The views of the Fusion Asia Society are stated in the editorials. Opinions expressed in articles are not necessarily those of the Fusion Asia Society's directors or of the journal's Advisory Board members.

FUSION ASIA is printed and published by Ramtanu Maitra for Fusion Asia Society at Parul Printers, NOIDA, (U.P.)

Registered Office: 39, Okhla Industrial, Complex. Scheme III Phase II, New Delhi-110020.

Editorial : C-9 Nizamuddin East New Delhi-110013.

Features

21 India's Space Programme—Boosting Industry

Ramtanu Maitra

Satellite communications and remote sensing—and self reliance in the provision of these services—are the official national development goals of India's space effort. Less well appreciated, but not less significant, is the critical, dynamic role the programme is playing in the country's industrial development.

36 Riemann and the Science of Life

Jonathan Tennenbaum

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

44 Riemann and the Gottingen School of Physiology

Robert Gallagher

One hundred years later, Riemann's view on how the ear works and his criticism of Helmholtz are being vindicated by modern biophysics.

51 The Mechanism of the Ear

Bernhard Riemann

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

News

11 INTERNATIONAL

Japan's Gekko XII Laser Scores Major Advances
Krypton Fluoride Laser Fired: 'New Dawn for Fusion Research'
Los Alamos Begins Work on Gamma-Ray Laser
Princeton Beta Experiment Shoots for Breakthrough

18 ASIA

Dhaka Meet Supports Nuclear Power for Development

60 SPECIAL REPORT

International Conference Puts Kra Canal Back on the Agenda in Thailand

Departments

2 EDITORIAL

3 COUNTERPOINT

8 NEWS BRIEFS

Australia, N. Zealand	A$ 4.50	Malaysia	M$ 8.75
Bangladesh	Tk. 30	Pakistan	Rs. 15
Burma	K. 10	Philippines	P. 65
China	U.S.$ 4.00	Republic of Korea	W. 2000
Hong Kong	HK$ 20	Singapore	S$ 8.75
India	Rs. 15	Sri Lanka	Rs. 25
Indonesia	Rp. 2500	Taiwan	NT$ 115
Japan	Y. 1250	Thailand	B. 75
		U.S. and Europe	U.S.$ 5

simulates the full physics of a radiatively active trace material where net heating effects drive the circulation while the distribution of material is itself continuously varying in response to the flow and to complex flow-dependent removal processes. Formulations of boundary layer processes in these models are necessarily somewhat crude because of the low spatial resolution.... Perhaps the most serious for the nuclear war particulate problem, the cloud microphysical processes that are primarily responsible for the removal of particulates from the atmosphere cannot now be included in detail in these models."

Nonetheless (and incredibly), after admitting that these models are irrelevant, the NRC committee makes their own "winter" forecast of "large temperature decreases near the surface (of the Earth) and temperature increases aloft for a period of weeks to months" after a war. These remarks underscore the methodological incompetence of existing criticisms of Sagan's "World."

A Scientific Approach

The achievements of the "continental" school of European science refute the methodology of the weather modelers. Gottfried Leibniz and his followers at the Ecole Polytechnique in France and the Goettingen school in Germany demonstrated that natural processes are creative or negentropic, that nature is differentiated at every level of scale and that the microphysical processes of nature perform work on the universe as a whole. As Leibniz wrote in his beautiful 1698 essay, *What Is Nature?*: "The whole of nature is a perfect work of God's making, and this so much so that every natural machine consists in its turn of an infinity of organs. This is the true but rarely observed difference between nature and art."

Leibniz continued: "All action is the action of an individual substance.... Not only is all that acts an individual substance, but every individual substance acts without intermission. And this is true also for corporeal substances, in which no absolute rest can ever be found.

"Hence, one must infer that in a corporeal substance there must be located a first entelechy, a first capacity for action, as to extension (or that which is merely geometrical) and mass (or that which is merely material). And it acts constantly, though variously modified by the concurrence of other bodies and their tendencies and impulsions."[6]

Bernhard Riemann demonstrated these ideas—and in doing so, the existence of Leibniz's monads that "act without intermission"—in his ground-breaking 1859 work on shock compression in gases, *On the propagation of plane air waves of finite amplitude.*

Imagine an infinite cylinder filled

SIX REFUTATIONS OF CARL

Edward Teller of Lawrence Livermore National Laboratory, S. Fred Singer of the University of Virginia, Sherwood B. Idso of the Institute for Biospheric Research in Tempe, Arizona and a special committee of the National Research Council in the United States has each exposed the arbitrary assumptions underlying Sagan's "result" of a nuclear winter.

(1) Singer points out that Sagan's cooling effect is based on the smoke blanket having unique and peculiar optical properties: for the cooling to occur, the blanket of smoke must (a) reflect visible solar radiation back into space but also (b) permit infrared radiation (heat) to pass through the blanket and escape from the Earth. This is the worst possible situation. But if the smoke blanket was opaque to all wavelengths, the heat given off by the Earth would be trapped by the blanket—reducing or eliminating a temperature drop at the surface. Secondly, it is also likely that a smoke blanket would *absorb* solar radiation and re-emit it as heat (infrared radiation) to warm the Earth.

(2) Teller argues that Sagan ignores the principal natural mechanisms for removal of smoke from the atmosphere. Even if as much as 225 million tons of smoke is injected into the atmosphere over northern hemisphere mid-latitudes as a result of war, the amount of water already in the atmosphere over these regions is 10,000 times greater. He shows that in the first ten days after a war—before the cooling effect occurs—an amount of water equal to a few thousand times the amount of smoke assumed to be thrown up, will rain out, cleansing the atmosphere.

(3) Singer and Teller both point out that fires themselves inject great amounts of steam into the atmosphere. This may be the source of the "capping cloud" of condensed moisture that forms over a smoke plume rising from a fire. Singer mentions that these clouds make it difficult to detect forest fires from space. Experiments have shown that these clouds created by fires reduce the number of small smoke particles—the ones Sagan relies on to shut sunlight out from the Earth—by 90 percent! Agglomeration of small particles into larger ones that fall or rain out faster is probably the principal mechanism.

(4) Teller adds that the Sagan model ignores the oceans and winds. But the oceans are a huge reservoir of heat that will warm the air over them and establish a great temperature gradient between the oceans and land at the beginning of a "nuclear winter" so as to moderate it and set into motion atmospheric processes to break up the smoke blanket over the Earth. He cites a model developed by the National Center for Atmospheric Research which in a limited way includes oceans and wind, but which was otherwise similar to Sagan's. This model arrived at a temperature drop that was, depending on the season, one-half to one-tenth the size of that asserted by Sagan.

Teller writes:

"If a nuclear winter were to begin, unusually great temperature differences would be established between the continents and oceans. This results in increased storms along the eastern coasts of the continents, with consequent mixing of air from high and low levels of the troposphere. Air from lower altitudes has a higher moisture content which is conducive to rainout. The

SAGAN'S 'NUCLEAR WINTER'

storms are mentioned by Turco et al. (i.e., Sagan) but not taken into account in the calculation of particle scavenging.... If the rain removed smoke from one area while leaving it untouched in another, the smoke layer would be patchy....

"The patchiness of smoke, in turn, could bring about further large temperature differences which will further drive the atmospheric processes that rain out more smoke. In this case, rainout of large smoke layers might proceed in an accelerating fashion."

(5) In a recent technical letter to **Nature,** Idso ridicules Sagan for his illogical reasoning:

"In their recent complaint about (**Nature** editor) John Maddox's criticisms of their climate modeling work on the 'nuclear winter' concept, Turco et al. attempt to buttress their case by stating that the climate model they used was partly calibrated by (a) 12 years of research on Martian dust storms, (b) the climatic consequences of volcanic explosions on Earth, and (c) the possible collision of an asteroid or cometary nucleus with Earth at the time of Cretaceous/Tertiary extinctions. In addition, they say that their work was reviewed by a large number of experts and that it referred to many previous studies. If these reasons are indeed the basis for their confidence, the criticism they received was well justified.

"To begin with, what good is a technique that is only *partly* calibrated? And how can a model be calibrated against a *possible* phenomenon which may or may not have actually occurred, and at that in the distant past? With respect to the climatic consequences of volcanic explosions, Turco et al. indicate in their complaint that these are caused primarily by sulphuric acid aerosols and not by the smoke and dust that is supposed to operate in the nuclear winter scenario. So how can this comparison be of any use? In addition, of what real comparative value is the planet Mars? It has no liquid water on its surface, while Earth is 70 percent covered by seas; and its atmospheric mass is miniscule. Dust there operates almost as if it were in a vacuum; and, again Turco et al. claim that it is not dust but rather sooty smoke from fires that is the major cause of nuclear winter. And as for citing a lot of background material and getting the opinions of a large number of experts, what does that prove? Absolutely nothing."

(6) According to Sagan's scenario, the dissipation of the smoke blanket, after months of freezing temperatures, would expose the biosphere to being "fried alive" by ultraviolet radiation because of the reduction by one-half of the thickness of the protective ozone layer by multi-megaton explosions. Teller refutes this as well. He points out that nuclear tests in the atmosphere indicate that a war with multi-megaton weapons might deplete the ozone layer 30 to 40 percent. This is comparable to observed geographic and seasonal variations in the ozone column. For example, the ozone over Miami is about 20 percent less than over Seattle. Therefore, he argues, "the changes are not likely to be significant." Furthermore, the present U.S. nuclear arsenal has few nuclear weapons with the yield required to deplete the ozone layer in the first place.

Each of these arguments is fatal to Sagan's "World."

with air at standard atmospheric temperature and pressure. The movement of a piston at one end of the cylinder sets a wave into motion down the length of the cylinder. Riemann embedded Leibniz's principles into this simple model with his assumption that the characteristics of the medium are such that its compression with the propagation of the wave through it is isentropic; that is, it occurs without the loss of energy. In other words, the action of the gas upon itself is perfect. On this assumption, Riemann's analysis showed that such a medium transforms the simple wave in a finite time into a shock front through its own properties of differentiation. Sonic booms and other shock phenomena confirm the appropriateness of Riemann's poetic analysis.

Riemann's work became a rosetta stone for Man's mastery of hydro- and aerodynamics. Let us now test Sagan's "World" against Riemann's demonstration of the constitutive physical principles of the real world.

Even assuming that a 225 million ton blanket of smoke and soot is formed over the Earth, reflecting sunlight, how long could such a structure persist? Teller points out that the smoke laden air in the troposphere would raise the temperature at the tropopause from -60 degrees centigrade to about +5 degrees centigrade. Meanwhile, surface temperatures on the continents of the northern hemisphere at mid-latitudes would drop to -30 degrees centigrade. How long could a blanket of mere smoke maintain such a huge temperature gradient? Suppose the blanket is established, the Sun would continue to pump energy into the air supporting the blanket at the tremendous rate of 00000 kilowatts per square meter.

Furthermore, Sagan insists that this insulation blanket does not radiate heat down to the atmospheric layers below it. Were this true, these layers would constitute an ideal container for structure formation within the blanket. (Were it not true, the Earth would be warmed.) Clearly the excited medium would destroy the smoke blanket. This would not even require the formation of shocks as they are commonly understood in the sonic boom and other such macroscopic phenomena. Vortex formation could produce the same effect.

Action of Infinitesimals

Perhaps the most poetic demonstrations of Leibniz's concept came from Karl Weierstrauss and Georg Cantor. They developed mathematical functions that represent the infinite differentiation that Leibniz insisted existed. Before Weierstrauss, it was assumed that all continuous functions were differentiable; that is, it was assumed that in the infinitesimally small they were straight lines. Weierstrauss constructed a function

everywhere but
nowhere. It is nowhere
Weierstrauss function has no
est scale. No matter how much you magnified the graph of the function, it would be just as intricate as when you began. The function is self-similar throughout all levels of scale. Leonardo da Vinci's water studies are suggestive of such differentiation.

Does such a function exist in nature? Recent work has shown that the so-called Brownian motion of air molecules is most simply described by a Weierstrauss function. M.V. Barry and Z.V. Lewis discuss this, though from a backward, statistical standpoint. A Weierstrauss function, they write, "is a model for the distance travelled along an axis in time *t* by a particle moving in infinitesimal steps which are equally likely to be backwards or forwards."[7]

Examples of the action of infinitesimals upon the universe abound. Lyndon LaRouche's concept of the "use value" of a commodity is perhaps the best elaboration of Leibniz's idea.[8] In fact, the striking success of the LaRouche-Riemann economic model is due entirely to its foundation on the Leibniz-Gauss-Riemann tradition. An economic product does not exist for the consumer only—through its consumption or "use," it acts on the economy as a whole. A nuclear power plant is not an abstract power source; rather, it is an engine for transforming the Sahel into a breadbasket through the deployment of its power to produce nitrogen-based fertilizers, desalinate water and pump irrigation water for agriculture. Its "use value" is greater than that of a comparable coal plant, which requires construction of a transportation infrastructure through which to bring in fuel before it can have any impact on economic growth.

Human hearing also provides examples of how infinitesimal action can affect a large scale process. The movement of the eardrum on the order of the diameter of a hydrogen atom coincides with the perception of sound. Georg von Bekesy argued that during ordinary conversation, the amplitude of the movement of the basilar membrane of the inner ear was about the radius of the hydrogen atom. Recent work indicates that a basilar membrane movement on the order of one picometer (one trillionth of a meter) correlates with sensation—in confirmation of von Bekesy's hypothesis.

If scale of resolution were the only criteria by which to judge models, this result would put weather modelers out by a factor of 10^{15} away from lawful processes.

Is Weather Modeling Possible?

The objection might be made that this discussion has transformed weather modeling into an impossible task. How can a computer begin to model the infinite differentiation that we here claim exists in the atmosphere? The complete failure of the modelers to account for the highly differentiated atmosphere of Jupiter underscores the problem. But merely improving the scale of resolution of existing models would not advance their predictive power one iota. The worst aspect of existing models is that they assume mere gas particles to be the elements of atmospheric processes.

This analysis has tried to show that action is the most elementary property of nature, regardless of what level of scale is investigated. From this standpoint, modelers would do well to make the (rotational) action of gas the "irreducible element" of future models. It will mean rewriting a lot of computer code but it's well worth the effort. The immediate benefit is that with rotational action as "the elementary particle" of models it will be possible to represent infinite differentiation. Ralf Schauerhammer and Jonathan Tennenbaum of the Fusion Energy Forum in the Federal Republic of Germany have represented a Weierstrauss function with a simple construction using three logarithmic spirals and rotational action.[9] If three logarithmic spirals can represent a Weierstrauss function (and "Brownian motion"), perhaps a computer can begin to model at least a section of the atmosphere with a few thousand spirals.

The interplay of spirals in this construction brings to mind the principle of dialogue in well-tempered counterpoint, where the dialogue of voices carries forward the differentiation or development of the theme. Assuming that rotational action is the "elementary particle" of nature, then nature is indeed musical and its processes reflect what Friedrich Schiller called the "play instinct" (*Spieltrieb*).

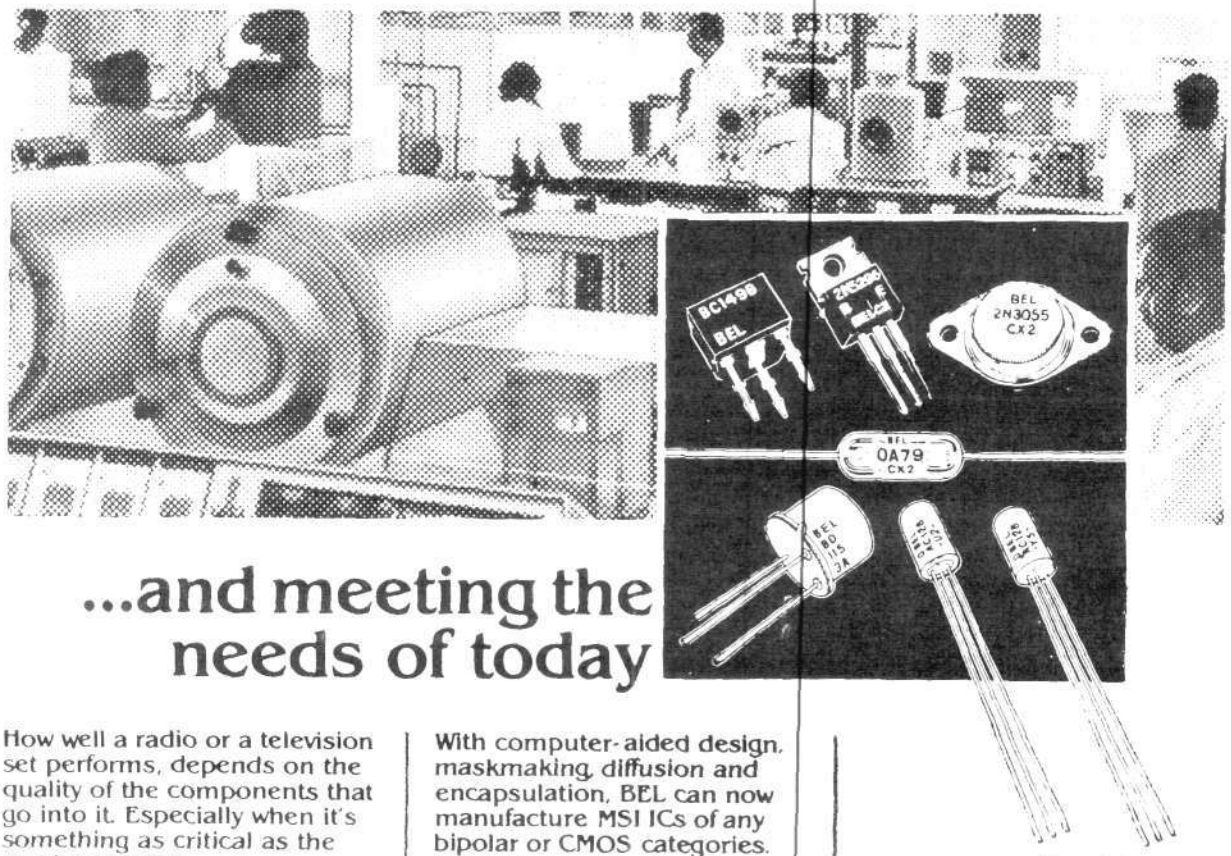
In accordance with this Joseph Fourier, who set off the development that led to Riemann and his successors, wrote: "Mechanical theories... do not apply to the effects of heat. These make up a special order of phenomena, which cannot be explained by the principles of motion and equilibrium.... If the order which is established in these phenomena could be grasped by our senses, it would produce in us an impression comparable to the sensations of music."[10]

REFERENCES

1. Turco, R.P., Toon, O.B., Ackerman, T., Pollack, J.B. & Sagan, C., "Global Atmospheric Consequences of Nuclear War." Distributed by the Nuclear Freeze Foundation (1735 New York Avenue, N.W., Washington, D.C. 20006) for the conference, "The World After Nuclear War." Later edited and published in *Science* (222), 1283-1292 (1983).
2. Edward Teller, "Widespread Aftereffects of Nuclear War," in *Nature* (310), 612, 23 Aug 1984.
3. S. Fred Singer, "Is the 'Nuclear Winter' Real? In *Nature* (310), 625, 23 Aug 1984.
4. Sherwood B. Idso, "Calibrations for Nuclear Winter," In *Nature* (312), 407, 29 Nov 1984.
5. National Research Council, *The Effects on the Atmosphere of a Major Nuclear Exchange*, 1984.
6. G.W.F. Leibniz, "What Is Nature?" in *Monadology and Other Philosophical Essays*, Bobbs-Merrill, 1965.
7. *Proc. R. Soc. Lond.* (A370), 459-484 (1980).
8. LaRouche, Lyndon H., *So, You Wish to Learn All About Economics?* New Benjamin Franklin House, New York, 1984.
9. *Fusion*, (5), No. 5, Nov 1982, p. 18-19.
10. Fourier, J., *Analytical Theory of Heat*, Dover, New York, 1955.

The growing world of BEL

Discovering newer directions in semiconductor devices...



...and meeting the needs of today

How well a radio or a television set performs, depends on the quality of the components that go into it. Especially when it's something as critical as the semiconductor.

The semiconductor is as vital to an electronic circuit as the heart is to the circulation system. It is one of the most crucial components in all electronic circuits — from TV receivers to radar systems.

BEL is part of this too...

Equipped with sophisticated design, manufacturing and testing facilities, BEL is moving into newer directions in semiconductor devices.

BEL has made heavy investments in systems and equipments to heighten its capabilities in semiconductors.

With computer-aided design, maskmaking, diffusion and encapsulation, BEL can now manufacture MSI ICs of any bipolar or CMOS categories. In a larger scale of vertical integration.

The country can now look forward to a new generation of silicon small signal and power devices. And with new equipment to extend the scope of CMOS technology, BEL has gone into ion implantation, doping and poly-silicon deposition.

BEL — a fast-modernising electronics base

In answer to the increasing demands of the electronics industry, BEL is constantly expanding its capabilities. And adding to its growing world of transmitting tubes, X-ray tubes, microwave tubes, passive vacuum devices, display devices, hybrid microcircuits, crystals, ICs and ceramic capacitors. That's the components side of the story. BEL is the country's leading manufacturer of professional electronic equipments and systems as well. Innovating and specialising in electronics for communication, radar and broadcasting. For defence and civil applications.

BEL. Where state-of-the-art electronics is poised for the future.

BHARAT ELECTRONICS LTD

(A Government of India Enterprise)

BEL–leaders in professional electronics

HTK-BEL-1396-2

News Briefs

LASERS FOR URANIUM ENRICHMENT UNDER CONSIDERATION

In April 1985 the U.S. Department of Energy (DOE) will make decisions on fund allocations for the construction of uranium enrichment factories based on new physical principles. These facilities will be based on the use of finely-tuned lasers to achieve the enrichment of uranium necessary to make fuel for Lightwater Reactors.

Although there is a worldwide excess of uranium enrichment capability (42 million Separative Work Units (SWU) against a demand of 39 million SWU in 1985), these capabilities will be insufficient by the early 1990s.

The new enrichment process using tuned lasers is fundamentally more efficient than ultracentrifugation, its present competitor. The process now under consideration by the DOE is laser-induced photoionization.

In the case of photoionization, uranium metal is vaporized at a temperature of 3000 degrees Kelvin by electron bombardment. The U-235 atoms, the fissile atoms, are then selectively excited by a finely-tuned dye laser operating in the blue-violet part of the electromagnetic spectrum. Once the U-235 atoms are ionized, these are then extracted with the help of electric and magnetic fields.

JAPAN: FUSION TECHNOLOGIES IN DEVELOPMENT PLAN

In its "blueprint" for 21st century Japan, the National Land Agency envisions a new wave of technological innovation stemming from concerted work in four broad areas: electronics, bioengineering, new materials development and nuclear fusion technologies. Biotechnology received particular attention for its wide potential application in such areas as the development of new medicines, increased food production and energy development.

The Agency foresees that biotechnology along with electronics technology will permeate the social system as a whole during the next century, and projects that the new wave of technological innovation will create new industries enabling Japan to achieve an economic growth rate of 6 percent in the coming century. The blueprint is part of the National Land Council's effort to work out a 15-year comprehensive national land development programme for Japan covering 1986-2000.

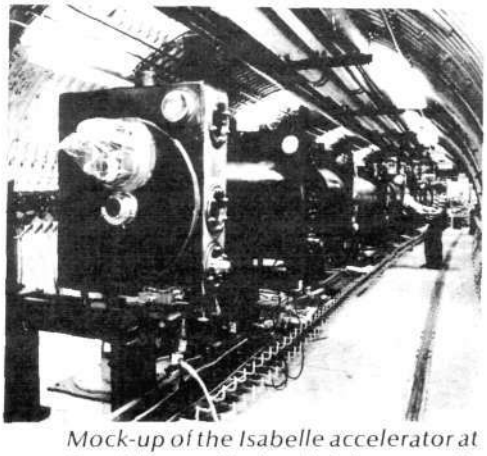
MUON-CATALYZED 'COLD' FUSION SHOWS PROMISE

Recent experimental and theoretical research findings at the Los Alamos National Laboratory and the Lawrence Livermore National Laboratory, both located in the United States, offer fusion scientists the possibility of utilizing muons to catalyze fusion reactions in hydrogen gas at only a few hundred degrees Celsius.

Muons are short-lived subnuclear particles generated in high-energy particle accelerators.

Muons, which have several hundred times the mass of electrons, are generated as a beam. This beam is then directed into hydrogen gas made up of heavy isotopes of hydrogen—deuterium and tritium, the best fusion fuel. As the muon beam penetrates the gas, a single muon will replace one of the two electrons of the deuterium molecule. But since the muon is far heavier, its orbit around the deuterium nucleus is much tighter and close to the nucleus. The "muonized" deuterium molecule, much smaller than the ordinary hydrogen molecule, is also 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.

The main objective of high-temperature, thermonuclear fusion is to utilize high relative velocities of nuclei so that they can overcome their mutual electric repulsion 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.



Mock-up of the Isabelle accelerator at Brookhaven National Laboratory in the U.S. This is the type of multi-GeV accelerator needed to generate high-flux muon beams.

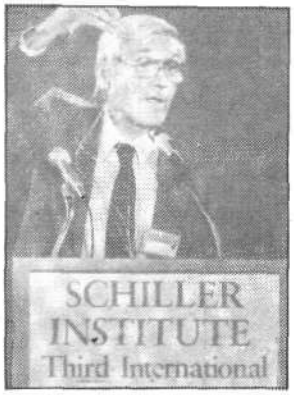
FEF SCIENTISTS TOUR INDIA

Dr. Jonathan Tennenbaum, editor of the German-language edition of Fusion magazine and director of the Fusion Forum of West Germany, and Dr. Winston Bostick, member of the editorial board of the *International Journal of Fusion Energy*, visited India in February. Dr. Tennenbaum is a mathematician by training. Dr. Bostick is a plasma physicist from the Stevens Institute of Technology. The two made a series of presentations on the latest findings on the plasma focus machine at Darmstadt and on the subject of electron morphology.

Dr. Bostick held seminars at the Saha Institute of Nuclear Physics and the Indian Association for the Cultivation of Science in Calcutta, and at the Indian Institute of Technology, Delhi as well as the Bhabha Atomic Research Centre at Trombay. The visiting scientists held talks with their counterparts at the Tata Institute of Fundamental Research in Bombay, the Indian Institute of Technology in Powai, and Delhi University. Dr. Tennenbaum also made a presentation on science and cultural optimism at the Gargi College for Women in Delhi.

Both the scientists took this opportunity to introduce the newly-revived and expanded *International Journal of Fusion Energy* (IJFE), published from New York. The latest issue of the IJFE (Vol. 3, No. 1: January 1985) has just appeared.

The first issue contains a report by Dr. Bostick, *Morphology of the Electron* in which the physicist's provocative hypothesis that the electron and other "elementary particles" are electromagnetic filamentary structures is presented. The journal also contains a report by Dr. James Frazer of the Houston (Texas, USA) Medical Center on the absorption and emission spectra of a variety of biological surfaces. Dr. Frazer's work suggests the presence of long-range coherence in electromagnetic action as the basis for numerous basic biological processes from membrane activities to DNA replication.



Winston Bostick


Jonathan Tennenbaum

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

Program administrators in the U.S. 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 Department of Energy 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 Department 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.

Fusion Energy Foundation executive director Paul Gallagher in New York called on the hundreds of thousands of FEF members and *Fusion* magazine 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?"

Japan's Gekko XII Laser Scores Major Advances in Inertial Fusion

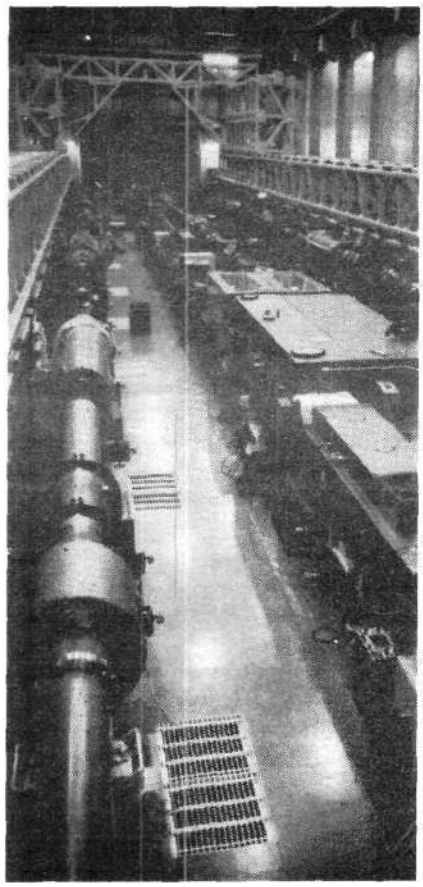
Major advances in the Japanese inertial confinement fusion program, achieved with the world's most powerful laboratory laser, the Gekko XII, were announced by Dr. Chiyoe Yamanaka at the 10th International Conference on Plasma Physics and Controlled Nuclear Fusion Research held in London Sept. 12-19, 1984. Japan may now have leapfrogged the United States in this important technology, although this is impossible to judge since U.S. research in this area is top secret and there is no official cooperation with Japan on inertial fusion.

Yamanaka heads the Institute for Laser Engineering at the University of Osaka, the world's most powerful and versatile inertial confinement fusion laser facility, which houses the 12-beam, 30-kilojoule, 50-terawatt Gekko XII glass laser. At the conference, Yamanaka reported that Gekko XII was able to generate more than 40 billion fusion neutrons. Since one of the primary products of the fusion reaction is neutrons, this provides a direct measure of the number of reactions achieved; 40 billion is essentially equivalent to the best result previously attained with the U.S. Shiva laser at Lawrence Livermore National Laboratory.

(Because of funding cuts, Livermore's Nova laser system, the successor to the Shiva, will not begin experiments until 1985.)

More significant, fuel compressions more than 100 times the normal liquid density of hydrogen were achieved. Since density is the key to high gain, this result is even more important than the amount of fusion achieved and, again is equivalent to the best results achieved by the U.S. program.

Yamanaka also reported new experimental results that promise greatly to enhance the efficiency and effectiveness of indirect-drive targets—results



that open up entirely new possibilities for inertial confinement. In indirect-drive inertial confinement, the incident laser beam energy is transformed into another form, usually X-rays, that is then used to compress and heat the fusion fuel target. Indirect-drive research is under top security wraps in the United States.

The Osaka Cannonball

The Osaka cannonball target surrounds a direct-drive target with a hollow metal sphere. (In direct-drive inertial confinement, the laser beams are symmetrically directed onto the target's surface, which ablates, creating a inertial force directed toward the center of the fuel.) The metal sphere has holes in it so that laser beams can be directed onto the interior surface of the sphere. Plasma generated by the laser irradiation of this interior surface quickly moves across these openings and thus traps the laser beams within the sphere.

There are two possible configurations in the cannonball target.

First, in a *plasma cannonball*, the fuel pellet surface is close to the interior surface of the metal sphere. The plasma generated by the laser irradiation of the interior of the metal sphere will come into contact with the fuel target and compress it just as the hot gases trapped in a gun barrel propel a cannonball (Figure 1).

Second, in an *X-ray cannonball*, the fuel pellet radius is significantly smaller than that of the metal sphere, and therefore the two surfaces are geometrically separated. In this case only soft X-rays from the plasma created on the interior of the metal sphere will make contact with the fuel pellet.

It has been known theoretically for some time that X-rays generated by a laser-produced plasma offer the best means of achieving uniform and efficient high-density compression of fusion fuel. This is because the energy of the individual laser beams has been uniformly spread out in the plasma generated over the interior of the metal sphere. Therefore, the resulting X-ray radiation is quite uniform when it falls onto the fuel pellet.

Also, it has long been known that X-rays have the ideal wavelength for coupling electromagnetic radiation to solid matter. This means that the X-rays will be most efficient in driving the implosion of the fusion fuel target.

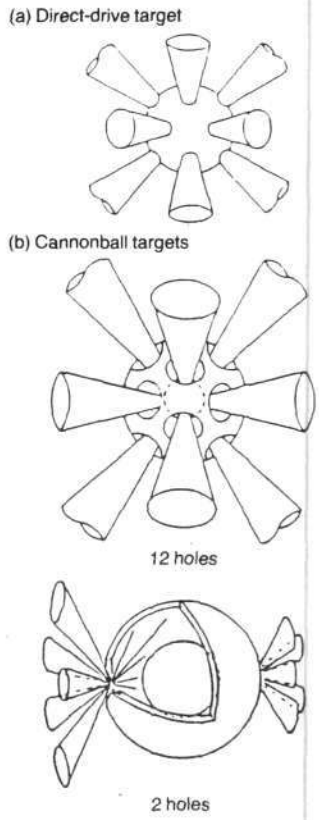
Experiments demonstrated that fairly high implosion efficiencies in the range of 5 to 6 percent were achieved with both the plasma and X-ray can-

nonball targets. Implosion efficiency is a measure of that part of the incident laser energy that goes into compressing the fuel. As seen in Figure 2, the cannonball targets achieved a higher absorption of incident laser energy at higher laser intensities than did direct-drive targets.

Figure 1
LASER FUSION TARGET CONFIGURATIONS

A direct-drive target is shown in (a), where the cones represent incident laser beams. In direct-drive fusion, the beams are symmetrically directed onto the surface of the sphere of fusion fuel. As the beam energy is deposited, the surface of the fuel target is boiled off, a process called ablation. Like a rocket exhaust, ablation creates an oppositely directed force toward the center of the fuel target, compressing the fuel to high densities. The fuel will now burn up before it blows up; that is, the small ignited core will generate sufficient fusion energy to heat and burn the remaining fusion fuel.

Two different geometries for cannonball targets are shown in (b). Here the incident laser beam cones are trapped within the cannonball. In this indirect-drive method, the incident beam energy is transformed into another form of energy, usually X-rays, that then compresses and heats the fusion fuel target.



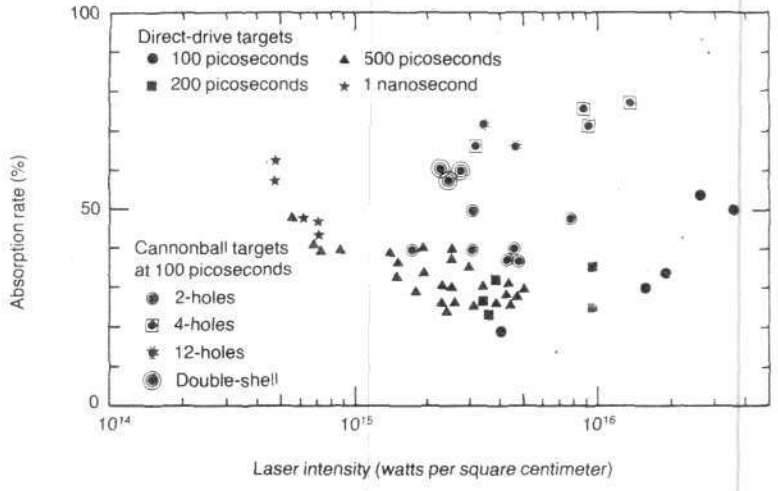


Figure 2
ABSORPTION RATE OF VARIOUS LASER TARGETS

The various types of cannonball targets achieved higher absorption of incident laser energy at higher laser intensities than did direct-drive targets. The experimentally measured absorption rate of incident laser energy is given in percentages; incident laser beam intensities are given in watts per square centimeter.

Tuning into the Target

In addition to successfully demonstrating the essential features of both plasma and X-ray cannonballs, the Osaka group discovered a new possibility that could significantly decrease the requirements for high-gain inertial confinement fusion. First, the Osaka group reported that in the laser generation of X-rays, the resulting X-rays can be tuned to specific wavelengths by choosing different materials for the interior of the metal cannonball. These "tuned" X-rays are often called *line radiation*.

Second, the fuel target can be made so that its surface consists of layers, each of a different material. The layers can be arranged so that X-rays of one wavelength will readily penetrate some layers and deposit their energy on an interior surface of another layer.

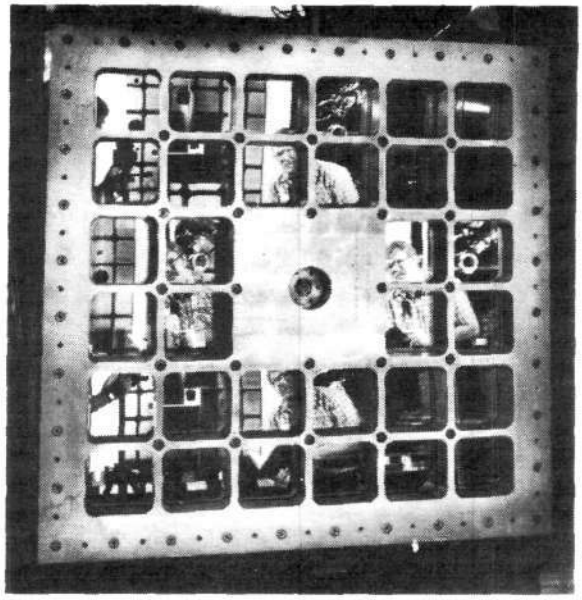
By generating several different X-ray line radiation wavelengths and using a number of material layers on the fuel target, the deposition of the total X-ray energy can lead to the simultaneous generation of several compression shocks on the interior of the pellet. This can lead to the tuning of the compression process to achieve the most efficient densification of the fuel.

This same type of tuned X-ray deposition can also be used to achieve an increase in the effective power density of the incident X-rays. The fuel target surface layers can be further modified such that in deposition of the line X-rays, their energy is transformed into soft X-rays (often called blackbody radiation), which are trapped between two surface layers.

Because the layers are imploding on one another, this trapped blackbody radiation will be driven to higher power densities. The theoretical papers of the Osaka group indicate that this type of X-ray power amplification can reduce the initial beam requirements for inertial confinement fusion by more than one order of magnitude.

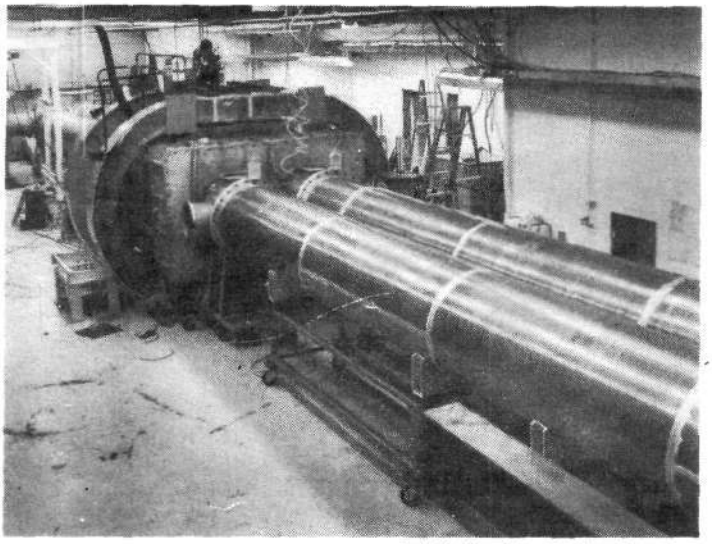
As these processes are further explored experimentally and theoretically they could lead to a major decrease in the projected costs of inertial confinement fusion power and to entirely new, energy-dense plasma regimes that will further advance the horizons of fundamental science.

—Charles B. Stevens



Fred Rick/Los Alamos National Laboratory

Quartz mirrors reflect multiple images of Los Alamos researcher George York as he checks the paper target that successfully documented Aurora's pinpoint accuracy.



Fred Rick/Los Alamos National Laboratory

The krypton fluoride laser at Los Alamos. In the foreground is a section of pipe through which electrons pass. The electrons energize containers of krypton fluoride gas located between the two large magnets that are used to generate magnetic fields that confine the flow of electrons. One of two Marx generators can be seen at left in the rear.

Krypton Fluoride Laser Fired: 'New Dawn for Fusion Research'

Aurora, the krypton fluoride gas laser at Los Alamos National Laboratory in New Mexico, was successfully fired July 3, 1984, making it one of the most promising candidates for practical laser fusion electric power reactors. Los Alamos titled its release on the event, "Aurora: New Dawn for Fusion Research?"

The krypton fluoride laser is also a primary candidate for a defensive beam weapon that can destroy nuclear-tipped missiles in their vulnerable boost phase.

Aurora takes us much closer to a fusion reactor because it meets the exacting specifications needed for practical laser fusion energy production. According to Louis Rosocha, manager for the Aurora project: "It has a short wavelength for efficient coupling of laser energy to fuel targets, the capability of being cost-effectively scaled to a large size, the ability to fire repeatedly, and a tremendous, economical efficiency in comparison with other lasers—a possible 10 percent efficiency . . . or more than five times that of some systems."

These same qualities—coupling of laser energy to targets, economic scaling to higher energies, high repetition rates (tens to thousands of shots per second), and high laser beam generation efficiency (10 percent)—also make the krypton fluoride laser an effective system against nuclear-tipped missiles.

Near-Term Developments

The July 3 test achieved a 3,000-joule laser pulse generated within 400 billionths of a second. Los Alamos experimenters plan soon to bring this total energy up to 10,000 joules in the same pulse length.

Experiments using angular multiplexing to compress the pulse length to 5 billionths of a second—increasing the beam energy flux density by a factor of 80—will also be carried out in the near term. Angular multiplexing is a form of optical compression in which the light pulse is cut up into many parts and spatially stacked to form a more compact and powerful pulse.

The Aurora laser module is the prototype for a full-scale multimodule laser needed for both fusion and beam-weapon applications. Los Alamos reports that a prototype multimodule system, the Polaris, is under design now, which would be only one stage removed from the million-joule energy levels needed for deployable systems for fusion energy production and for beam defense.

"So impressive is the new system, the 50,000-joule laser called Polaris may be underway as early as mid-fiscal-year 1986," the lab said. Polaris can be realized this quickly because it can make use of the existing structures of Los Alamos's long-wavelength carbon dioxide laser, Antares.

The KrF Laser and the X-Ray Laser

When combined with the nuclear-bomb-pumped X-ray laser, the KrF laser provides the overall capability for making offensive nuclear missiles obsolete. The X-ray laser is the most lethal beam weapon yet demonstrated. Each X-ray laser system popped up into space when a large-scale missile attack is detected could destroy scores of ICBMs as they rise out of the atmosphere.

But the X-ray laser must kill above the Earth's atmosphere (about 70 kilometers altitude), because dense air absorbs X-rays and prevents the propagation of the X-ray laser beams. In this regard, the krypton fluoride laser provides a major complement to the X-ray laser. The krypton fluoride laser beam

is capable of penetrating well below the 70-kilometer altitude limit of the X-ray laser, killing missiles within the atmosphere and in their boost phase.

In fact, the krypton fluoride gas laser represents the most effective laser for achieving this complementary capability to the X-ray laser, because it has just about the shortest wavelength with which optical transmission can be achieved. At the even shorter wavelength of X-rays, all existing types of materials used in optical systems, such as mirrors and lenses, are destroyed by the electromagnetic waves. The 0.248-micron wavelength of the krypton fluoride laser represents the current minimum for which such materials can still be utilized.

Wavelength and Lethality

Both in terms of propagation range and coupling of laser energy to a target, wavelength is an essential parameter. Laser beam divergence is directly proportional to wavelength. Therefore, given laser beam pulses of equal energy and utilizing the same size mirrors, the 0.248-micron krypton fluoride laser would have a lethal range 10 times that of the 2.7-micron chemical laser.

In terms of coupling, the advantage of shorter wavelengths becomes most evident. For the longer-wavelength chemical lasers, upwards of several thousand joules per square centimeter may be needed; the krypton fluoride laser can achieve the same result with just a fraction of the energy flux density. The krypton fluoride laser and X-ray laser pulses achieve kills by shock-induced damage, while longer-wavelength lasers depend on burning holes through their targets.

At the krypton fluoride wavelength, the laser light is deposited right on the target's surface. At longer wavelengths the energy is deposited instead in the low-density plasma generated during the laser light irradiation of the target. The result is that the energy in the latter case is deposited over a larger volume, therefore generating a smaller pressure buildup per unit energy. This difference between the short and long-wavelength coupling is analogous to the difference between trying to drive a nail or a hammer through a piece of wood.

Please turn to p.16

Los Alamos Begins Work On Gamma-Ray Laser

Scientists at Los Alamos National Laboratory have launched a major research project "that could result in the world's first nuclear laser in just a few years," the lab announced Sept. 21. A research team headed by Dr. George Baldwin has studied this idea of a gamma-ray laser (or "graser") for 20 years and now feels confident in going ahead with the next step: actual experiments to discover what material will be a good graser substance.

"Grasers offer enormous scientific potential," said Baldwin. "In the 1960s they looked utterly impossible to make. Now I think it can be done and in just a few years." Achieving the graser, however, will be "as difficult a challenge as any ever undertaken," according to Baldwin.

Most graser research has been carried out in the Soviet Union over the past several decades. Now the United States will try to catch up with experiments designed to discover whether the extreme conditions needed to attain gamma-ray lasing can be practically realized.

Gamma-Ray Lasing

Unlike ordinary lasers, which utilize electron energy levels (characteristic of chemical reactions), the graser almost certainly must be based on nuclear-level transitions.

Baldwin's team will explore candidates for the host material with the help of the Los Alamos atom smasher accelerator. The sought-after host substance must be able to absorb a precise amount of energy in the nucleus from an external source, store the captured energy while remaining in an excited state, and release this extra energy as gamma-rays and not as other kinds of radiation.

The Los Alamos team will try to find out if there are ways of producing the desired nuclear transitions and maintaining them until a sufficient amount of such "excited" material has been concentrated in order to produce the macroscopic conditions for grasing.

For generating the desired nuclear transitions, the Los Alamos team has been exploring the possibilities of a two-stage process. Nuclei are first irradiated with neutrons and brought up to a certain energy level. Then when they are assembled in a concentrated form, they are irradiated with a laser pulse. This pulse changes the electron configuration of the atom and is found in some cases to effect a transition in the nucleus.

Through this means it is hoped to find a way to transform quickly a long-lived nuclear excited energy state into a short-lived one capable of lasing.

A second type of experiment being carried out is that of using lasers for rapidly separating excited nuclei from unexcited ones. In this way the excited nuclei can be concentrated quickly in a sufficient dense quantity to support grasing.

Why the Graser?

The graser will have importance in military defense as part of an antiballistic beam defense, because it will fire highly energetic pulses of penetrating radiation in repeatable and accurate beams that can easily pass through the atmosphere. In fact, the graser will have all the advantages of the X-ray laser, only more so, because of its shorter wavelength and higher frequency.

Electromagnetic radiation ranges over a spectrum of wavelengths and characteristic energies of action, with wavelength and frequency being directly inverse. The longest wavelengths are those of radiowaves, which also have the smallest characteristic energy of action. X-rays have far shorter wavelengths and are far more energetic and penetrating. Visible light waves, which are the energy form in lasers, fall in between, and gamma-rays have the shortest wavelengths and highest characteristic energies of action.

The distinction between gamma-rays and longer-wavelength ranges of the electromagnetic spectrum is like that between chemical and nuclear reactions. In fact, light waves and X-rays are generally capable of directly inducing only chemical types of transformations in matter, whereas gamma-rays are capable of producing nuclear

reactions.

This is because of the respective wavelengths. Imagine a grid with slits through which the light or ray must pass, where the size of the slits controls what wavelengths or "widths" of rays can pass through. On the atomic scale, such "slits" are on the order of 10^{-10} meter (or 1 angstrom) for the atomic radius, including the electron energy levels where chemical reactions are controlled. Thus visible light with wavelengths on the order of 10^{-7} meter can affect only the outer shells of atoms while X-rays with wavelengths on the order of 10^{-9} to 10^{-12} meter can actually penetrate the atoms.

To interact with the atom's nucleus, however, requires wavelengths commensurable with its radius of about 10^{-13} meter. Only gamma-rays have small enough wavelengths (down to 10^{-20} meter) to reach and interact with nuclei.

Grasers for Beam Defense

Gamma-rays are in fact the most penetrating form of radiation, and pass easily through the atmosphere without deflection or loss of energy. This offers great possibilities for a system of defensive beam weapons to shoot down attacking nuclear missiles. One advantage of the graser over that of the X-ray laser is that it could penetrate more deeply into the atmosphere. This would mean that even fast-burn rocket boosters could not escape destruction. Moreover, when "tuned" to the appropriate wavelength, gamma-rays will react vigorously with atomic nuclei.

Because of these characteristics, graser beams would be the most efficient and effective beam weapons. They could be tuned to efficiently propagate through the air and other material barriers. At the same time they would react vigorously with "heavy" nuclei like the uranium and plutonium fuel used in nuclear weapons. Because the incident gamma-rays would generate *nuclear* reactions, only a minute energy deposition would effectively denature a nuclear weapon, turning it into a dud. In other words, with an energy equivalent to the tap of a human fist, the graser beam could kill offensive nuclear warheads.

In terms of range, the short-wavelength graser has the potential of attaining destruction of nuclear warheads over gigantic distances—millions of miles. In fact, just as the X-ray laser will be vastly superior to the first-generation chemical lasers that should be on-line now, so the graser will supersede the X-ray laser for beam defense.

A Revolution for Science

Lasers produce coherent beams of radiation—electromagnetic waves in phase and all at the same wavelength. This means that the radiation they generate can be focused to extremely high power densities. Since gamma-rays can cause nuclear reactions without being focused, a focused graser beam would provide the means of attaining supernuclear energy densities, a unique state of matter providing the conditions for all sorts of experiments addressing fundamental problems in physics, such as the birth of the universe.

Having a coherent source of electromagnetic radiation also makes three-dimensional pictures—holograms—possible. The wavelength of the coherent radiation determines the resolution with which the three-dimensional picture of an object can be made. Holograms made with light lasers, whose resolution is only in the range of one-millionth of a meter, are already used in industry.

For example, a hologram of a piece of machinery can be superimposed on the actual machine. As the machinery is brought into operation its physical shape becomes distorted by strain and stress. These distortions will cause visibly apparent interference patterns with the superimposed hologram image. In this way the actual stresses can be seen on a microscopic scale.

Experiments are already being carried out to use coherent X-rays from X-ray lasers and synchrotron radiation facilities to produce X-ray microholograms. The much shorter wavelength of X-rays makes possible the imaging of individual molecules. Most significant, the shorter-wavelength radiation also makes possible much smaller temporal resolutions.

The net result is that it is possible to achieve something like a moving picture of the molecules of living matter. Because of the even shorter wavelength of grasers, this type of micohology of living cells can be greatly extended in both resolution and the types of objects that can be imaged. Thus, as a diagnostic tool, grasers will provide a unique way of dissecting the nucleus and atom and become a potentially powerful microscope that could actually examine individual cells and their structure in unprecedented detail. The most exciting aspect of this is not merely the possibility of viewing molecules of DNA in detail, but the fact that such molecules will be living and in action while viewed.

For the first time, man will be able to observe directly the structures and chemistry responsible for life itself. Cancer and aging research, as well as all aspects of disease and health care, will be revolutionized overnight. Genetic bioengineering will become a fully elaborated science. The potential impact is so great scientifically that the comparison to the discovery of the telescope falls far short; it is like the invention of the eye. Graser microholography promises to revolutionize all medical and biological research.

This is best seen in the case of nuclear spectroscopy. For over a century spectroscopy with electromagnetic radiation in the light range has been used to unravel the chemical dynamics of matter. In other words, this type of spectroscopy is used to "see" the electron structure of atoms in molecules. Grasers will extend this capability to the nucleus itself. Besides vastly improving the possibilities of extending our fundamental understanding of nuclear processes, graser nuclear spectroscopy will open up entirely new forms of nuclear energy.

—*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

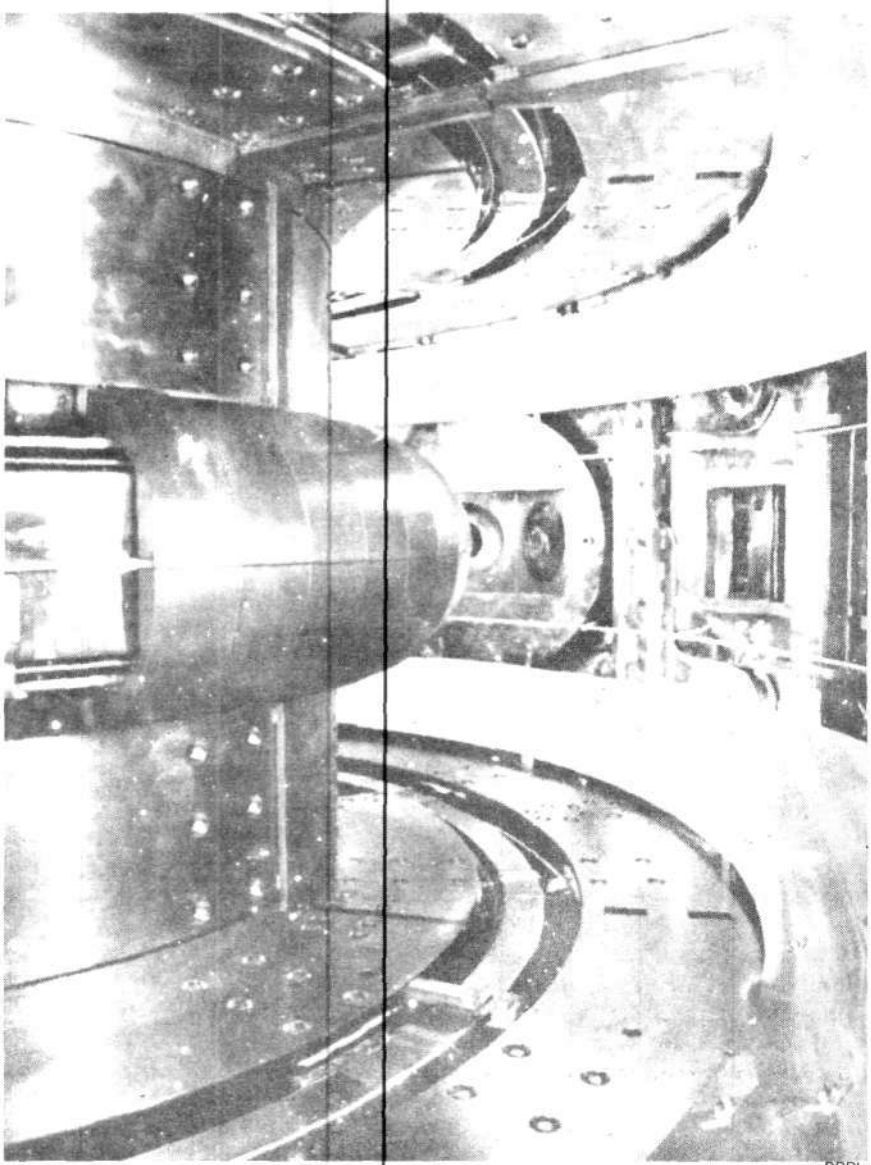
Most tokamak experiments have operated with plasma betas below 1 percent; for a fusion reactor to be economical, it is projected that plasma betas on the order of 5 percent must be attained. The Doublet III tokamak in San Diego has achieved a plasma beta of more than 4.5 percent. And there is little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

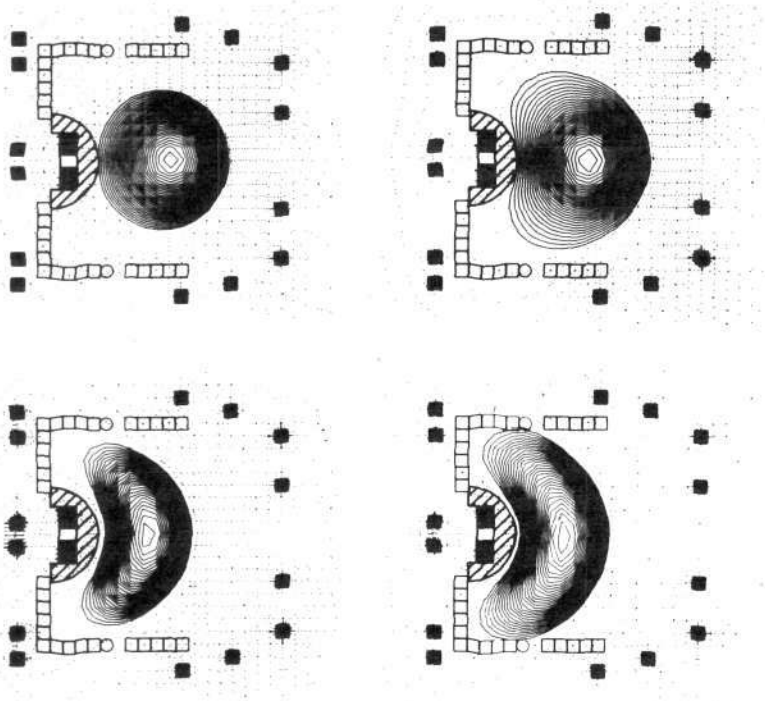


Figure 1
CREATION OF A PBX PLASMA
A circular plasma is formed within the PBX and is increasingly indented as the pusher coil produces an indentation at the inner side of the plasma's major radius.

Krypton Fluoride Laser

Continued from p. 13

Deployment and Future

Although the X-ray laser unit itself, because of its small size, would be popped up into space on a small rocket for boost-phase intercept, the krypton fluoride laser would most likely be deployed either on mountaintops or large aircraft. The krypton fluoride laser beam would then be transmitted via orbiting mirrors to be directed to the target. These mirrors would be of two types—some orbiting during peacetime and others popped up when an attack is detected. Each krypton fluoride laser could generate tens to hundreds of lethal shots per second.

Once the Polaris system is realized, deployment would only be a question of engineering resources.

—Charles B. Stevens

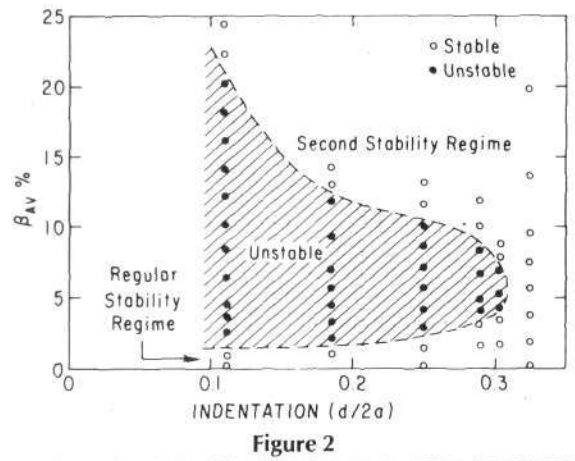


Figure 2
INCREASING INDENTATION PROTECTS AGAINST BALLOONING IN THE PLASMA
Increasing the indentation of a plasma (horizontal axis) can provide protection against ballooning mode instabilities accompanying increasing beta values (vertical axis).

New International Science Journal Launched

The Fusion Energy Foundation of New York has relaunched its quarterly scientific journal in an expanded format modeled on the 19th-century Crelle's Journal that played a leading role in fostering the advance of science 100 years ago.

The first issue—January, 1985—of the new-format International Journal of Fusion Energy (IJFE) was just released. It includes two feature articles, one on the electron and the other on the neutrino, which challenge fundamental preconceptions of current physics dogma.

Editor-in-chief is Robert James Moon, professor emeritus at University of Chicago, who is known for his many "firsts" in the field of physics—from building the first cyclotron to designing the first model of the CAT scanner. Instead of the traditional "referee system," Moon said, where a panel of peers rules on an article, IJFE will give prospective authors a hearing and let them defend their work. "We want to publish new concepts, new work."

The Non-Newtonian Electron

The lead feature in the January issue is a ground-breaking work on the electron by fusion scientist Winston Bostick, who pioneered research on the plasma focus machine at Stevens Institute of Technology in New Jersey. Bostick draws on his research with self-organized plasma filamentary structures to develop a concept of the electron as composed of "highly concentrated self-gravitational electromagnetic fields," instead of a Newtonian point mass.

His article, "The Morphology of the Electron," will be expanded in book form to include other elementary "onta" (as he has renamed particles), such as the proton and the neutron.

The second feature, by Erich Bagge, based on his experimental work at the University of Kiel in West Germany, indicates the neutrino "may be purely a figment of the imagination of high-energy physicists," as Dr. Moon put it. Bagge uses his experiments with the pair production of electrons and positrons in a Wilson cloud chamber to show that beta-decay occurs without neutrinos.

As Moon points out in his editor's note:.."..free neutrinos have not been isolated *per se* to date. Indeed, how could they be? It would require 10^{18} meters of lead to stop one-half of the neutrinos traveling through it."

Other articles in the 104-page journal include "The Relation Between Angular Momentum and Star Formation in Spiral Galaxies," by Mexican astronomers L. Carrasco and A. Serrano; "New Frontiers in Biophysics" by James Frazer of the Houston Medical Center; and translations of E. Betti's 1869 paper "On Electrodynamics" and B. Riemann's paper "A Contribution to Electrodynamics." The journal also includes a section of abstracts in fusion and astrophysics.

—*Marjorie Mazel*

"Physics today is stultified in the grip of quantum electrodynamics; with this journal we hope to be patrons of work which breaks out of this and reconnects science to the traditions of Gauss and Riemann. For that reason we're emphasizing work in plasmas, where nonlinear effects are observed. We're trying to bring together work in biology and high-energy plasmas, the key to the notion of a 'living universe,' as Kepler called it. In current physics there's no room for that conception, even though that is the fact of the universe. This journal has a very free editorial policy, and will allow publication by people who are otherwise denied opportunity by the science mafia today."

—Carol White
Editor-in-Chief, *Fusion*
Board Member, *IJFE*

IJFE for news and ideas in:
—*highly organized plasmas of increasing flux density*
—*directed energy processes*
—*areas of biological research whose physics is of the same character as fusion and directed-energy processes*

Subscriptions: In the U.S., $80 per volume (four issues) Foreign airmail, $100 per volume

Write to: IJFE
Fusion Energy Foundation
P.O. Box 1438, Radio City Station
New York, N.Y. 10101, USA

Dhaka Conference Supports Development of Nuclear Power

"We have, therefore, no other alternative but to turn to nuclear power for the production of electricity..." Those were the concluding remarks of Dr. Anwar Hossain, Chairman, Bangladesh Atomic Energy Commission (BAEC) and former President of the Bangladesh Physical Society, at the end of the first plenary session on the final day of the International Conference on Physics and Energy for Development held in Dhaka from 26-29 January, 1985.

During the four-day conference, which consisted of eight technical sessions generating as many as 85 papers and two plenary sessions, intense discussion and debate took place over the future energy policy of Bangladesh. Which development path is most "appropriate" for one of the world's poorest and most densely populated nations: the "hard" path of nuclear power and advanced technologies, or the "soft" path of solar, biomass, the so-called renewable sources, and traditional labour-intensive technologies?

Local press covered daily proceedings carefully, adding extra interest to the conference. The Bangladesh Physical Society sponsored the meeting, with cosponsorship from BAEC, Dhaka University, Government of Bangladesh Science and Technology Division, Bangladesh Academy of Sciences, the International Centre for Theoretical Physic (ICTP) of Trieste, and the Co on Science and Tech- Developing Countries

Set Tone

nference was set by the Chief r of Bangla- speech e selec- there is a necessity for installation of an atomic reactor in the western region of the country." President Ershad also called for "a proper use of science and technology to achieve the national goal of self-sufficiency" in the coming Third Five Year Plan, and announced the decision to formulate a national science policy.

In light of the debate on energy now raging in Bangladesh among various lobbies the President's speech was balanced. Though he emphasized the necessity of burning the available natural gas to meet the basic power needs of the country, President Ershad asked the scientists to find a long-term solution to the energy shortage. He requested local scientists to solve the problem of fuel by conducting researches in solar, air, various biosources as well as hydroelectric generation potential. In his address he congratulated the Bangladesh nuclear scientists for installing the first 3-MW Triga experimental reactor at Savar, 40 km north of Dhaka (see **Fusion Asia**, Vol. 1, No. 2, Jan. 1984). "I believe this reactor will provide training facilities and help build infrastructure for our nuclear power programme," he said.

Welcoming the participants and guests, Professor M. Shamsul Huq, Chairman of the Reception Committee and Vice-Chancellor of Dhaka University, further underscored the need for a vigorous science and technology programme in developing nations. "The slogan of appropriate technology was created a few years ago as a euphemism for updated traditional technology," Prof. Shamsul Huq stated. "The concept was probably well-intentioned, but it was based on the unacceptable premise that the technological gap can never be bridged." But neither scientific breakthroughs nor the adoption of advanced technologies by poor developing nations is accomplished by "magical willpower"—facilities for scientists to work and investment in creating basic scientific literacy in the population are required, he said.

The plan to set up a nuclear power station in Bangladesh is not new. In fact, it is even older than the 13-year-old nation. The plan to install a small power reactor at Rooppur was hatched way back in the early sixties when Bangladesh was a part of Pakistan. But political instability during the Pakistan days, the nine-month-long war that led to the separation of Bangladesh from Pakistan in 1971, economic constraints that followed the liberation and a well-orchestrated campaign unleashed by the developed nations to discourage Bangladesh bureaucrats about the high captital cost of a nuclear power plant has left Bangladesh with one of the lowest rates of per capita electricity consumption in the world. It became clear during the conference that the elite in Bangladesh is deeply concerned about the lack of electrical power and its economic consequences.

Need Large, Dense Power Supply

Dr. Hossain's speech at the plenary session detailed the present energy generation capacity in Bangladesh and the future availability of energy sources. The 1981 figures indicate that per capita commercial energy consumption in Bangladesh is 46 kg coal equivalent, compared to the world average of 1893 kg and an Asian average of 597 kg. Bangladesh, a nation of 96 million people, produces 1200 MW of electrical power in toto, and the present plan is to increase electricity generation capacity by the year 2000 to about 8000 MW which would mean a per capita

electricity generation of 200 kwh. Power starved India and Pakistan each presently consume about as much.

It is evident from those figures that without the use of large size power plants Bangladesh will not be able to reach even this meagre consumption capacity. Endowed with flat land, Bangladesh has very little hydro electricity generation capacity. With an estimated reserve of 50-100 million tons of coal—that too at depths between 640 and 1050 metres—Bangladesh can hardly look to its coal reserves for easing commercial energy problems. Biogas, which is neither cost effective nor has any viable prospect to play a significant role in meeting future commercial energy demands, will be able to achieve a limited objective at a great cost.

Solar energy, on the other hand, is still being touted by some as a panacea for the developing nations. But it is evident that solar energy can only be used in a limited way, as a means, for example, of drying crops, salt and fish. Any plan for a centralized solar energy plant, as Dr. Hossain noted, will not be convenient compared to its decentralized uses on a smaller scale.

Nuclear Technology Applications

With such inadequate exploitable fossil fuel reserves and hydroelectric power potential, Bangladesh must adopt nuclear power for its sheer survival. A number of feasibility studies have already been done and the Rooppur site by the River Padma has been selected to install the first nuclear power station. Keeping in mind the size of the grid and the rise in demand, a 300-400 MWe plant is being envisaged. Setting up another plant of similar capacity in near future is also being discussed.

Dr. M.A. Mannan of the BAEC presented a comprehensive paper on the application of atomic energy in Bangladesh. The paper outlined the use of radioisotopes in the field of agriculture, food preservation and sterilization of medical products. In all these areas Bangladesh has advanced rapidly and the country is in the process of adopting the use of radiation to enhance the shelf life of perishable food items on a commercial basis.

In the field of nuclear medicine, too, Bangladesh has done well. Dr. Mannan pointed out in great detail the provisions made at the Nuclear Medical Centre of the Dhaka Medical College to treat patients with a variety of diseases. Plans for setting up a number of such medical centres are progressing rapidly.

A Political Fight

While Bangladesh is prepared to use nuclear power to solve its commercial power shortage, whether or not the country will actually follow through on this path is still undecided. A vocal and influential lobby rooted in the bureaucracy and some academic institutions has dug in its heels against the nuclear option. The ongoing fight was reflected in the conference proceedings, as the proponents of photovoltaics for energy generation were heavily represented in the conference programme.

From the outset it was clear that the photovoltaic lobby is interested mainly in providing electrical power to pump water; industrial energy use does not figure in their vision. Many also championed the use of photovoltaics for use in flash lights, railway signals and remote areas. Neither the fact that Bangladesh has very little territory that might be classifed as "remote areas," nor the fact that it has not yet become feasible economically to couple photovoltaics with irrigation pumps seems to have daunted this lobby.

Moreover, the local lobby enjoyed high-powered spokesmanship from one Dr. B.O. Seraphin, Professor at the University of Arizona and a representative of the ICTP, Trieste. It was an ironic spectacle to see Dr. Seraphin, a denizen of the rich American "sun-belt" where per capita domestic consumption of non-solar electricity is among the highest in the USA, entreating Bangladeshi scientists to use low-efficiency, high-cost photovoltaics to solve the staggering power problem of a country whose population is 90 times that of Arizona! It is a well-known fact that Trieste has joined hands in recent years with the World Bank-IMF neo-Malthusian axis to push low-level technology in the developing nations.

A Scientific Counterpoint

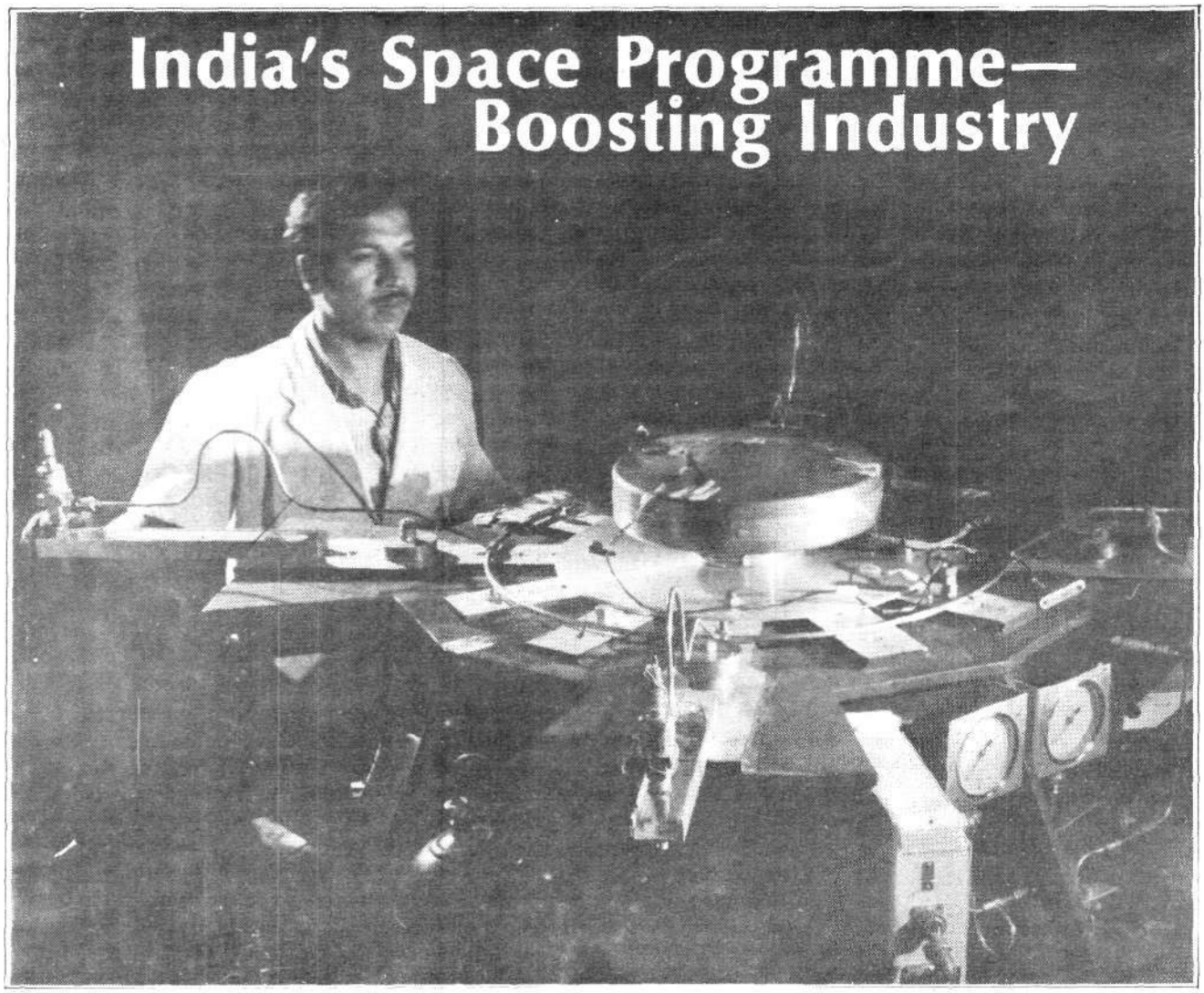
In Dhaka, however, the solar lobby met its match on the first morning of the conference when Dr. Uwe Henke-Parpart, Research Director of the Fusion Energy Foundation of New York and advisor, **Fusion Asia**, spoke on "A Scientific Approach to Energy Economics." Parpart compared the energy flux density of various commercial power sources with that of solar energy and biogas. He pointed out that the energy pay-back time, a critical factor for Bangladesh in determining its energy policy, is extremely high for solar compared to both nuclear power and fusion. Later, Dr. Parpart presented a paper updating the development of fusion power research around the world.

In a technical session devoted to exploring the tremendous implications of ongoing developments in high-energy physics—developments ushering in a new industrial revolution appropriately named "The Plasma Age"—Dr. Jonathan Tennenbaum, editor of the German-language **Fusion** magazine and director of the Fusion Energy Foundation in Europe, presented an enlightening paper on the industrial applications of medium to high power lasers.

In the session on nuclear power Ramtanu Maitra, **Fusion Asia** editor, presented a paper on the concept of the "nuplex"—a nuclear power-centered agro-industrial complex. This design concept introduces new economies into the development of nuclear power.

Amongst the technical papers presented at the conference, a number were of high quality. Special mention should be made of papers read by Dr. U.A. Mofiz of BAEC, M. Salimullah of the Jahangirnagar University, and N.T. Mollah of BAEC.

India's Space Programme— Boosting Industry



ISRO

Momentum wheel developed by ISRO for the APPLE satellite.

by Ramtanu Maitra

As early as 1968, the architect of the then-nascient Indian space programme, Dr. Vikram Sarabhai, predicted the industrial benefit that would be derived from space technology. In a speech dedicating the Equatorial Rocket Launching Station at Thumba Sarabhai described the direct benefits in meteorology, geodesy and communications, pointing out in particular that opting for satellite communications would involve only one-third the capital cost of conventional communications systems and allow India to "leap-frog" into a position of dealing on equal terms with more developed countries. Sarabhai's foresight did not end there; he went on to discuss the broad economic "spin-offs" which would accompany the investment in space.

"I might illustrate this from the experience which we are gaining in the development of rockets. This requires new disciplines and an understanding of materials and methods; of close tolerances and testing under extremes; the development of guidance and control and the use of advanced information techniques." Dr. Sarabhai said. "Indeed, I often feel that the discipline and the culture of the new world which emerges through the pursuit of activities of this type are amongst the most important from the standpoint of a developing nation."

Nearly twenty years later Indian industry has begun to get the benefits of such spin-offs in significant doess. The Indian Space Research Organisation (ISRO) has transferred a variety of technologies to Indian industry; so far, more than 67 processes and products have been licensed to 33 different industries. This includes know-how in chemicals, polymers, special materials, instruments, telecommunications and TV equipment, electronic subsystems, electro-optic hardware, computer software and special purpose machines. In addition, nearly 30 new items are in the pipeline for imminent transfer to industry.

Moreover, within the past two to three years the

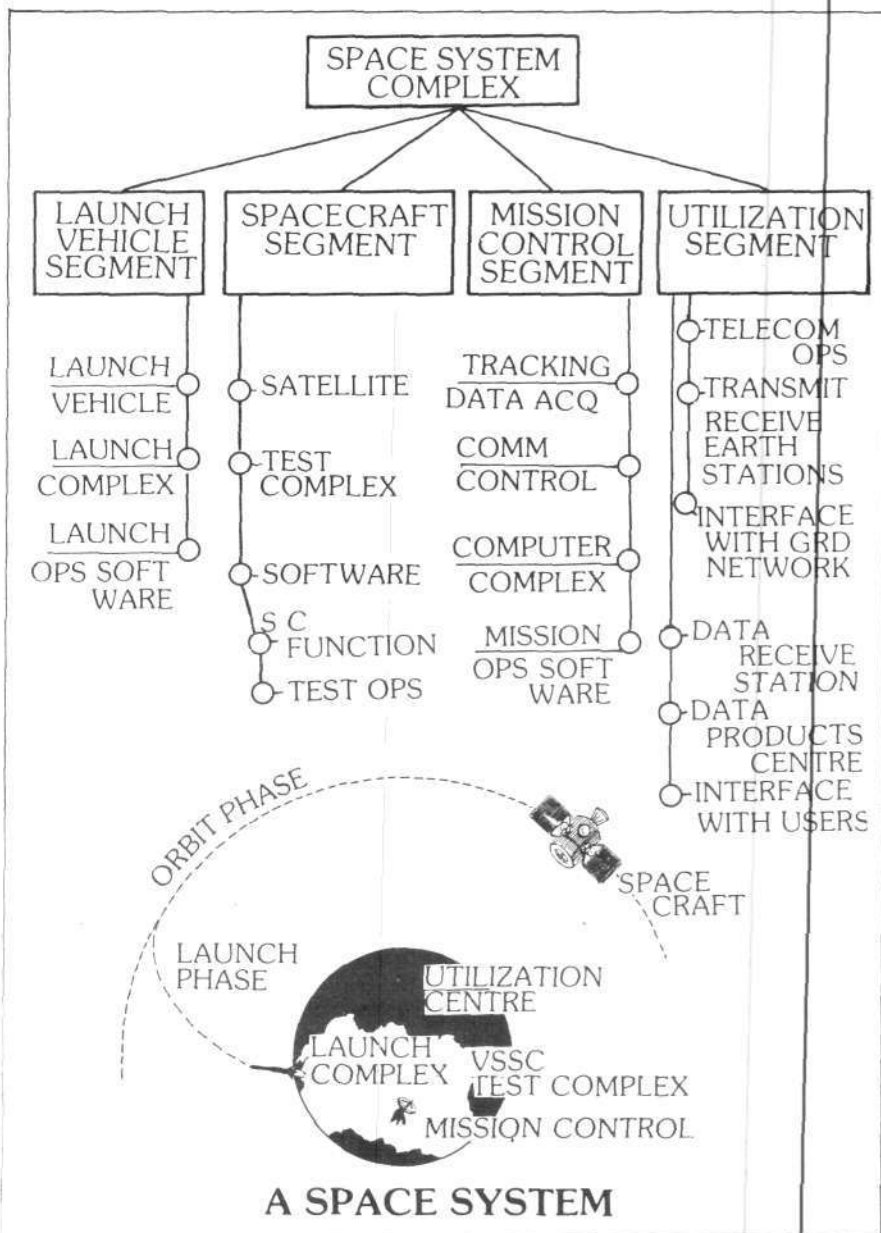
programme's direct demands on industry have to led to establishment of two complete chemical plants and the establishment of new divisions within a number of private and public sector industrial corporations devoted exclusively to supplying the space programme. An estimated 50-60 industries across the length and breadth of the country are involved.

Starting with a modest annual budget of $20 million in 1962, India's space programme has jumped to what will be $300 million annually under the Seventh Plan beginning 1986. While not large in absolute terms in an annual plan budget that totals $60 billion, this fifteen-fold jump in the space budget's dollar value gives a kind of baseline definition of the growing impact of the programme on the country's economy. It is expected that nearly half of that will go directly to the Indian engineering industry for supply of goods and services.

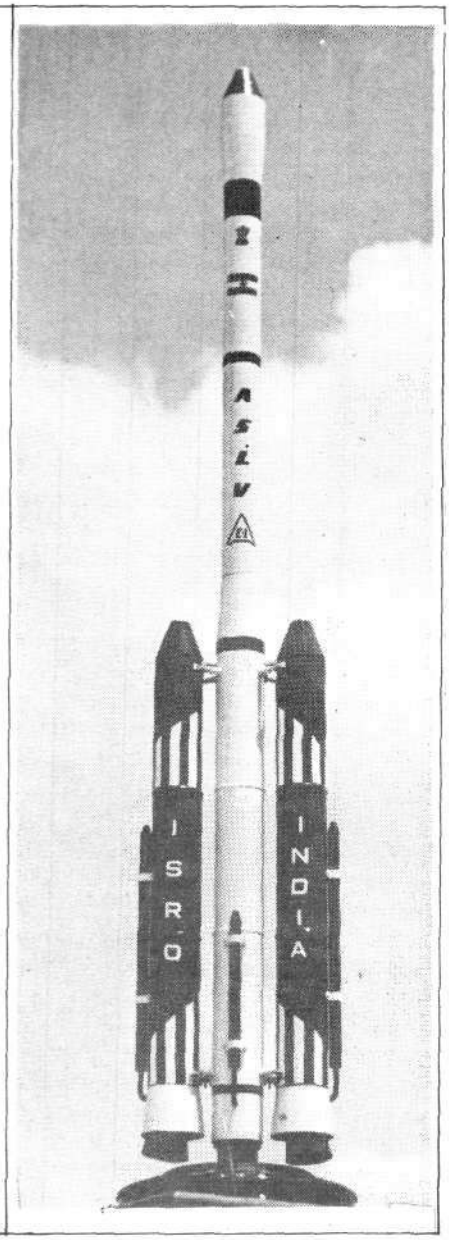
In actuality the impact is geometrical. Not only are ISRO's direct requirements providing an increasingly direct spur to industry, but the programme's applications in communications and remote sensing are coming to fruition in telecommunications, education, agriculture, meteorology and resource identification—and this translates into an explosion of demand for user systems and technologies.

Fundamental Impact

In all countries advanced technology and especially space technology has acted as a growth catalyst to existing industries and through the generation of new tech-



A SPACE SYSTEM



ISRO

India's Ancient Tradition of Space Science

Indian astonomers' interest in planetary motion and various phenomena in the sky was recorded as early as the Vedic days. There are several references in the Rgveda and in the Brhmanas of the Sun's path through the heavens. The Moon, the most conspicuous object in the night sky, Rgveda's authors recognized, has no light of its own. It assumes the brilliancy of the sun, as they put it, or "is adorned with Surya's (the Sun's) arrowy beams."

The rejection of lunar centered cosmology and the evidence of polar long-cycle astronomical calendars from this period which, as Bal Gangadhar Tilak has shown, could have been no later than 4500-4000 B.C., points to a development of science that was unequaled in the much later Mesopotamian and other cultures ordinarily cited as the "cradle" of civilization. The potency of the heritage is further indicated by the brilliance of later figures about whom more is known. Among them, Aryabhata (b. 476 A.D.), Varahamihira (b. circa 505 A.D.), Bhaskara I (b. circa 600 A.D.), and Brahmagupta (b. circa 598 A.D.) excelled in mathematical-astronomical work.

While Europeans were disputing the revolutionary hypotheses of Kepler, Raja Sawai Jai Singh (1686-1743), himself a skilled astronomer, built a string of observatories in five cities in India. Jai Singh found that the calculation of the places of the stars in tables available in the Persian and Hindu as well as the European source books, were in many cases widely different from those determined by observation, and he sought to right the records.

In 1767, the nucleus of what later developed into the Survey of India (SOI) was set up, and years later, in 1823, the Colaba Observatory was opened at Bombay. This was followed in another fifty years by creation of the Indian Meteorological Department. In 1916 ionospheric studies began at Calcutta University. From this time onward, research on the upper atmosphere and astrophysics began in earnest.

By the late 1950s a strong base had already been formed within the country in the field of near-earth and outer space science related areas. Most of this work was based on ground-based techniques for ionospheric and magnetospheric studies. With the launching of sounding rockets from the new Equatorial Rocket Launching Station in Thumba and the buildup of the space programme in the 1960s, Indian scientists were able to significantly deepen their studies.

The temporal behaviour of ionospheric irregularities and their association with the spread of conditions in the ionosphere, the behaviour of electrojet current systems and their effect on the dynamic of the upper atmosphere, the study of magnetosphere-ionosphere and ionosphere-thermosphere interactions including their energetics, the role of inner constituents such as ozone, nitrous oxides and metallic ions are some of the areas where significant studies have been carried out using rocket-based and ground-based instrumentation.

"Some of the fundamental problems which concern scientists today are not different from those that have excited man's curiosity from earliest times. We would like to understand the creation of the Universe, the solar system, the stars and the planets, the origin of life itself and the seemingly mysterious influences through which the Sun affects the course of human existence on Earth. Space research is related to all these."

—Dr. Vikram Sarabhai, the architect of India's space programme

In the field of basic research where Indian scientists such as S.K. Mitra, A.P. Mitra, B. Ramachandra Rao and K. Ramanathan, among others, have contributed considerably, the use of rockets and satellites has greatly enhanced the scope for discoveries through in-place studies of the upper atmosphere. Research activities on the energy spectrum and composition of primary cosmic rays has led to studies on the origin and acceleration of cosmic rays. These studies were extended to related fields of x-rays, gamma-ray astronomy, and nuclear geo-cosmophysics, and large-scale labelling of solar system materials by cosmic ray particles. Similarly, studies on time-variation of cosmic rays, which were traced to the modulation of cosmic rays in interplanetary space by electromagnetic fields and plasma streams of solar origin, have led to futher work in solar physics, interplanetary space and solar wind-magnetosphere interactions.

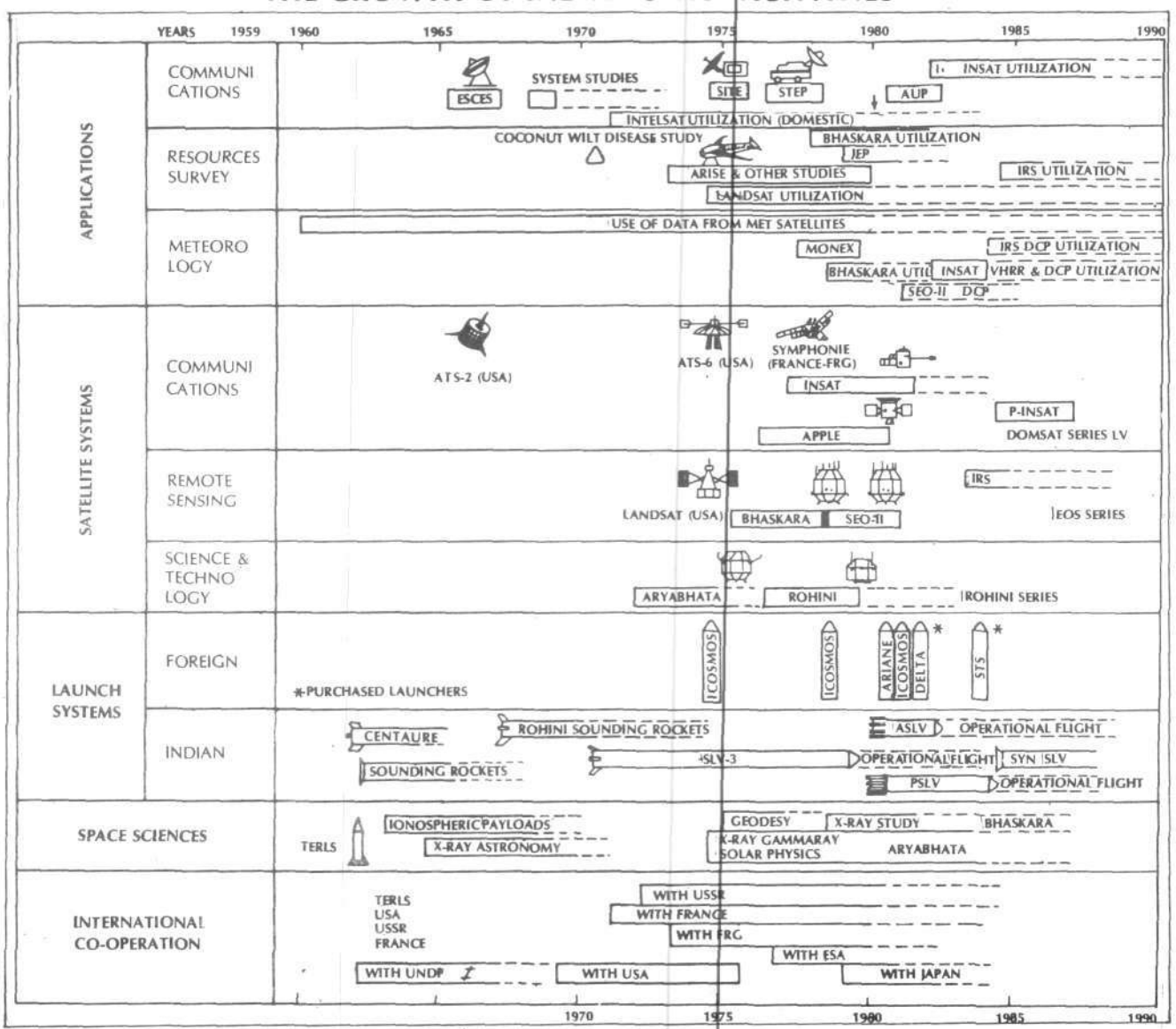
In the field of astronomy, the use of the Ootacamund-based radiotelescope with lunar occultation techniques has provided information on a number of pulsars and extragalactic radio sources, and also on the solar wind characteristics near the Sun. Meteorites and lunar samples have been used for studies in geocosmology. X-ray and gamma ray astronomy studies on both discrete and general cosmic background have been carried out using balloons and rocket-based techniques.

nologies created new industrial potential. In Europe the organisation and implementation of the European space programme during the last two decades has resulted in a remarkable strengthening of the industrial base and the ability to complete in international markets. France and West Germany lead in this. Studies have shown that for every dollar invested in space technology, the industries that have actively participated have already reaped nearly fourfold benefit. Similarly in the United States studies show that for every dollar in the NASA budget, the American economy earned $14 in return. In the U.S. today it is virtually impossible to pick up a single product of which the crucial part or parts did not emerge from the space programme, and the range of sophisticated technologies and products which make up the country's high standard of living owe their existence significantly to NASA.

It is impossible to make direct comparisons between the American, European or even Soviet programmes on the one hand, and the Indian programme on the other. But it is perhaps not an overstatement to say that ISRO's impact on the Indian economy may be even more profound. In the United States, Europe and the USSR a sophisticated technological and industrial base had already been built up as a result of defense programmes by the time of the postwar period. In each case, the space programme built upon this base and gave it a new dimension. But contrast, in India the space programme was launched in conditions of an extremely weak economic infrastructure. The sophisticated industrial base was not there to be augmented and "shaped," it had to be built from proverbial" scratch."

From the outset the Indian programme's basic principle was "self-reliance." Not in the sense of recreating the

THE GROWTH OF INDIAN SPACE ACTIVITIES



ISRO

wheel, ISRO scientists explain, but in the sense that India must master indigenously all of the essential technologies involved in being in space. Like the decision to invest in space in the first place, the considerations were eminently practical. Dr. Sarabhai, with Dr. Homi Bhabha the space programme's "moving spirit," was the most articulate exponent of this approach.

"Clearly the development of a nation is intimately linked with the understanding and application of science and technology by its people," he wrote in 1966. "It has sometimes been argued that the application of technology by itself can contribute to growth. This is certainly true as an abstract proposition, but fails in practice. Witness the state of development and social structure of countries of the Middle East where for decades resources of oil have been exploited with the most sophisticated technology. History has demonstrated that the real social and economic fruits of technology go to those who apply them through understanding. Therefore a significant number of citizens of every developing country must understand the ways of modern science and of the technology that flows from it."

A Three-Phase Process

India's space planners started work on all four of the basic fronts at once—applications, satellites, launch vehicles and mission support—simultaneously building up an all round capability. It was a carefully orchestrated process projected over three decades.

The first ten years, during the 1960s, were a "learning" process. The space effort emerged out of the Department of Atomic Energy's Indian National Committee for Space Research, set up by government order in 1962 to advise and help organise the country's space programme. Under the leadership of Dr. Homi Bhabha, then chairman of DAE, and Dr. Vikram Sarabhai, the space programme was conceptualised and the people and expertise recruited to work.

The Experimental Satellite Communication Earth Station (ESCES) was established at Ahmedabad in 1963 to develop ground support and applications know-how. The Thumba Equatorial Rocket Launching Station (TERLS) came up at the same time to give impetus to work with sounding rockets. Both projects involved international assistance: given strict resource constraints it was imperative to take maximum advantage of opportunities for international cooperation at each step consistent with building indigenous capabilities.

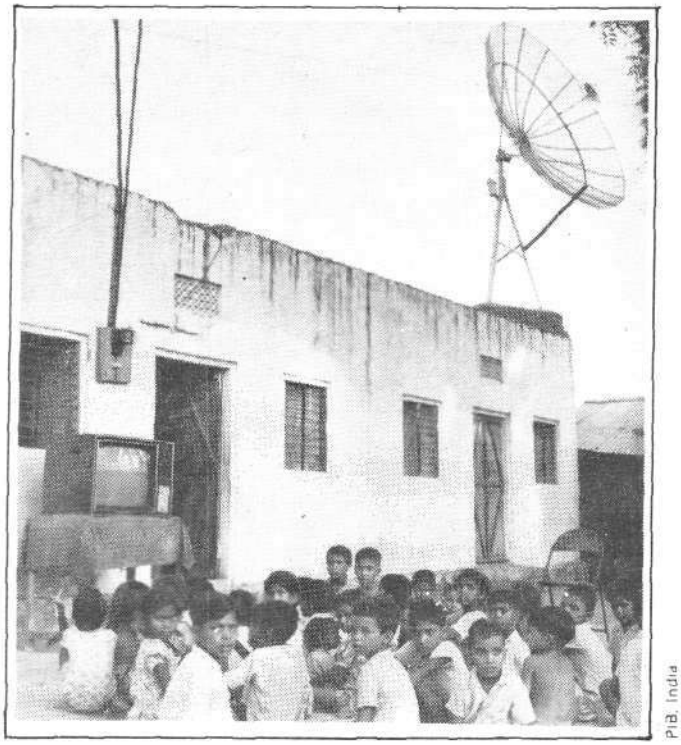
As the pace of activities accelerated, DAE established the Indian Space Research Organisation (ISRO) to deal with all matters relating to space, and by 1972 an independent government Department of Space under a Space Commission was set up to encompass ISRO. During the 1970s a series of time-bound projects and goals were defined—officials call it the "projectisation" phase of the space programme.

The key was to undertake a series of projects which would give crucial hands-on experience at minimal investment risk. The 1975-76 Satellite Instructional Television

Satellites for Development

In the 1960s an operational Indian National Satellite (INSAT) system for telecommunications, weather forecasting and nationwide television was first given a thought. ISRO, with the Ministry of Communications and the Ministry of Information and Broadcasting, prepared studies in 1967, and the Satellite Instructional Television Experiment (SITE), the Satellite Telecommunications Experiment Project (STEP) and APPLE (the Ariane Passenger Payload Experiment) were the result.

SITE, dubbed the "Teacher in the Sky" programme, was carried out using the ATS-6 satellite loaned to India by the United States in 1975-76. The experiment involved 2400 villages in six states, and proved the need and feasibility of a satellite-based communications system in the country. During 1977-79 ISRO and the Post & Telegraph Department of the Ministry of Communications conducted the STEP using a transponder on board the Franco-West German satellite Symphonie. Several experiments in digital satellite communications, single channel per carrier systems, radio-networking and television transmissions with several audio channels were carried out. The satellite was linked to three Earth stations at Delhi,



PIB, India

SITE in an Indian village.

Ahmedabad and Madras, and with two mobile stations.

In parallel, India had begun constructing its own satellites. The first, the 358 kg Aryabhata, was launched into near Earth orbit by a Soviet rocket in 1975 with a payload of three scientific experiments. Designed for a six months operational life, Aryabhata functioned for six years until March 1981. The second, Bhaskara, was India's first experimental Earth observation satellite. It carried two television cameras and a microwave radiometer, and was launched in the the Soviet Union in 1979. An improved version, Bhaskara-II, was launched in 1981 and is still providing useful Earth observation data even beyond its design life. The Bhaskara series built up the basis for the Indian Remote Sensing (IRS) programme.

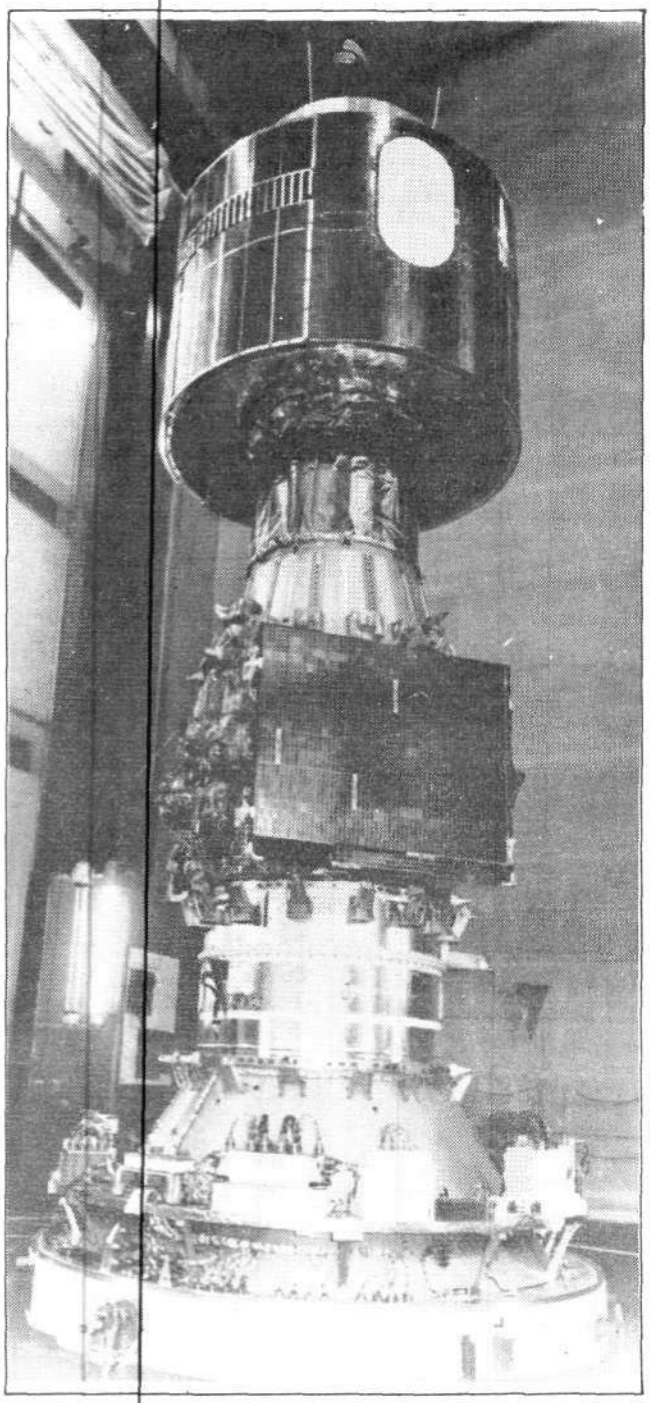
In 1981 the launch of APPLE was a milestone. The 670 kg APPLE, put into orbit by a European Space Agency spacecraft, was a three-axis stabilized geosynchronous communications satellite fully designed and constructed indigenously. APPLE, which provided information until 1983, was used to carry out extensive experiments on time, frequency and code division multiple access systems, radio networking, computer interconnect, multiple access protocols and other protocols based on fixed and demand assignment. The successful construction and deployment of APPLE, with SITE and STEP, established the basis for the future INSAT system.

INSAT

INSAT reached operational status with the commissioning of the INSAT-IB satellite in 1983. INSAT-1, designed by ISRO and manufactured to specification by the Ford Aerospace Communication Corporation of the U.S., is a unique multipurpose satellite. The satellite design provides for domestic long-distance telecommunications, meteorological Earth observation and data relay, as well as a nationwide direct satellite television broadcasting capability. INSAT is designed as a twin satellite system—one satellite being the primary satellite and the other acting as an active on-orbit spare with certain major path telecommunications functions.

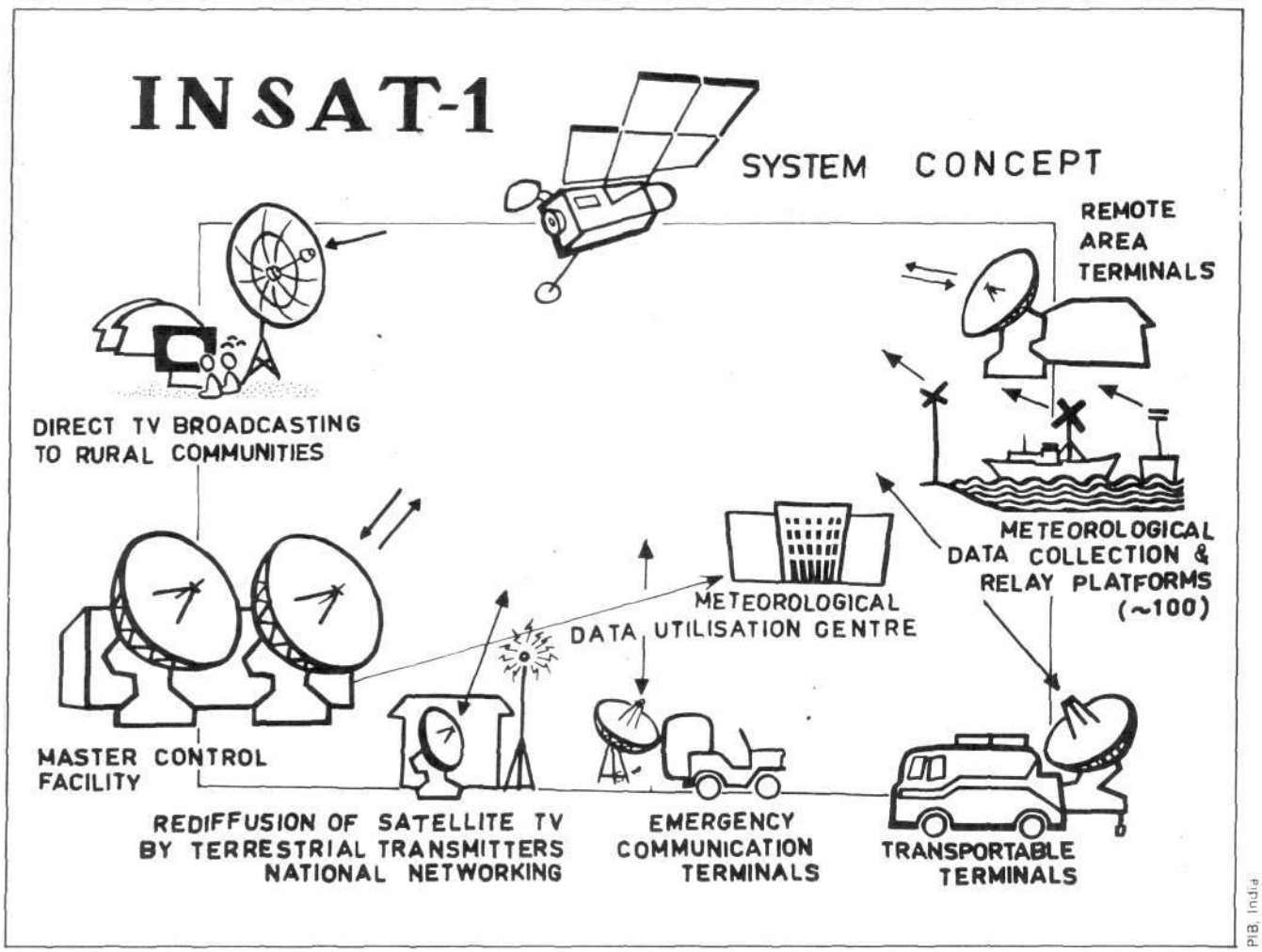
Support work for the INSAT satellites after separation from the launch vehicle is handled by the Master Control Facility (MCF), built up in the Hassan district of Karnataka. These operations consist of initial orbit-raising, orbit determination, deployment, station acquisition and on-orbit checkout operations and the subsequent satellite health monitoring and control, including station-keeping maneuvers. The MCF consists of two independent satellite control Earth stations with 14 metre diameter, fully steerable antennae and a satellite control centre with associated support facilities including a standby power system with a no-break component.

The satellites themselves are biased-momentum, three axis stabilized with a precision altitude control system. Each consists of 12 C-ban transponders and 2 S-ban transponders, a very high resolution Radiometer (VHRR)



ISRO

The APPLE spacecraft, middle section, mated with the European METEOSAT satellite, top, prior to vibration testing at a French facility.



operating in the visible and near infrared bands, and a data channel with global receiver coverage. The satellites use an asymmetrical solar array to ensure effective functioning of the radiation cooler for the VHRR.

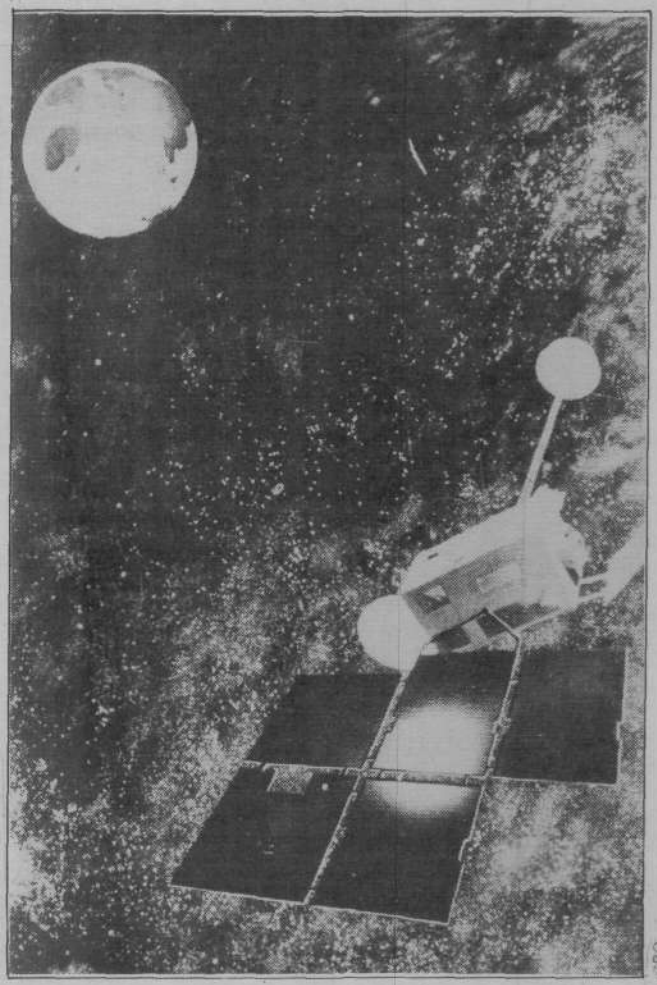
INSAT-1A, which was launched in 1982, malfunctioned and had to be deactivated as a result of loss of Earth lock due to what ISRO scientists have identified as unexpected Moon interference. INSAT-1B was launched by the U.S. Shuttle in August, 1983, and has been functioning successfully. INSAT-1C, scheduled for launch in mid-1986, will act as the on-orbit spare for the INSAT system. The satellites are designed for a seven-year operational life.

The INSAT-II satellites required for replacement are already being designed for indigenous construction and deployment in the 1991 time frame and onwards. The first proto-INSAT-II test satellite is expected to be launched in 1988-89. The INSAT-II series will accomodate a several-fold increase in telecommunications and TV requirement anticipated for the 1990s, and will also encompass qualitative enhancement of meteorological Earth observation capabilities.

Remote sensing

The experience gained with the Bhaskara satellites in terms of observation payloads, ground systems and parallel projects to assess and develop user capabilities is now culminating in the even more challenging Indian Remote Sensing programme (IRS). In 1986 the first Indian remote sensing satellite (IRS-1A) will be launched by the Soviet Union into a 900 km polar sun-synchronous orbit. This 850-kg satellite, the first in a series, will be a semi-operational/operational satellite with three-axis stabilization and Earth pointing payloads providing images in visible and near infrared bands.

Designed and built fully indigenously, and with a design life of three years, the IRS satellite will be the major element in India's space-based remote sensing system for national natural resources survey and management in agriculture, forestry, geology and hydrology. The satellite will carry two types of payloads—one, a camera providing spatial resolution of 73 metres with a swath of 150 km, and the other, two cameras, each having 36.5 metres spatial resolution and a combined swath of about 148 km. The experience with Bhaskara, where the technology of



ISRO

Artist's drawing INSAT-I.

dissemination to users was perfected, has contributed to the development of ground systems to handle the IRS data. The National Remote Sensing Agency has this responsibility. A wide user network of skilled professionals is being developed, and a National Natural Resources Management System is under evolution.

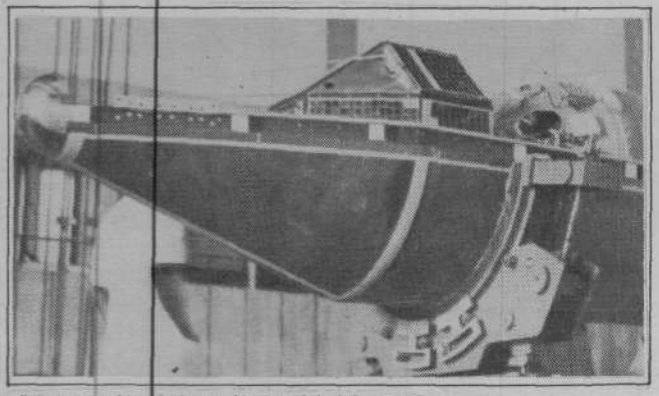
During the 1970s a series of satellites were designed for spacecraft technology development. The first, the 40-kg Rohini, was successfully launched by India's first indigenous launch vehicle, the SLV-3, in 1980. The launch of two more Rohini satellites, with payloads designed to monitor functioning of the launch vehicles, successfully concluded the development of the SLV-3 and confirmed India's self-reliance in this critical area. These satellites also carried experimental payloads designed to test new observation and classification systems.

Testing satellites

ISRO is currently designing a new series of small, low-cost satellites called the Stretched Rohini Satellite Series (SROSS) to be launched by the new, more powerful launch vehicle, the Augmented Satellite Launch Vehicle (ASLV) now nearing completion. The SROSS is being designed to handle a payload mass of 15 to 35 kg and to point continuously in a given direction or scan the sky as instructed. The spacecraft will, furthermore, be modular to accomodate varying payloads. The first two SROSS

The first two SROSS mission payloads have already been identified. Since the first mission will be with the maiden flight of the ASLV, the payload is mainly oriented to monitoring the performance of the launcher. SROSS will carry a Shock, Accoustic and Vibration Experiment which will take a series of measurements of the shock, accoustic load and vibration of the launcher at different intervals related to the sequence of launch vehicle operations. Also on board will be a Velocity Increment Determination Experiment designed to measure the other critical parameter of effective launch capability, namely the magnitude and direction of the velocity increment provided by the final stage of the launch vehicle.

In addition SROSS will carry a laser tracking experiment and a gamma ray experiment. The second SROSS will carry a new stereo scanner device built by the West German Space Agency which is designed to generate stereo imagery; that is, the same area on the ground will be imaged from three different angles in space.



ISRO

RS-1 on the SLV-3, heat shield open.

The SROSS missions will test a range of design ideas, materials and systems. The satellites' solar panels will be made entirely of solar cells fabricated indigenously, and the spacecraft will carry new "S" bank TTC system designed for later use in the second-generation IRS and INSAT satellites. The satellite's unusu l length, the answer to a volume restriction imposed on S SS by the size of the launch vehicle envelope availabl , will pose some challenges to attitude and orbit control systems, and efforts are underway to replace the main structural elements with more advanced materials. The spacecraft will also incorporate the first large scale use of microprocessors by ISRO.

On the horizon are more advanced communications and remote sensing satellites, including microwave satellites. ■

Experiment (SITE), using the USA's geosynchronous satellite ATS-6, is a good example, as is the 1977-79 Satellite Telecommunications Experiments Project (STEP), using the Franco-German satellite Symphonie. All ground systems for these experiments were built and managed indigenously. The experiments were essential in preparing the way for the Indian National Satellite System (INSAT).

Similar steps were taken in satellite technology, with time-bound plans laid to design, build and test satellites for scientific experiments beginning with Aryabhata in 1975. Work on launch vehicle technology also proceeded from its beginning in 1962 at the "test tube" level. This area, where the technological complexity of the job is even greater that than its high cost, presented the greatest challenge. With worldwide development so closely tied to military applications the details of the technology are less readily available and one is forced to proceed from the known basic science of the matter on one's own.

It is the project phase of the 1970s that shaped ISRO into the dynamic functioning team—managed by scientists and engineers and with a consistent ratio of scientific and technical staff to administrators of more than 2 to 1—that we know today. Besides building up capabilities in the four basic areas, by the end of the decade ISRO had also developed a concrete notion of what users want and need.

ISRO officials view the 1980s as the "operationalisation" phase. It is in this decade that the INSAT system has become fully operational, and the Indian Remote Sensing (IRS) system will be deployed. With indigenous launch capability established in the 1983 success of the SLV-3 three more advanced launch systems are now under development. Their completion, and the design and indigenous production of more advanced satellites will place India's space programme on a completely developed and entirely self-reliant footing by the early 1990s. Appropriately, a full-fledged Ministry of Space has now been established to direct the programme.

Dynamic ISRO-Industry Interface

In 1978 the Department of Space took a policy decision that all space projects would make maximum use of Indian industry, but in the initial phases ISRO was doing everything itself, "in house." Gradually capabilities were developed in industry such that an ISRO-made prototype could be reproduced in quantity on order, with close collaboration from ISRO. In the final phase, now beginning, ISRO will increasingly be giving only functional specifications to industry for a component or subsystem, thus involving industry more in the development as well as fabrication of the required items.

Today the main features of ISRO's interface with industry are well defined. Interaction takes place in three ways: 1) technology transfer to industry of products and processes developed by ISRO, either on a buy-back basis or for developing spin-offs; 2) placing orders with industry directly; and, 3) technological consultancy services offered on a wide range of expertise ISRO and developed in technology and systems development and management.

The commitment is paying off in the expansion of high technology production capabilities in a kind of "multiplier effect" over a wide range. The space programme now buys back a large amount of mechanical precision equipment, electronic subsystems, chemicals and other items that its own scientists had helped industrial houses to develop or improve.

For instance, Unsymmetrical Dimethyl Hydrazine (UDMH) is now being produced by Indian Drug Products Ltd. (IDPL) under an ISRO license. UDMH, a liquid propellant fuel to be used in the PSLV, is also finding applications as an agricultural chemical. Similarly, process know-how for an epoxy-based insulation coating and resin hardener was successfully transferred to United Electricals Ltd. of Quilon; now additional parties are evaluating the coating system for resistors and capacitors. At present the compounded insulation-coating material is being imported.

Bharat Electronics Ltd. (BEL) has established a separate space electronics division to support ISRO, and the division had made steady progress. Electronics packages supplied by the Division to ISRO include PCM systems, power supplies, telemetry receivers, helical filters, various antennae types, and more. In additional, BEL has undertaken development and fabrication of High Precision Coherent Monopulse C-Band tracking radars.

Cooperation with Hindustan Aeronautics Ltd. (HAL) has been extended for development and fabrication of aerospace structures for the ASLV, PSLV, IRS and the SROSS. The production plant at HAL, Nasik for 19 special chemicals, adhesives and sealants completed its first year of operation. Thirteen items are already under regular production, with five more in shop trials and one under development. HAL is also producing precision Miniature Rate Gyroscopes based on ISRO technology.

And these are but a few of the leading examples. In the past few years production lines and divisions of small, medium and large undertakings have been set up with ISRO technology or a combination of ISRO R&D and industrial experience and in late 1984 a special working group was constituted of ISRO and members of the Association of Indian Engineering Industries (AIEI) to spell out the modalities of long-term interaction between ISRO and the engineering industry.

The other area where ISRO is contributing directly is with consultancy services. Under the scheme started in 1982 ISRO has been providing its expertise to Indian industries in a wide range of technology and engineering disciplines. The expertise areas include chemical and polymer technology, process engineering, pyrotechnic systems, communications and electronic data transfer systems, precision fabrication and testing, electro-optic sensors and systems among others.

Product Development

Development of any product to be used for the space programme is hard and interesting work. Space scientists

Building a Rocketry Programme from Scratch

India's rocketry development started modestly in the 1960s at the earliest stage of the space programme. The main efforts were directed toward development of a variety of sounding rockets for exploration of the upper atmosphere and ionosphere and to carry out astronomy experiments.

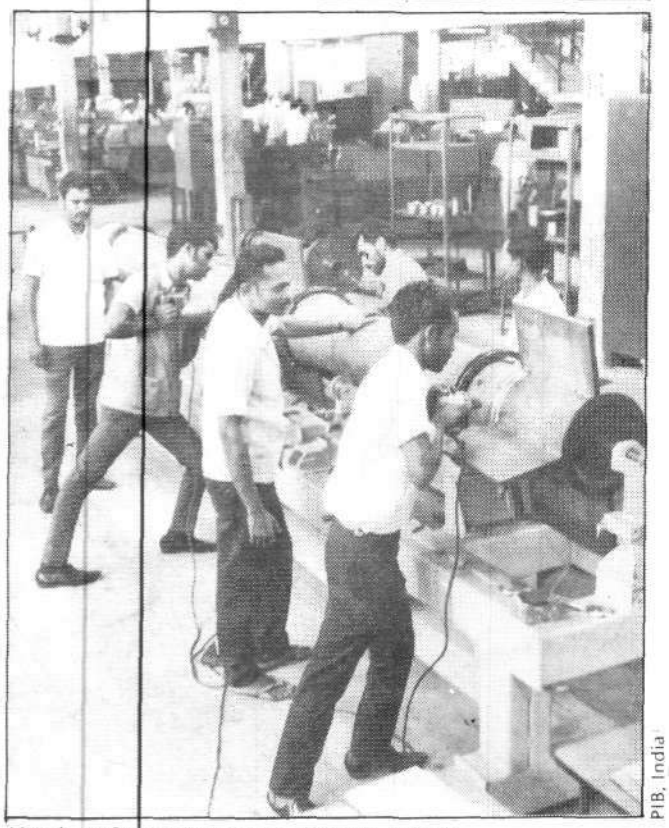
The first set of sounding rockets, the Rohini Sounding Rocket programme (RSR), were launched from the Thumba Equatorial Rocket Launching Station (TERLS) near Trivandrum. Because of its proximity to the equator, the station is ideal for conducting atmospheric studies. ISRO has developed a series of rockets indigenously, the RH-125, RH-200, Centaure, RH-300 and RH-560, weighing from 20 kg to 1500 kg, complete with payloads, for collecting information on meteorological parameters such as temperature, wind speed and direction, besides carrying out experiments to study characteristics of different ionospheric layers, the electrojet which passes over the Thumba region, the properties of natural atmosphere and X-ray astronomy.

While the RSR programme provided space scientists the basic understanding of rocketry, it was the successful launch of the Satellite Launch Vehicle-3 (SLV-3) in 1980 which marked Indian rocketry's coming to age. The decision to develop an indigenous satellite launch vehicle had been taken in the late 1960s and a well-defined, time-bound project to design, develop and flight test the SLV-3 for injection of a 40 kg satellite into near earth orbit was initiated in 1973.

Whereas the Rohini sounding rockets were single-stage rockets, the SLV-3 was designed to bring India into the state-of-the-art space club dominated by the United States, USSR, Europe and Japan. The 22.7 metre long SLV-3 is a four-stage solid propellant vehicle with an estimated launch weight of 17 tonnes. Its major sub-systems include solid rocket motors for different stages and their propellants, interstages, stage separation mechanism, heat shield, control and guidance instruments and vehicle electronics. On July 18, 1980, the SLV-3 placed a 35 kg Rohini satellite, the RS-D1, into an eliptic orbit of 900 km apogee and 300 km perigree at an inclination of 40 degrees. India's launch capability was confirmed with two more successful launches from the Sriharikota launching station off the coast of Andhra Pradesh.

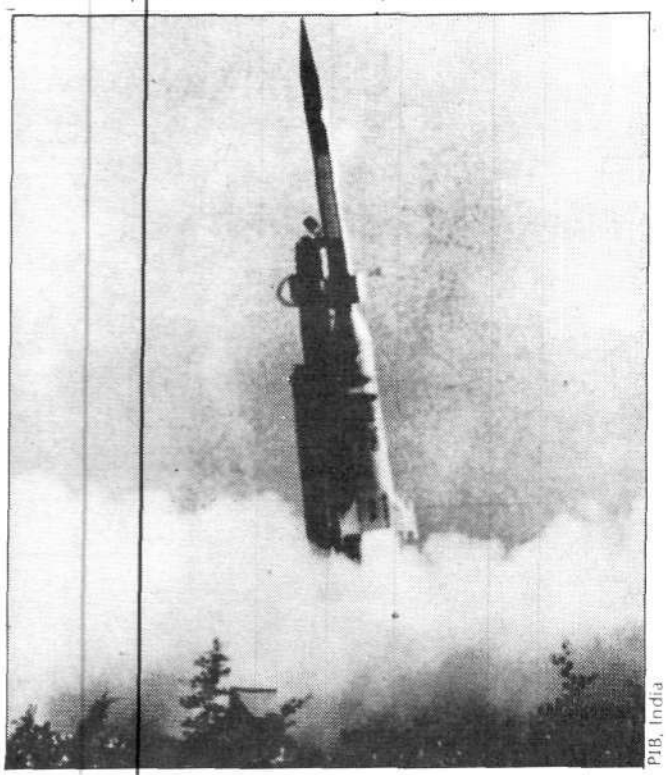
Bigger stronger rockets

The basic satellite launch vehicle technology mastered, Indian scientists are now developing a bigger and stronger rocket, the Augmented Satellite Launch vehicle (ASLV).



PIB, India

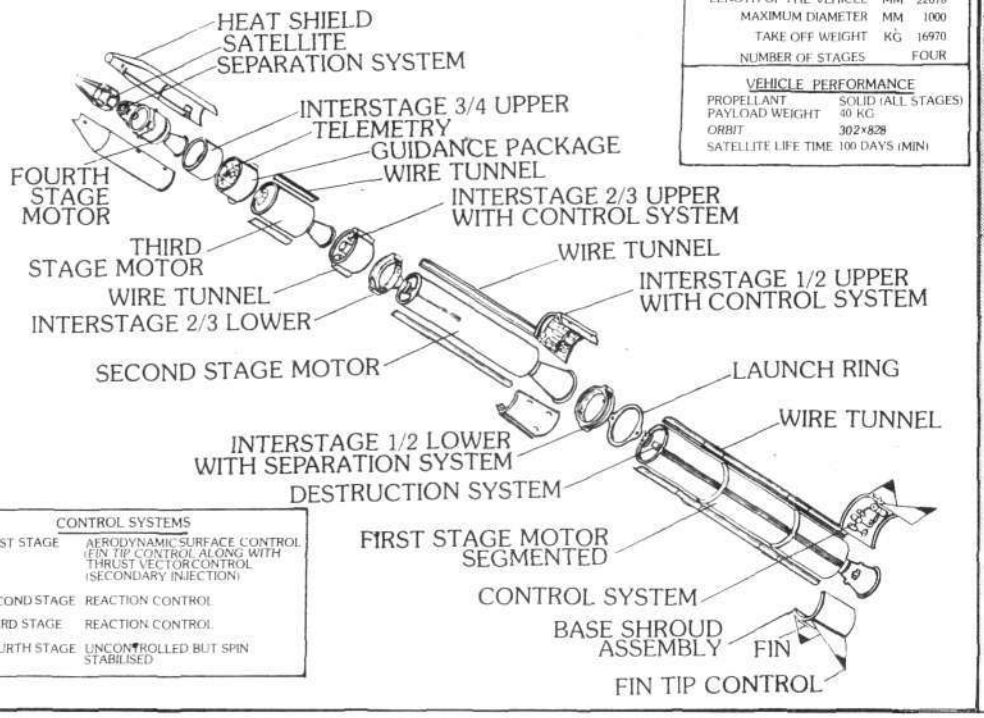
Work at Space Research Centre, TERLS.



PIB, India

RH-560 lifting off from Sriharikota Range.

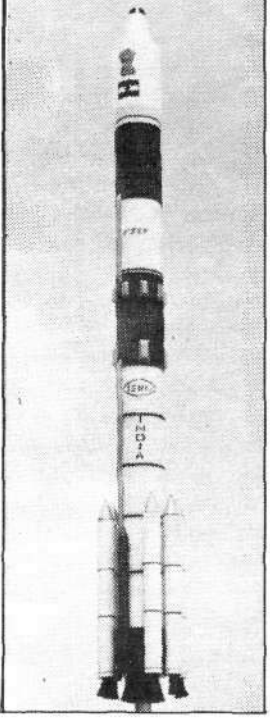
EXPLODED VIEW OF SLV-3



VEHICLE CONFIGURATION & WEIGHT		
LENGTH OF THE VEHICLE	MM	22678
MAXIMUM DIAMETER	MM	1000
TAKE OFF WEIGHT	KG	16970
NUMBER OF STAGES		FOUR

VEHICLE PERFORMANCE	
PROPELLANT	SOLID (ALL STAGES)
PAYLOAD WEIGHT	40 KG
ORBIT	302×828
SATELLITE LIFE TIME	100 DAYS (MIN)

CONTROL SYSTEMS	
FIRST STAGE	AERODYNAMIC SURFACE CONTROL (FIN TIP CONTROL ALONG WITH THRUST VECTOR CONTROL (SECONDARY INJECTION)
SECOND STAGE	REACTION CONTROL
THIRD STAGE	REACTION CONTROL
FOURTH STAGE	UNCONTROLLED BUT SPIN STABILISED



ISRO

ASLV is far superior to the SLV-3 in terms of structural anatomy and launch capability, though it is designed around the SLV-3 as the core vehicle. ASLV will take India into the frontier area of strap-on booster technology; the ASLV will have two strap-on motors, each of which will be as heavy as the first stage of the SLV-3. As against the 17-tonne launch weight of SLV-3, ASLV will have a lift-off weight of 39 tonnes and the capability to place a 150 kg satellite into a near Earth orbit. The first launch of ASLV is scheduled for 1985.

The next immediate goal of India's rocket research is the Polar Satellite Launch Vehicle (PSLV), which requires a complex multistage rocket to put 1000-kg class satellites into polar sun-synchronous orbits. The lift-off weight of the PSLV will be about 276 tonnes—more than 16 times the weight of the SLV-3 rockets—with a height of 44 metres. Getting satellites into polar orbit, though it requires enormously high boost energy in the rocket, offers great advantages for Earth observation.

A satellite in polar orbit moves around the Earth in a circle that keeps it always in line with the Sun, even as the Earth rotates beneath it. With the angle of solar incidence thus fixed, you have illumination control for optimal remote sensing pictures. PSLV is aimed at providing indigenous launch capability for the IRS satellites, but scientists agree that once PSLV is proven it will be the "bread and butter" of the space programme. With this capability India could offer commercial launch services to other nations.

Civil works are in progress for the various test facilities, and the first test launch is scheduled for 1988. It has been decided that the vehicle will have a liquid fourth stage instead of the solid propellants used in the earlier rockets. A full scale PSLV model has been fabricated for studying mechanical interface problems, and contracts are being entered into for major fabrication.

The next generation of Indian rockets, the Geosynchronous Satellite Launch Vehicle (GSLV), is already on the drawing board, and there are indications that the plan to introduce these in the mid-1990s may be speeded up. The GSLV involves a qualitatively superior fire power to reach the geosynchronous orbit at 36,000 km from Earth.

A glance at what's involved in rocketry helps put the Indian accomplishment into perspective. Rockets are unique in that they can operate at any altitude, or even in empty space, because the rocket carries both its fuel and the oxidizer to burn it. If the rocket is a solid propellant device, the oxidizer and fuel are mixed together in the solid charge that is loaded into the burning chamber in assembling the rocket. When ignited, the propellant burns without requiring any oxygen from the air. The burning propellant fills the burning chamber with high-pressure gas that is forced out of the nozzle to form the rocket jet that creates the thrust, making the rocket go. If the rocket is a liquid propellant device, the fuel and

oxidizer are both forced into the burning chamber in such a way as to mix them thoroughly for burning.

The basics

A rocket consists basically of a structure that carries propellant storage space, a burning chamber, a nozzle, steering equipment, and a place to carry a payload. The trick is designing and assembling these elements into a workable machine which maximizes the laws of thermodynamics and aerodynamics to do what you want it to do. For this there are certain basic parameters which must be taken into account: jet-exhaust speed, specific impulse, mass ratio, thrust, and propellant type among them.

Jet exhaust speed is the speed at which the burnt propellant leaves the rocket. The faster the jet gases move in leaving the rocket nozzle, the greater the thrust they exert on the rocket. To attain high jet-exhaust speeds, propellants are used that contain very high energy.

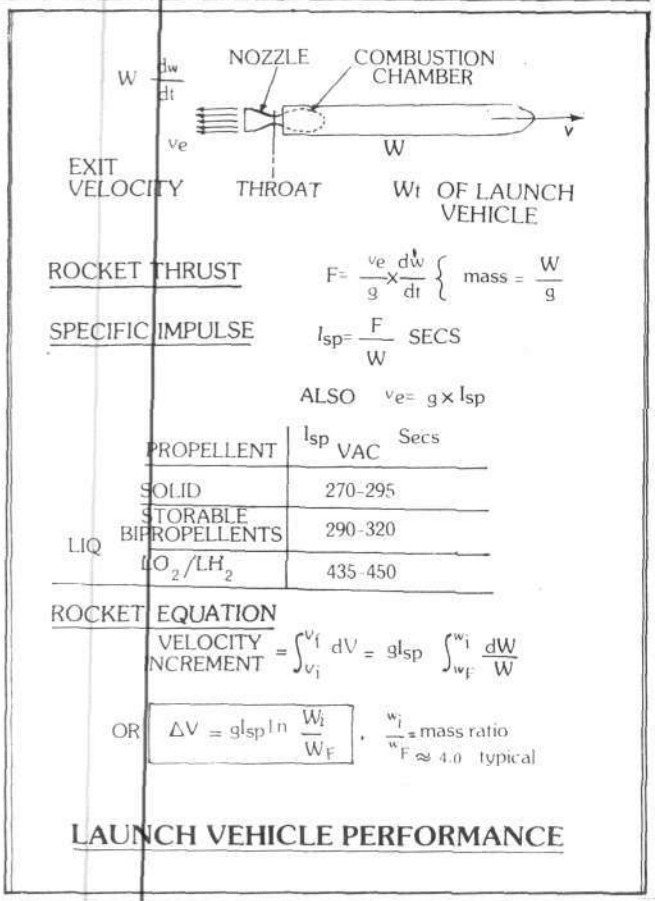
The **specific impulse** delivered by the rocket motor also tells how good the rocket design is. Specific impulse is defined in terms of the amount of propellants that have to be burned every second in order to maintain a thrust of a given amount. Specific impulse is to a rocket what miles per gallon is to an automobile.

Mass ratio, another indicator of the quality of rocket design, is the ratio of the total mass of the rocket at take-off to the mass of empty rocket at burnout. Since the total mass of rocket contains propellants at take-off, the ratio is always much larger than one. But as the propellants burn out during the rocket's flight, the total mass decreases causing the ratio to reduce. It is for this reason that multistaging provides a clear advantage: the unnecessary weight of the burnout stage can be dropped, improving the mass ratio and resulting in increased rocket velocity at each stage.

While the jet-exhaust speed or specific impulse and mass ratio determine the ultimate speed or altitude the rocket can attain, regardless of its size, the amount of **thrust** determines how much payload the rocket can carry. For the larger space rockets today, big motors are required to handle the large flow of propellants needed to generate the huge thrusts that must be used to drive the rockets plus payload. This puts a premium on, among other things, lighter and stronger materials.

Indian rockets use chemical **propellants** which store their chemical energy within and release it by burning. The energy released raises the products of the burning to high temperatures of several thousands of degrees and high pressures of between 10 and 100 atmospheres, depending on the particular rocket. Among the chemical propellants are both solid and liquid propellants. The modern solid propellant is a composite-type propellant, generally a hydrocarbon. Asphalt-type materials, rubber compounds and plastics are all used as fuels. The oxidizer will be some compound like ammonium nitrate, potassium chlorate or ammonium chlorate.

Liquid propellants, on the other hand, consist of liquid fuel and liquid oxidizer. Their advantage is in the ability to



ROCKET THRUST $F = \frac{v_e}{g} \times \frac{dw}{dt}$ { mass $= \frac{W}{g}$

SPECIFIC IMPULSE $I_{sp} = \frac{F}{W}$ SECS

ALSO $v_e = g \times I_{sp}$

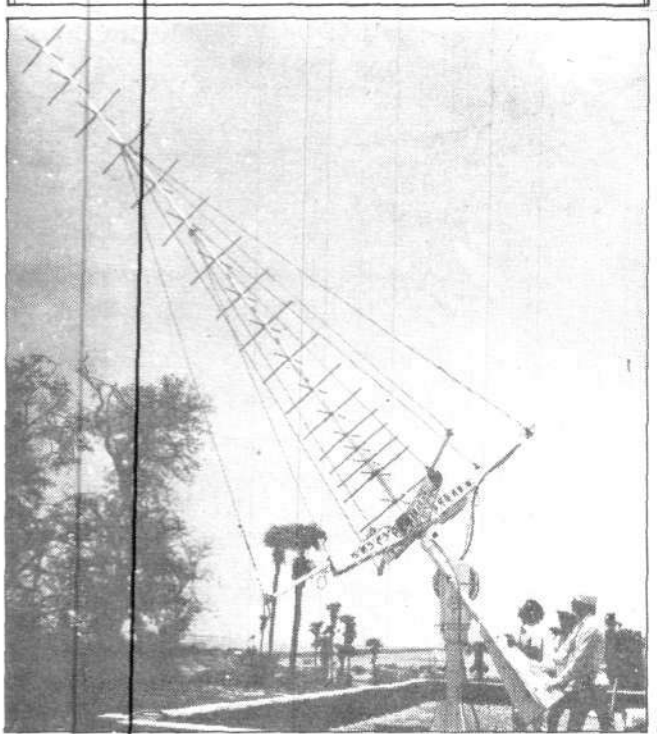
	PROPELLENT	I_{sp} VAC Secs
	SOLID	270-295
LIQ	STORABLE BIPROPELLENTS	290-320
LIQ	LO_2/LH_2	435-450

ROCKET EQUATION

VELOCITY INCREMENT $= \int_{v_i}^{v_f} dV = g I_{sp} \int_{w_F}^{w_i} \frac{dW}{W}$

OR $\boxed{\Delta V = g I_{sp} \ln \frac{W_i}{W_F}}$, $\frac{w_i}{w_F}$ = mass ratio ≈ 4.0 typical

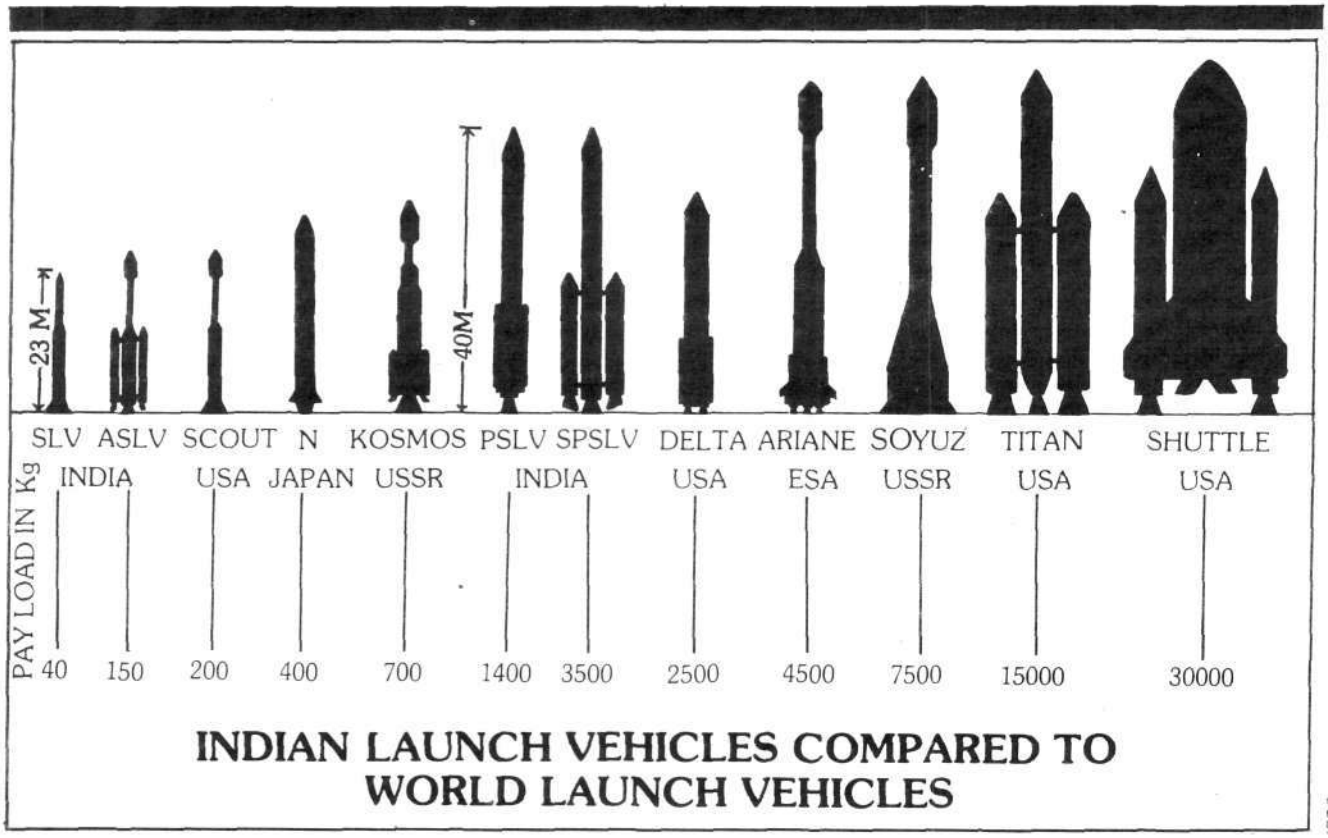
LAUNCH VEHICLE PERFORMANCE



ISRO

PIB, India

Telecommand antenna at Sriharikota.



INDIAN LAUNCH VEHICLES COMPARED TO WORLD LAUNCH VEHICLES

ISRO

control, or even stop, the burning by means of valves. Among the liquid propellants are the so-called cryogenic materials as well as storable ones such as kerosene, gasoline, analine, etc. A cryogenic propellant is more difficult to handle, but more powerful. It is a gas at ordinary temperatures, and therefore must be maintained at very low temperatures to keep it in liquid form. The chief cryogenic fuels are liquid hydrogen, with a temperature at atmospheric pressure of -235 degrees centigrade, and liquid ammonia, with a temperature of -33 degrees centigrade.

The low temperatures of the cryogenic fuels make the pumping, operation of valves and storage difficult. In addition, many of these substances are extremely corrosive and poisonous. Indian rockets have so far not used cryogenic fuel, but the next generation rockets, the GSLVs, are expected to use this technology to obtain the higher specific impulse needed to carry the rocket to geosynchronous orbit.

A challenging task

These then are the basics of rocketry, which it took 30-40 years to develop during the first half of the 20th century in simultaneous efforts in Russia, Germany and America associated with the names of Tsiolkovsky, Hermann Oberth and R.H. Goddard respectively. The fundamental principles were not different from those employed by the early Chinese, allegedly the first to build rockets.

But it was during the Second World War, with the work of scientists like Durnberger, Riedel and von Braun at the Peenamunde proving ground, and in the immediate postwar period that rocketry was really perfected. Heavier payloads, precise orbital placement, and other considerations have made the job enormously more complex. ■

first determine the quality of the product necessary. The basic technology, if not in use in the country, is developed by the scientists themselves at the Vikram Sarabhai Space Center in Bangalore or the Space Applications Centre in Ahmedabad. ISRO scientists are constantly on the lookout for work going on at other labs and institutes in the country that may be of use in the space programme, and in some cases buy technology from these groups to adapt or develop. Then they look around for enterpreneurs who have the physical capability to produce the technology for space use. "Space quality" work means a high level of precision and low tolerance.

The case of maraging steel, developed for use in the future PSLV motor casing is an eye opener. Maraging steel is a lightweight steel alloy. It is extremely economical for certain requirements, but it is also a difficult alloy to fabricate. India had no experience with this alloy whatsoever. The composition of the alloy had to be worked out, and the forging, welding and heat treatment parameters and composition of welding rods determined. Then someone had to be found to roll the plates, make the rings of 3-4 metres diameter, and fabricate the motor casings themselves.

ISRO mobilized its own scientists from the metallur-

gical and science divisions, and then tapped the Welding Research Institute (WRI) and Bharat Heavy Electricals Ltd. (BHEL) in Trichy, among others. Many different industries, including public sector units, got involved in the process. WRI has developed the welding technology, and together with Mishra Dhatu Nigam (MIDHANI) produced the compositions for welding rods. MIDHANI is producing blooms, ingots and slabs; Rourkela Steel Plant is rolling the slabs into large plates; and BHEL has undertaken trial segment fabrication. Now India possesses the manufacturing technology and the fabrication capability for maraging steel. The fabrication of 37 segments for the PSLV project will be undertaken by Walchandnagar Industries Ltd. and Larsen & Toubro. In the future maraging steel will be used not only for making motor casings for the PSLV and GSLV rockets, but also in defnece and probably in the nuclear industry.

For the most part, ISRO has itself developed a needed technology when it was not available in the country. One exception is, however, instructive of the flexible approach. ISRO entered into a technology transfer agreement with France to produce transducers. France agreed to give ISRO the technology to manufacture transducers, which France needed, on condition that the product would be exported to France. The Department of Space has adopted the technology and supplied the French transducers over the last ten years. Now, under the terms of the agreement, the technology will be disseminated to industry and India will possess the capability to export transducers to the world market.

There are many areas where such developments have taken place involving sister concerns, private industry and ISRO scientists. Plants and production lines have also begun to be established to utilize ISRO-licensed technologies for non-space applications. Industry has clearly become alert to ISRO's spin-offs. In fact, according to ISRO officials, there has hardly been a single product that hasn't had a buyer. On the contrary, the difficulty is choosing among the number of applicants for each offering.

Exciting Possibilities

To make but a few of the ISRO-developed items now in regular production in various industries: pressure and thrust transducers, until now the major bottleneck to development of a control technology industry in India; ISRO dry powder, a unique extinguisher effective against both metal and oil fires; a range of different adhesives and sealants which can effectively bond a variety of substrates such as rubber, metal, plastic, cloth, etc. to themselves and to each other and provide very high structural-peel strength under adverse environmental conditions; a remote multiplexing encoding unit; 13 different TV studio equipment pieces, including digital time base correctors; high power amplifiers; UHF communications equipment; a data collection, storage and transmission system for INSAT meteorological data collection platforms; INSAT radio networking terminals; among other items.

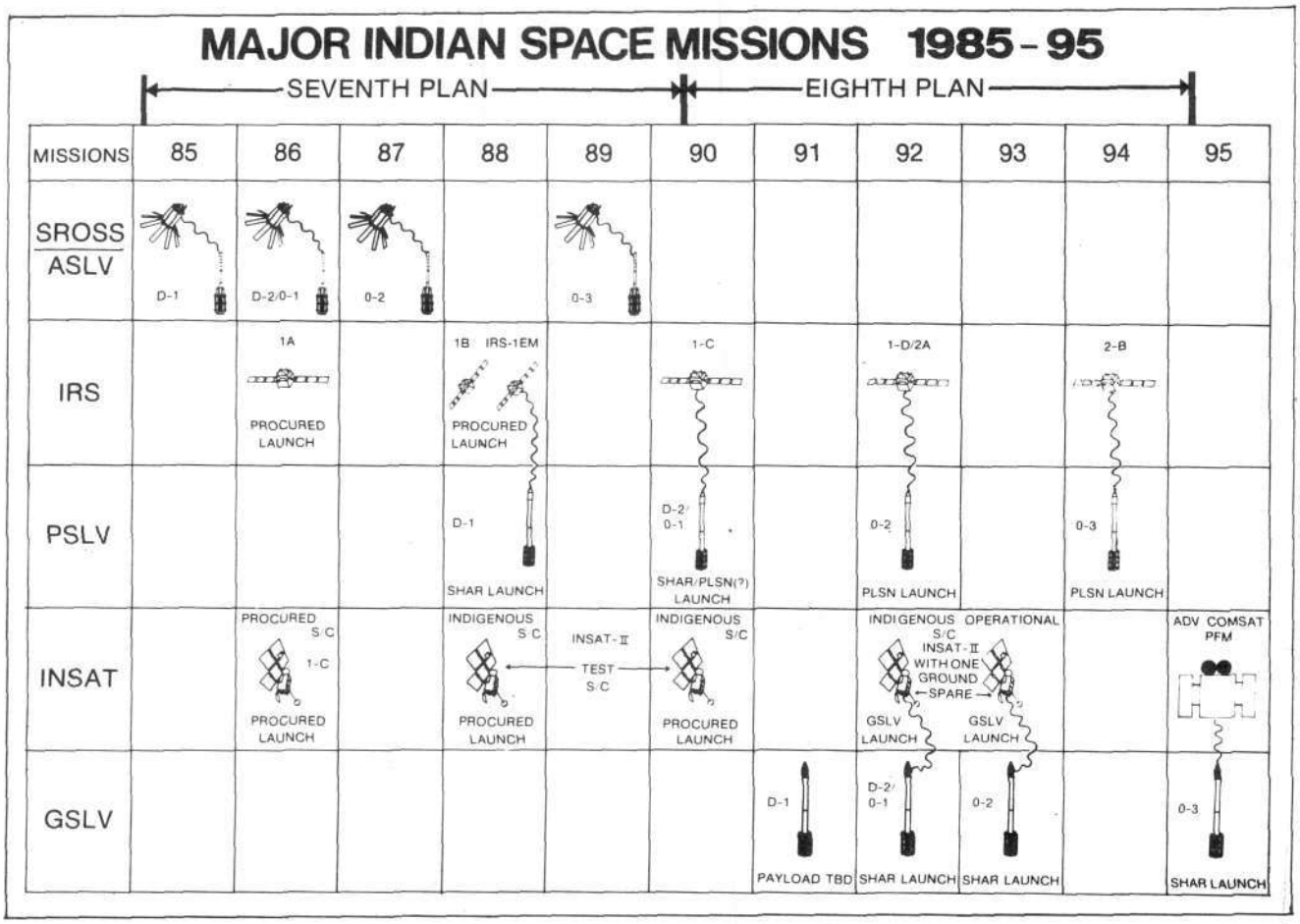
Recently ISRO also transferred its "spacetruder" technology, an automatic "pultrusion" machine to produce fiber reinforced plastic (FRP) structural sections of uniform cross section in a continuous manner, to an industrial firm in Hardwar. FRP sections have the advantage of a high strength to weight ratio, electrical and thermal insulation, corrosion resistance and energy storing capacity, and will thus have a wide variety of uses in different sectors of industry.

In the electronics industry the space programme is also making a significant contributions. A whole range of precision instruments mainly for control devices have come onto line and been improved for use in the space programme. Here ISRO does not so much develop new devices; rather, it developes new systems in which to use the items the industry itself is developing and fosters

PIB, India

PIB, India

Political and scientific leadership combined to make India's space programme a success. The late Prime Minister Mrs. Indira Gandhi championed the effort, ensuring it the necessary support during the critical 1970s period when the programme came "on line." Above, Dr. Vikram Sarabhai, architect and first head of the programme, with Prime Minister Gandhi at the Thumba Equatorial Launching Station in 1968. Below, left, Dr. Satish Dhawan, who just retired as head of the programme, and Dr. U.R. Rao, present Chairman of ISRO.



ISRO

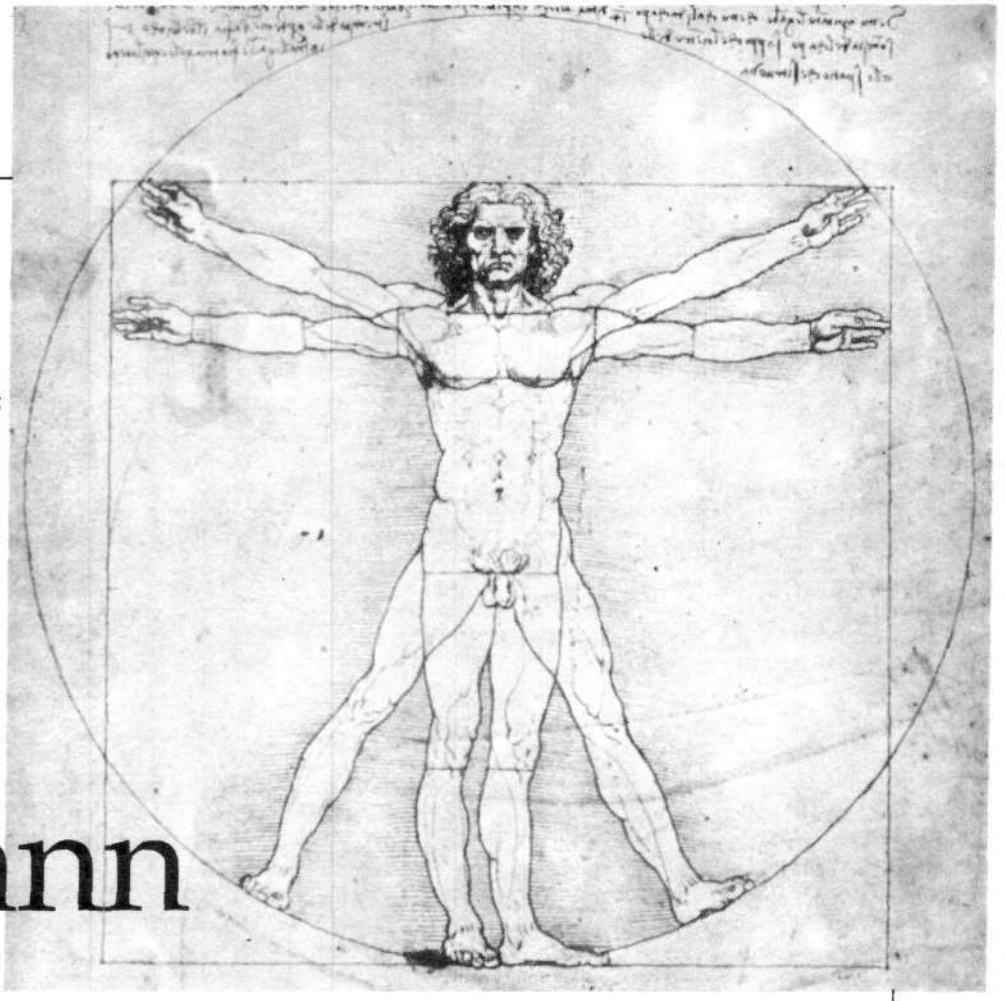
quality improvement by virtue of the stiff "space quality" requirements.

In a 1983 address to the Punjab-Haryana-Delhi Chamber of Commerce and Industry, then Chairman of the Space Commission Dr. Satish Dhawan described what this has meant for Indian industry and indicated what it means for the future. "Those industries which undertake to work with the space technologies invariably find that the demands of extreme reliability or complex specifications and performance force innovation," Dhawan told the industrialists. "For example, in fabrication tasks extreme tolerances would be required, calling for special tooling and measurement techniques. Similarly, high strength and light weight requirements lead to use of special materials such as special steels, titanium or beryllium or composites. The processing of such materials requires changes in metal cutting, heat treatment and forging processes, etc. The successful solution of such problems brings into being new industrial technology with wider applicability. In this area we are still in the beginning stages in India, but the process has begun and if industry looks ahead and seizes the opportunity there are many exciting things possible in the coming years."

Some idea of the potential Dhawan was pointing to can be gleaned from a look at the Indian Remote Sensing (IRS) programme, which will come into its own in the 1980s. This programme alone holds out enormous potentials and opportunities for industry in the years immediately ahead. A preliminary survey in 1983 showed that the initial requirements for simple optoelectronics ground truth equipment, such as radiometers and interpretation equipment, like colour additive viewers, will amount to as much as 10 million by 1988. Much of this equipment has been indigenously developed by ISRO and the National Natural Resources Management System set up for IRS applications management, and the technology is presently being transferred to capable manufacturers. In addition there will be a market for as many as 100 computer-based interactive systems worth tens of millions of dollars for processing, recording and disseminating the data received from IRS. An additional demand for high quality printing and photographic products will be prompted for the generation and distribution of data products.

The estimates are probably conservative if you consider the amount of information that will be generated by IRS on a daily basis. In each pass over India—seven or eight times per day—the IRS will send down the equivalent of 4000 volumes of 300 pages each of data, amounting to a large library of 10,000 books each day! Within ten years, with the use of active microwave sensors which can gather data in night as well as day and in any weather, this information flow will increase by an order of magnitude! ■

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

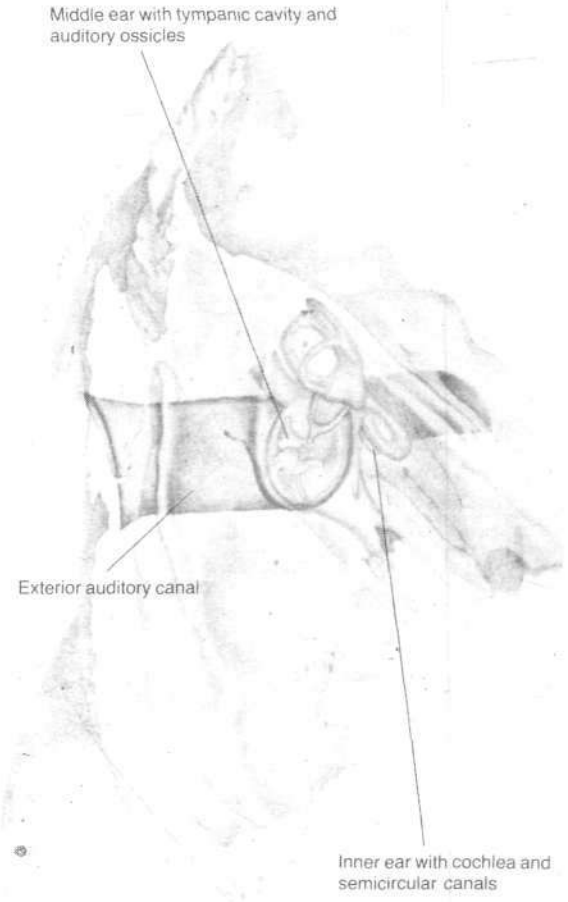


Figure 1
STRUCTURE OF THE EAR
Helmholtz applied a "systems analysis" approach to try to explain the functioning of the ear from its anatomy using textbook physical laws. In contrast, Riemann took as his starting point the extraordinary sensitivity and discrimination of human hearing, believing that its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

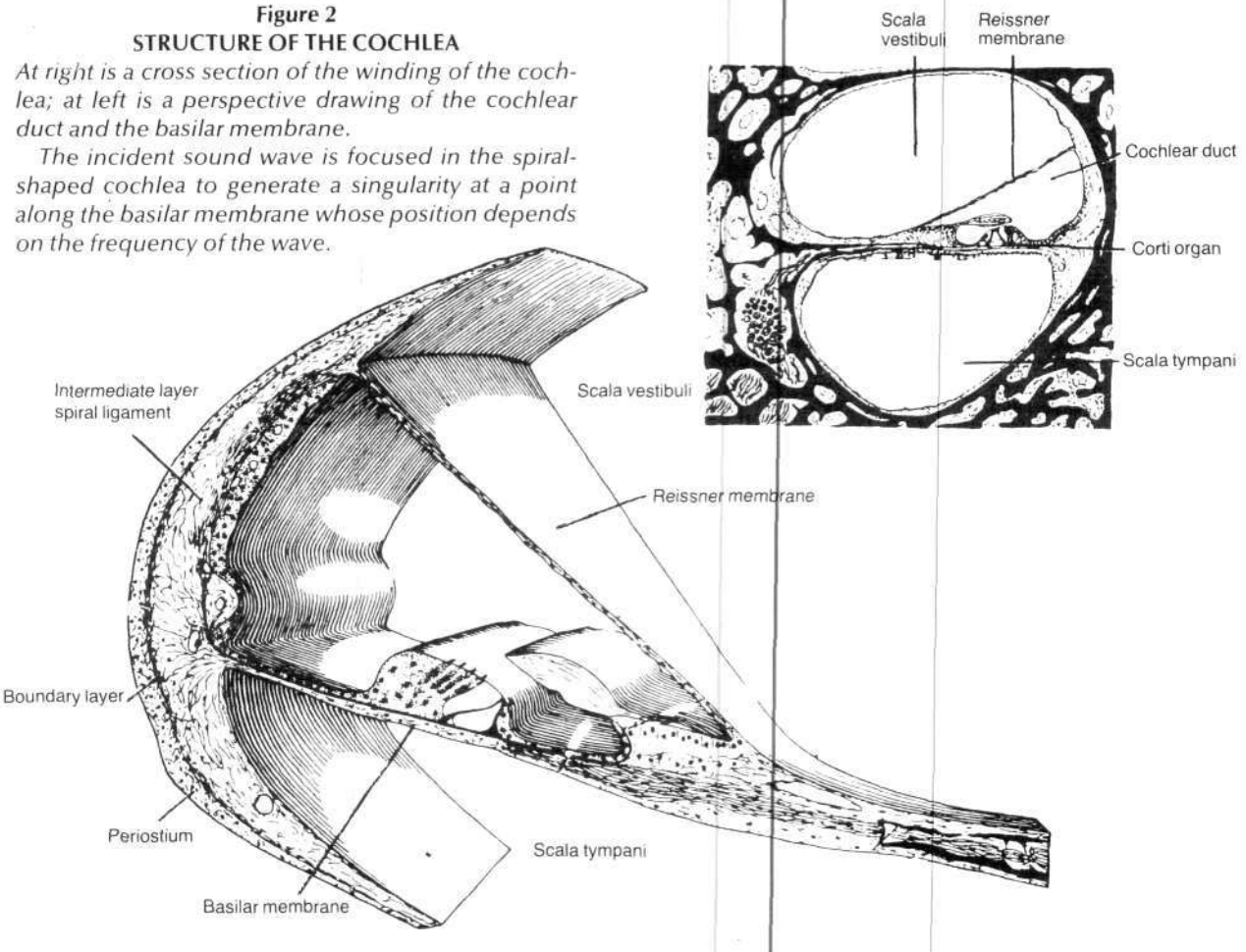
As we can see from a brief examination of the highlights of the development of research into the ear, Riemann was completely correct in his suggestion that the kind of physics employed by Helmholtz, what today is known as classical physics, would be totally unable to explain the observed functioning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



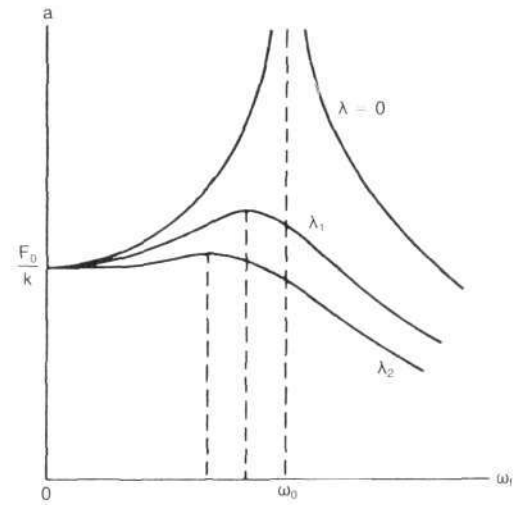


Figure 3
DAMPING OF RESONANCE VIBRATIONS
The damping of resonance vibrations for different damping factors, λ, are shown. The smaller the damping, the more pronounced is the amplitude of the resonance ($\lambda_2 > \lambda_1$). For $\lambda = 0$ the amplitude of the resonance is infinite.

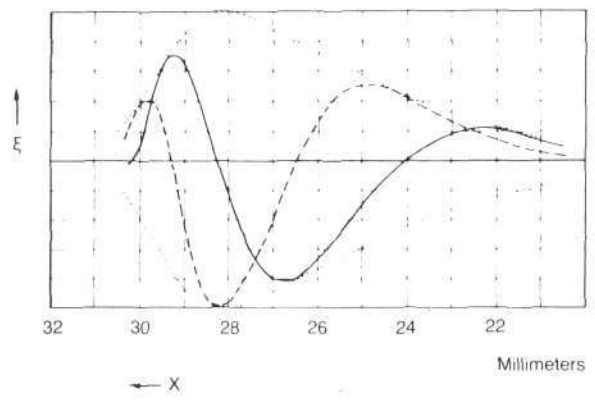


Figure 4
TRANSVERSAL TRAVELING WAVE OF THE BASILAR MEMBRANE
A traveling wave is shown here in two positions: one following the other by a quarter period. The tone has a frequency of 200 hertz. The x-axis represents distance from the oval window, considered to be toward the right.

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.[1] 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,

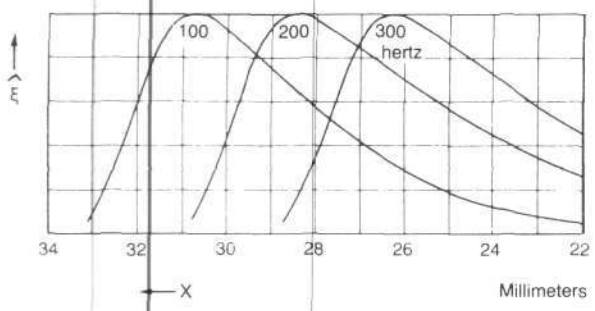


Figure 5
AMPLITUDES OF TRANSVERSAL VIBRATIONS OF THE BASILAR MEMBRANE
The place on the basilar membrane where the amplitude of the traveling wave is at its maximum shifts in accordance with the frequency of the tone presented to the ear.

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.

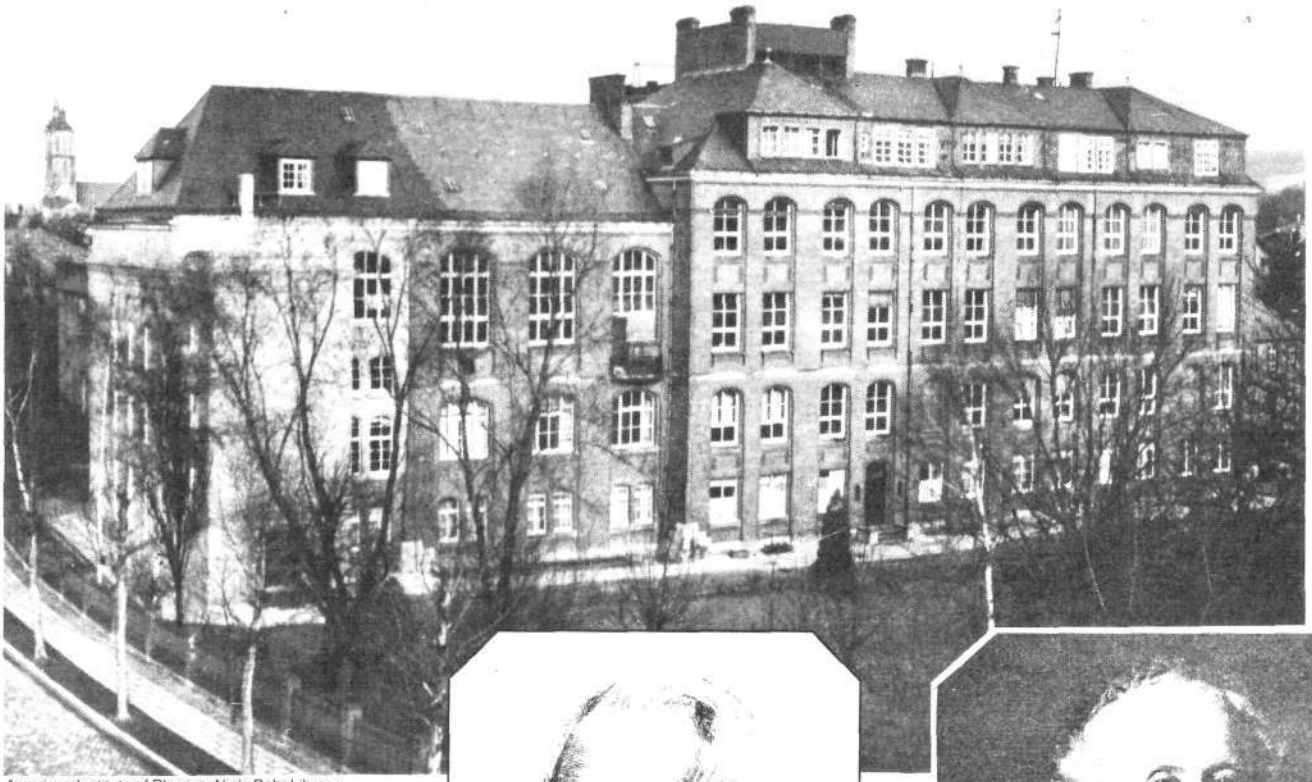
Finally, having provisionally identified the role of individual organisms in the process of improvement of the biosphere, we apply the same approach within the given organism.

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]

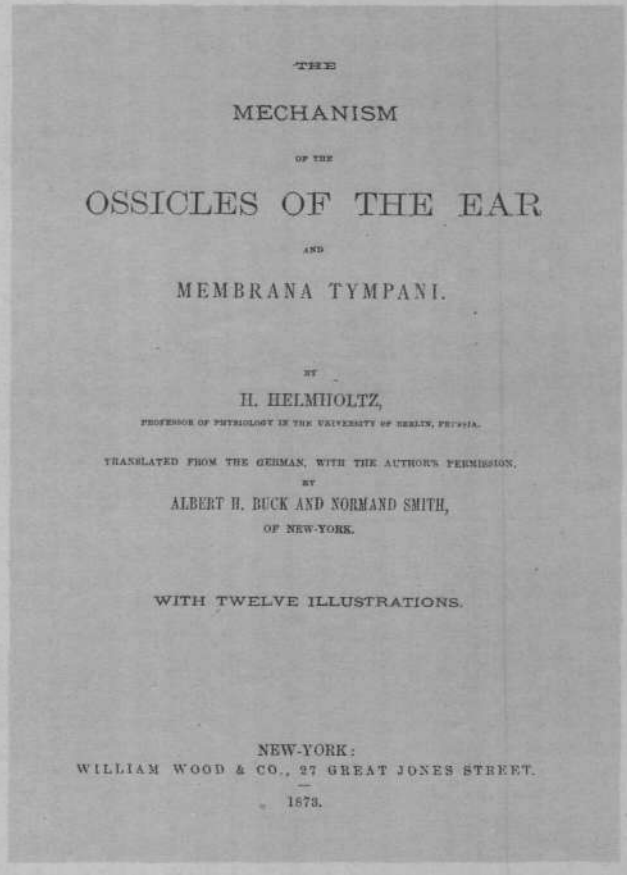
Furthermore, Helmholtz argued that the intensity of the "clicking" varied with temperature and with the air pressure inside the tympanic cavity of the middle ear so that not only did the ossicles destroy the fidelity of the sound wave, but they did so to different degrees—literally—depending on the weather.

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:

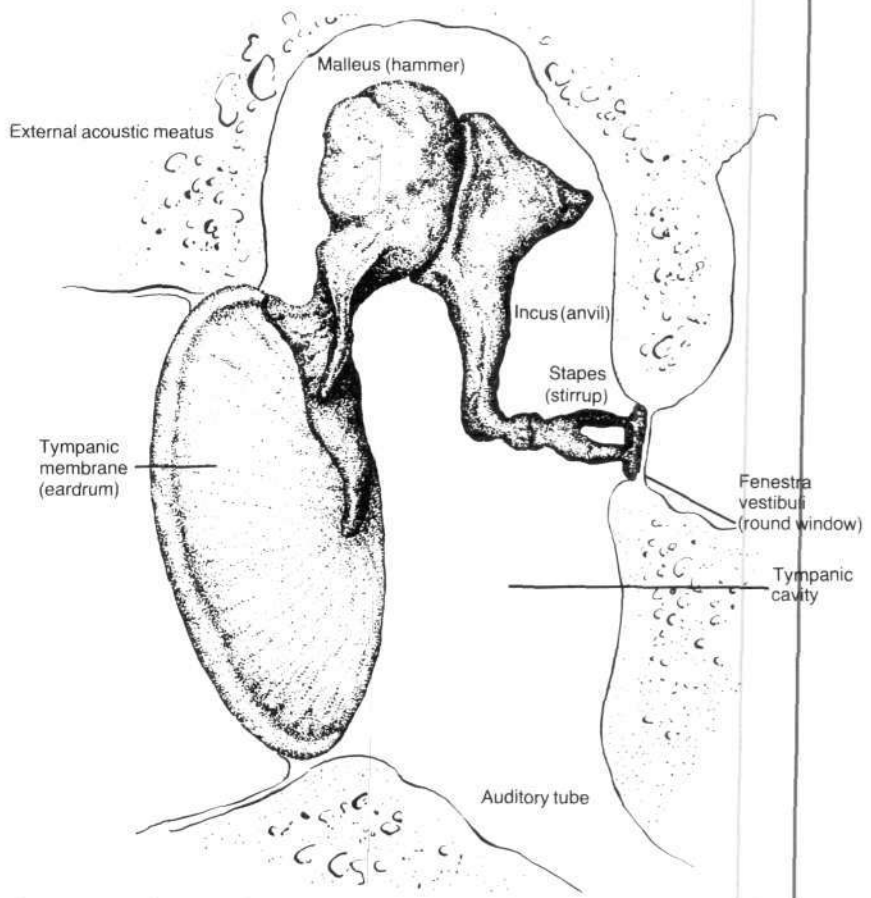
> The Law of Causation . . . is a mere hypothesis and not otherwise demonstrable. No previous uniformity can give proof of future uniformity . . . [but] without the Law of Causation there can be no thought. . . . Are we justified in thinking, and has our thought any meaning?[7]

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'

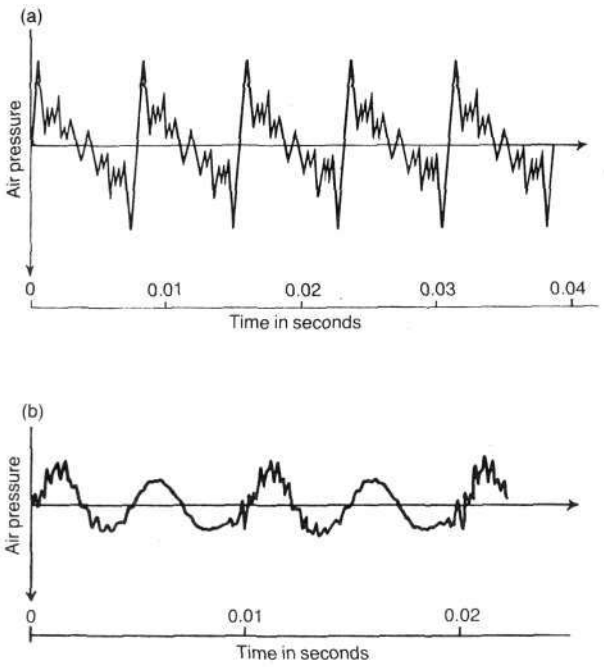


Figure 2
WHAT IS A 'TIMBRE CURVE'?

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.

Hèlmholtz 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. . . .

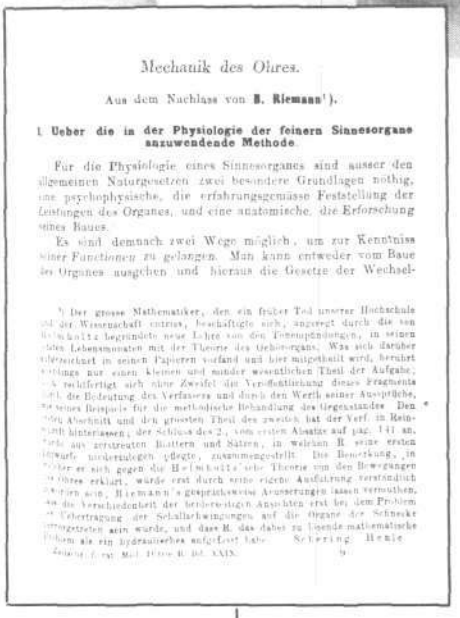
    "These results support the conclusion already reached from our earlier experiments that the ear's distortion is produced in the cochlea and not in the middle ear. We can now carry this statement further and say that the distortion is largely in the final sensory processes, or at any rate is not in such 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 vorgefunden in seinen Papieren vorfand und hier mitgetheilt wird, beraubt [illegible] nur einen kleinen und minder wesentlichen Theil der Aufgabe, [illegible] befriedigt sich ohne Zweifel die Veröffentlichung dieses Fragments [illegible] die Bedeutung des Verfassers und durch den Werth seiner Aussprüche, [illegible] seines Beispiels für die methodische Behandlung des Gegenstandes. Den [illegible] Abschnitt und den grossten Theil des zweiten hat der Verf. in Reinschrift hinterlassen; der Schluss des 2., vom ersten Absatze auf pag. 141 an, [illegible] aus zerstreuten Blättern und Skizzen, in welchen R. seine ersten [illegible] niedergelegen 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 werden 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 wurde, und dass R. das dabei zu lösende mathematische Problem als ein hydraulisches aufgefasst habe. Schering. Henle.

Gesamm. d. wiss. Math. Werke u. Wiss. Nachl. 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.

* * *

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-

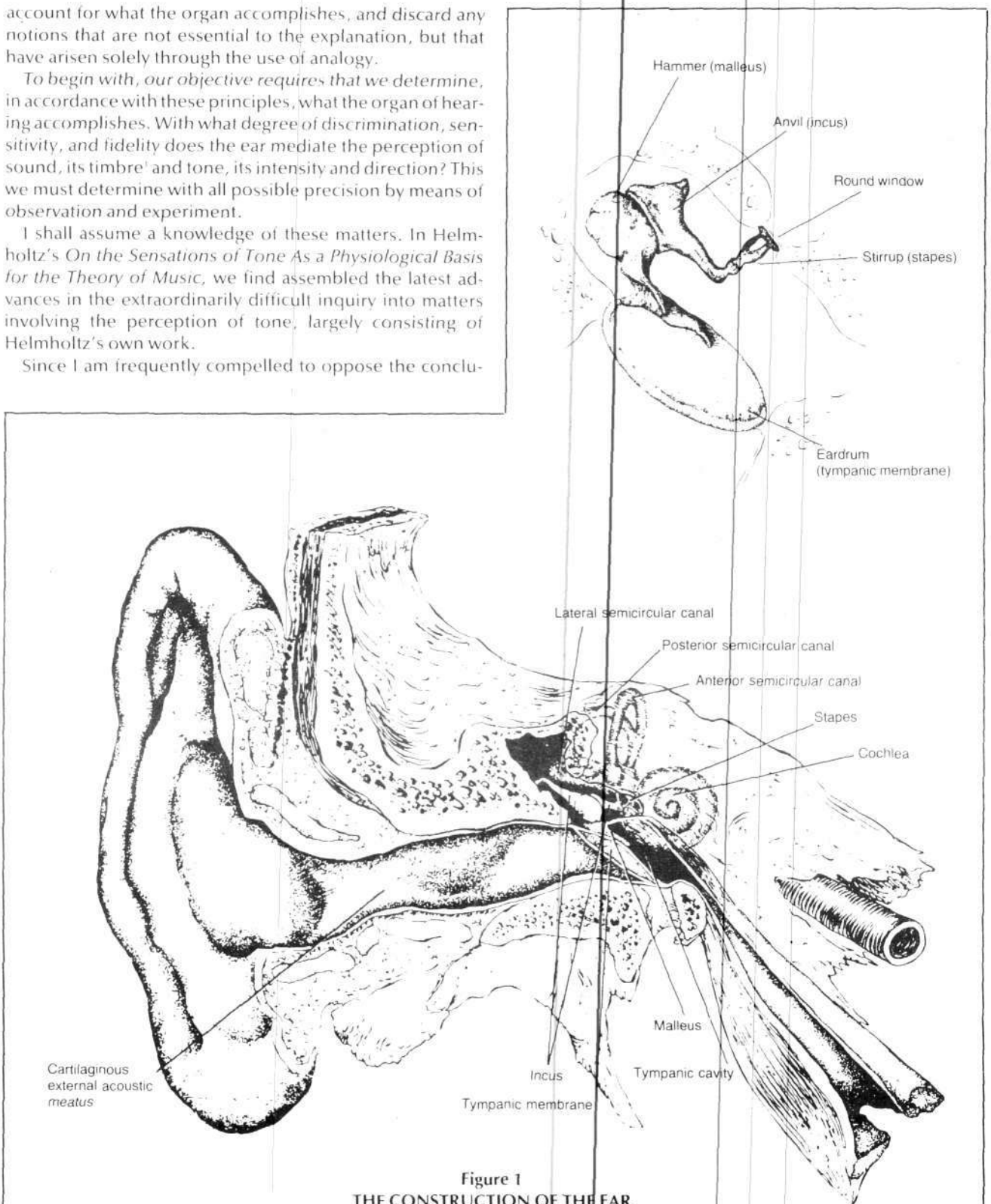


Figure 1
THE CONSTRUCTION OF THE EAR

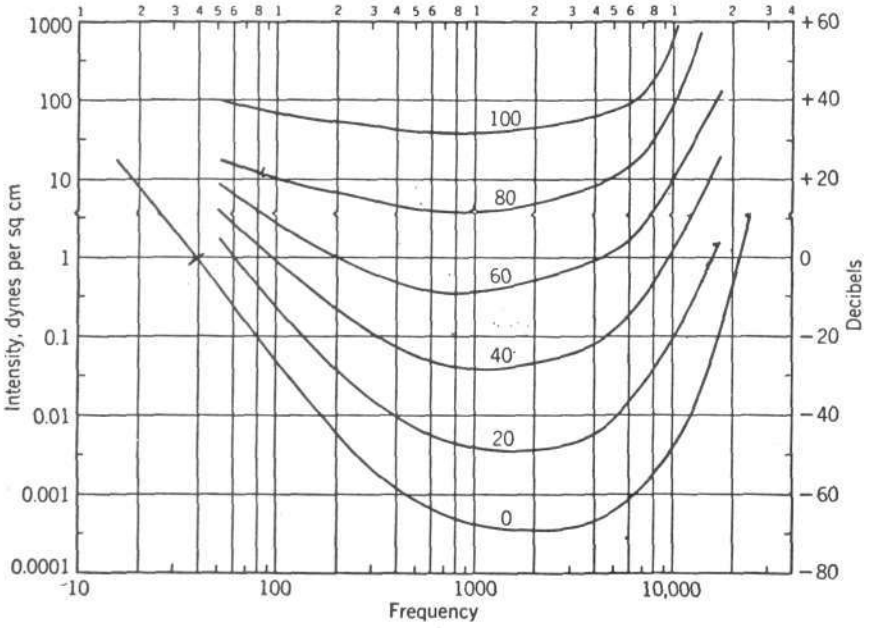
Shown is a section through the outer ear, the external auditory meatus, and the middle ear and cochlea. The inset shows the detailed construction of the hydraulic system of the middle ear—the eardrum, auditory ossicles, and the vestibular window.

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.

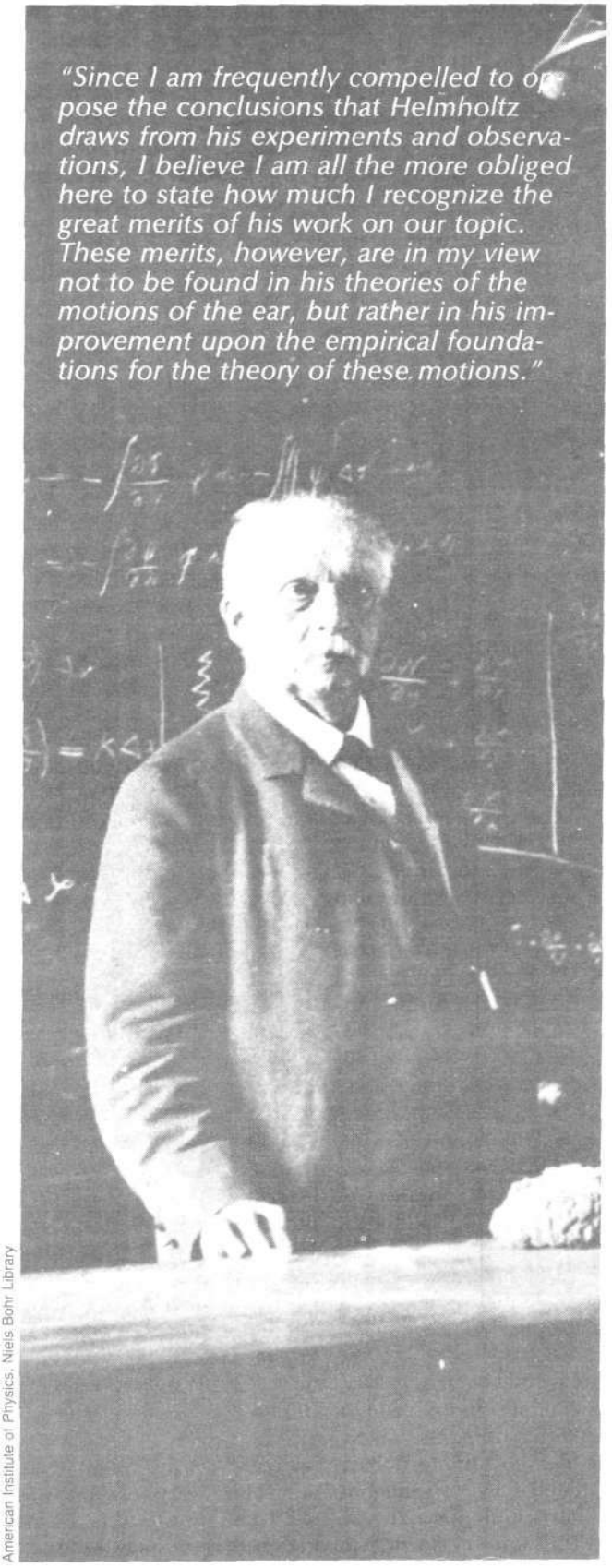
If, analogously, we divide sounds—from familiar intensity down to those barely perceptible—into eight magnitudes, then the mechanical force of a sound of the second magnitude would be about $\frac{1}{10}$, the third $\frac{1}{100}$, . . ., the eighth $\frac{1}{10,000,000}$—one ten-millionth the intensity 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 $1:\frac{1}{10}:\frac{1}{100}:\frac{1}{1,000}$. 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,

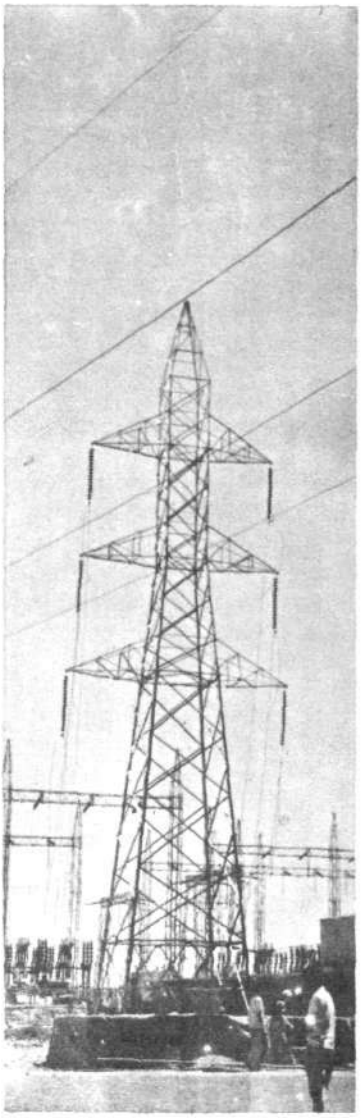
(2) or in the effect of the posterior fold of the eardrum,

(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.

PROGRESS IN POWER SECTOR IN ANDHRA PRADESH
1956-1983
GROWTH IN 27 YEARS



POWER GENERATION TWENTY NINE FOLD INCREASE	**INDEX OF DEVELOPMENT** *FROM 100 MW TO 2901 MW*
POWER LINES TWENTY SIX FOLD INCREASE	**ARTERIES FOR CURRENT FLOW** *FROM 9120 KM TO 2,40,000 KM*
CONSUMERS TWENTY ONE FOLD INCREASE	**WHOM ELECTRICITY SERVES** *FROM 1.5 LAKHS TO 31.65 LAKHS*
PUMPSETS ONE HUNDRED THIRTY TWO FOLD INCREASE	**FOR FOOD PRODUCTION** *FROM 4300 TO 5.67 LAKHS*
INDUSTRIAL SERVICES THIRTY THREE FOLD INCREASE	**FOR INCREASED EMPLOYMENT** *FROM 2000 TO 66,700*
ELECTRIFIED VILLAGES THIRTY THREE FOLD INCREASE	**CONTRIBUTION TO RURAL DEVELOPMENT** FROM 630 TO 21,066
PER CAPITA CONSUMPTION NINETEEN FOLD INCREASE	**AN INDEX OF PROSPERITY** *FROM 7 UNITS TO 133 UNITS*
HARIJANS & GIRIJANS	*ON THE PATH OF PROGRESS* *HARIJANWADAS IN OVER 90% OF THE ELECTRIFIED VILLAGES.* *1523 TRIBAL VILLAGES ELECTRIFIED.* *36,865 WEAKER SECTION HOUSES GIVEN ONE LIGHT IN EACH HOUSE.*

ANDHRA PRADESH STATE ELECTRICITY BOARD

International Conference Puts the Kra Canal Back on the Agenda

On October 31, 1984 more than 200 businessmen, engineers, government officials and representatives from nearly all the ASEAN nations, India, Japan and the United States gathered in Bangkok for two days of deliberation on the feasibility and desirability of building a canal through the Kra Isthmus of Thailand. Sponsored by the Ministry of Communications of Thailand, the Fusion Energy Foundation of New York, and the **Executive Intelligence Review**, the meeting was a landmark in the effort to revive the Kra project for implementation by the Thai government.

Titled "The Kra Canal and the Industrialization of Thailand," the conference's four panels covered all aspects of the project, from economic, technical and financial feasibility to its implications for the economy and security of Thailand and the other countries of the region. For the first time a detailed discussion of the national economic potentials that would be unleashed within Thailand with the Kra project's adoption took place, and the interdependence of security and economic development was addressed directly. In the final panel speakers from the region focussed support for a positive decision by the Thai government for the project.

"The final impact will not only be beneficial for Thailand but also for the region as well as any other country that uses it, "Thai Minister of Communications Samak Sundaravej stated in his inaugural address. "We should, therefore, dedicate it to the world." Indeed, as was brought out during the course of the conference, the Kra Canal is more than just a waterway. It is the shortest route to industrialization, both for Thailand and the region. As the hub for new trade, new industry, a new superport, and new cities, the Kra Canal will be an engine for development in the entire region. For Japan and South Korea, the canal will reduce the time required for vital transport of raw materials and oil for industry. For India, the canal the Kra project has a potentially dynamic and beneficial effect on the industries and ports of the eastern coastal areas.

"The question is can we do it, how and which way?" Minister Samak said. He stressed that the conference speakers were providing the detailed information necessary for the Thai government to take the first step in scheduling the project for a cabinet session. In addition to representatives of ten top Japanese corporations and banks, South Korean construction companies, and diplomats from Southeast Asia, Japan, and the Soviet Union, the Thai government, as well as the military and business community, was well represented at the conference. Delegates were present from the ministries of foreign affairs, industry, communications and the Prime Minister's office. In a press conference following his opening remarks, Minister Samak stated that his ministry, which has jurisdiction for projects like the Kra, would study the "feasibility report" contained in the conference proceedings, and would then compile its own report.

Economic and Technical Feasibility

The project's economic and financial feasibility was the subject of detailed discussion in the first panel. An economic feasibility study was presented by the Fusion Energy Foundation's Director of Research, Dr. Uwe Henke von Parpart (see page 00). Parpart was joined in this discussion by Dr. Nimit Nontapunthawat, the Vice President and chief economist of the Bangkok Bank, who put forward a financing plan for the canal project. At an executive "working session" on the Kra proposal in Bangkok in March, Dr. Nimit had argued that the project need not jeopardize Thailand's foreign exchange or balance of payments position. The financing plan he presented on October 31 is based on establishment of a Thai currency fund during the construction phase of the project. Foreign and other contractors will hold accounts in the fund for use against future freight tolls.

The discussion of advanced technologies for canal construction was led by Dr. Milo Nordyke of Lawrence Livermore National Laboratory in the United States and Mr. Harry Ekizian of the Tippets-Abbett-McCarthy-Stratton (TAMS) engineering consulting firm. Both Lawrence Livermore and TAMS were involved in the feasibility study for the canal that was conducted in 1973-74. While Mr. Ekizian showed that advances in the efficiency and scale of construction technology would offset the effect of inflation in an updated cost estimate for the canal's construction, Dr. Nordyke sparked a full discussion of the option of using nuclear construction technologies.

NSIPS

An international mandate was delivered for the Kra Canal. From left, Pakdee Tanapura, Zainuddin Bahari of Malaysia, Dr. Norio Yamamoto of Japan, Panel Chairman Dr. Svasti Srisukh of Thailand, General Saiyud Kerdphol of Thailand, speaking, K.L. Dalal of India, and H. Roeslan Abdulgani of Indonesia.

Nordyke reviewed the highlights of Livermore's 1974 study proving the feasibility of using so-called peaceful nuclear explosions (PNEs) to dig the canal, noting the fact that this option would cut construction costs and time by nearly one-half. Participants found the frank and open discussion of PNEs refreshing, although it was emphasized that while the advantages are straightforward the project remains perfectly viable with conventional technologies.

What the Canal Zone might look like, what economic growth prospects it might spur and what its development will mean for other countries was the subject of a series of contributions under the panel caption, "High Technology Industrial Development in the Canal Zone." Representatives of the Thai Office of Atomic Energy for Peace described how the energy requirement for canal zone industrialization could be met by the country's as-yet-untapped nuclear power capability. **Fusion Asia** editor Ramtanu Maitra supplemented this with a discussion of the use of nuclear energy for integrated industrialization—the "nuplex" concept.

A paper was submitted on how to make Songkhla into an "Asiaport," and Mr. Douglas Headley, an American power engineer who has lived and worked in Asia for more than 15 years, discussed some practical aspects of technology transfer in industrialization. Dr. R.K. Hazari, an economist and consultant from India, described the positive impact the Kra project could have on India's economy, especially in the area of trade and as an impetus to revitalization of the heavy engineering capacities of West Bengal and the ports all along the coast, including interesting potentials for the strategic Andaman-Nicobar Islands.

Within Thailand the canal project has sparked the imagination of a number of the country's political leaders. Panelist Pongpol Adireksarn of the Chat Thai Party, the sole opposition party in the country, pointed out that with the Kra Canal and the industrial zone in the south Thailand could become a consolidation point for maritime traffic in the region. Thailand could also emerge as one of the top exporters of canned food, he said, noting that Thailand already ranks seventh in the world in fishing. "We have to create jobs for our children and grandchildren," Pongpol said, and "develop the population in the provinces into a productive labor force." Thailand is luckier than many of its neighbours, Pongpol pointed out, in that the country has no "national disasters" and no significant religious or ethnic problems. "The obstacles to our progress are ourselves," he said.

Development and Security

The deeper significance of these potentials was brought out in the final panel, "The Kra Canal and Its Implications for Asia," where the relationship between economic development and security was brought to the fore. General Saiyud Kerdphol, former Supreme Commander of the Thai Armed Forces, argued that development of the Kra Isthmus is the key to solving the security problems in southern Thailand where fundamentalist guerrillas have been active. "Development and security must go hand in hand as a coordinated effort. We must recognize that economic, political and social development all contribute to security—but that security, in itself, is not development," Saiyud stated, insisting that the southern development plan be treated as a national priority.

Security is important as a factor to development because it permits development to take place he continued, but "from my own experience, I can assure you that

when the country is under the threat of armed insurgency—whether it be communist or non-communist inspired—it becomes exceedingly difficult to convince the authorities that they should attack the problems through a combined formula of development and security. The temptation is to use all available military power to overwhelm the insurgents without realizing that the insurgents, themselves represent only the symptom of a number of complex economic, political and social problems.

This theme was echoed by Dr. H. Roeslan Abdulgani, Chairman of the Advisory Team to President Suharto of Indonesia on the State Ideology, *Pancasila,* in remarks describing Indonesia's efforts to bring areas of this far-flung island nation into the national mainstream. Economic development projects proved critical in this, Abdulgani said, adding that real gains for stability anywhere in Southeast Asia was a benefit to the whole region. Mr. Zainuddin Bahari of the Malaysian Institute of Strategic and International Studies heartily endorsed the canal project along the same lines. Malaysia shares the fundamentalist, guerrilla trouble along its border with Thailand and would welcome joint development of the area and its resources.

In a contributed paper on the pivotal role of Thailand in the development of Southeast Asia, *Executive Intelligence Review* founder and economist Lyndon H. LaRouche emphasized the cultural aspects of this equation. "In a period such as the present period, in which the major danger to continued existence of developing nations comes from various kinds of separatist insurgencies, there can be no effective national security unless the nation has strong internal defenses against the spread of those kinds of cultural and religious movements which organize these insurgencies," he said. "The long-term line of national defense against foreign-steered separatist insurgencies must be the strengthening of a sense of national consciousness and of common national culture among the various regions and strata of the population."

Panelist K.L. Dalal, former Ambassador of India to Thailand, drew on the precedents in Thai history, such as the flourishing Sukhothai period that oversaw the development of irrigation projects, and the cultural tradition behind them, in motivating the "act of faith" such grand nation-building projects as the Kra require. "If Hanuman in the Ramakien epic could move mountains, why can't we, with today s modern technology, do the same?" Dalal remarked. It is such visionary, multiply useful projects, moreover, he argued, which are necessary to sustain and develop the national culture that is the nation's glue.

Dr. Norio Yamamoto, an official of the Mitsubishi Research Institute, placed such nation-building efforts in the context of the Institute's proposal for a "Global Infrastructure Fund" (GIF), to promote a series of large infrastructure projects in the developing countries to foster a revival of the world economy. Yamamoto charted the history of this proposal, which has been under consideration by many heads of state. The Kra figures prominently in the proposal.

Time of Decision

The main themes developed in two days of deliberation were refocussed in a concluding presentation by Fusion Energy Foundation Bangkok representative Mr. Pakdee Tanapura. Tanapura zeroed in on the challenge and opportunity facing Thailand at this time. He presented the conclusions of a study conducted by an FEF team (see page 00) demonstrating that the Thai economy is running up against mounting structural difficulties which only a bold thrust toward industrialization can remedy. In this light it is essential to recognize that the Kra Canal project is not merely a canal, he insisted. It is a commitment to nation-building that will set into motion the needed process of positive transformation of the economy.

By all accounts the arguments marshalled from virtually every standpoint for the Kra project are compelling. Yet it is not for the first time that the Thai government has been faced with taking a decision on the project. It was first envisioned several hundred years ago by King Rama I. Obstacles repeatedly got in the way, including in the recent period, as Minister Samak told the press, the British insisting they be given veto power over any such canal project as a condition of settlement following World War II. During the 1970s the project came under fresh consideration, and in 1973-74 a feasibility study was comple-

Pakdee Tanapura, second from right, introduces Communications Minister Samak Sundaravej, right, to, from left, Indonesian Ambassador Air Marshal Soebambang, Philippines Ambassador Lt. Gen. Ileto, and Dr. Uwe Henke von Parpart.

ted. But a government decision to proceed was tabled when the oil shock knocked down world trade and the government of Thanom Kittikachorn was overthrown following a "student uprising." The Thanom government had agreed in principle that the canal should be built.

During the late 1970s the Kra Canal idea was picked up again, this time by Japan's Mitsubishi Research Institute, and incorporated into the Institute's GIF proposal. While the GIF and the Kra Canal in particular was discussed by Japanese Prime Minister Nakasone and President Reagan at the 1983 Williamsburg summit of developed nations, it was not until the fall that the Kra project was given a substantial new impetus. Following a tour of Asia, including visits to India, Thailand and Japan, EIR founder Lyndon LaRouche became convinced of the necessity for a long-term strategy of development of Asia which viewed the Indian and Pacific Ocean basins as an integral unit, and which was based on a series of large multinational infrastructure projects in the region. The Kra Canal project emerged as the cornerstone of the 50-year perspective outlined by LaRouche in a book-length policy proposal that was the basis of a series of conferences in the USA and elsewhere.

One year ago, in October 1983, the Thai Communications Ministry, the FEF and EIR formally launched the debate on the Kra Canal anew with a similar though smaller conference in Bangkok. The debate has been building steadily since, involving every relevant force in the Thai political scene. The Thai press as well as the Asian trade press has actively mediated the discussion, which has reverberated in such internationally prominent locations as the Financial Times of London. A March 1984 seminar of businessmen, builders and trade executives in Bangkok brought an endorsement of the projects's financial feasibility from Thai business leaders. With the recent, international conference the project was given a loud and clear regional mandate—Singapore being the only conscientious objector.

Whether the Thai government can muster the courage and vision to see the project into implementation this time will largely determine Thailand's fate and the fate of the region as we enter the 21st century. If the attitude of Communications Minister Samak, the point man for the project in Thailand, is any indication the answer will be positive. "When I got into office two years ago, people asked me if there is any possibility of the Thai government actually implementing this project," Samak told the *Yomiuri Shimbun* recently. "Some said the project is so huge; others said that it was impossible. Here is what I always replied: 'Is it possible to do this project? If it is, then go right ahead. See to it. But if it is impossible, then why ask this question?'

—Susan Maitra

In the following pages we reprint the texts of two addresses to the conference, "The Kra Canal and the Industrialization of Thailand." The reports, delivered by Uwe Henke von Parpart and Pakdee Tanapura are based on the work of a Fusion Energy Foundation research team led by Sylvia Brewda and Peter Rush.

The impact of the Kra Canal project on the growth of Thailand's economy

by Pakdee Tanapura

Historically, the successful industrialization of what are now advanced-sector economies has without exception been based on the execution of large-scale infrastructure projects. Appropriate infrastructure creates the opportunity and first impulse for industrial development and is a decisive productivity-producing economic factor. Two examples are the internal waterways and railroad projects in the United States and Germany, without which the successful development of these countries would have been unthinkable. And it was the so-called spin-offs from these infrastructure projects and their driving force which propelled the U.S. and German economies into leading positions by the end of the 19th century. More recently, the "spin-off" effect of such "non-productive" large-scale ventures as the U.S. "Apollo Project" has allowed American technology and industry to maintain their leading role.

When considering the desirability and the need for a project of the very large dimensions of the Kra Canal, it is insufficient or even misleading to proceed only from the indispensable but relatively narrow "accounting perspective" developed in a typical economic feasibility study. The impact of the project on the development of the national economy of Thailand and on relevant regional Asian economies, as well as broader strategic considerations, must be taken into account. We confine our attention here to the Thai economy, adding a few brief remarks on broader issues.

The Outlines of the Crisis

A recent study of the Thai economy by the Fusion Energy Foundation (FEF) produced the following conclusions: Over the past 20 years the Thai economy has realized impressive growth rates averaging 7.8% in GNP terms per annum. However, unlike the cases of the economies of Korea, Taiwan, or Singapore, this growth effected disappointingly small structural changes. The unfavorable, essentially colonial-style structure of production and export of agricultural commodities and raw materials in exchange for manufactured goods remained largely unaffected. Long-standing demographic imbalances—singular population concentration in Bangkok, in particular—have been exacerbated rather than alleviated. In the current depressed world economic conjuncture, the critical vulnerability of the deficient structure of the Thai economy manifests itself in stagnation, pressure on the national currency, and crisis of financial institutions.

The current stagnation, however, is due not only to external factors; it is a powerful signal that economic growth within the existing structural framework has run its course. Resumption of reliably sustained economic expansion will be possible only as the result of concerted public and private efforts to effect fundamental structural change through combined infrastructure, basic industry, and high-quality manpower development. Modernization of agriculture and decentralization (creation of new population centers and centers of economic activity) must be principal included features and goals of such efforts.

Contrary to physiocratic notions widespread, in particular, in International Monetary Fund and World Bank circles, the history of successful industrial capitalist development in Western Europe, North America, and Japan demonstrates that it is not the resource base that determines the wealth of a nation, but rather the quality, development, and distribution of the manpower and labor force. Consequently even a first rough-cut analysis of the past performance, present level of development, and future growth potential of a nation's economy must proceed from labor-force analysis rather than from analytically questionable and unreliable GNP-type measures.

A look at the historical evolution of the distribution of the Thai labor force over principal categories of economic activity yields the picture shown in **Table 1.**

The 33 years of economic development have produced only a relatively minor shift from agricultural into industrial employment. This picture is further dimmed by the

Table 1

Thai labor force by category of occupation

(percentage of total)

	Agriculture	Industry	Services
1947	85	3	12
1960	84	4	12
1965	82	5	13
1970	80	6	14
1975	78	7.5	14.5
1980	76	9	15

Sources: 1947 Census: *World Tables* 3rd Edition (World Bank).

fact that in 1981 the capital goods (machinery and transport equipment) and industrial chemicals sectors critical for successful independent economic development jointly accounted for only 18% of total industrial output. A comparison with the Korean (ROK) economy will be instructive.

Current Structural Deficiencies

Table 2 shows a 32% shift out of agricultural into primarily industrial employment, compared to only a 9% shift of the Thai economy in the same time span. Moreover, the Korean industrial production structure is more healthy and self-reliant, capital goods and chemicals production accounting for 29% of value-added output, compared to Thailand's 18%. Five additional crucial comparative level-of-development indicators—degree of modernization of agriculture, level and rate of urbanization, per capita energy production and consumption, export/import structure, and level of scientific and engineering manpower—were employed in the FEF study of the Thai economy. These indicators, along with the already mentioned labor force and industrial structure indicators, have been found by FEF study teams to provide a consistently highly reliable measure of degree of development and growth potential for a wide range of developing sector economies in Latin America and Asia analyzed during the past several years. Let us now look at each of the five additional indicators in turn.

Fertilizer consumption, an accurate measure of degree of modernization of agriculture, has doubled in Thailand during the last decade (**Table 3**). Still, by modern agricultural standards, it remains extremely low. Progress in this area would easily allow Thailand to triple rice production on the same amount of land presently under cultivation.

Despite some economists' recent claims about a "decoupling" of energy and economic growth, if growth is measured in productive output (agriculture, industry, mining) rather than misleading GNP terms, then there is no question not only of a close correlation, but indeed a causal connection between energy and economic growth.

Table 2

Korean labor force by category of occupation

(percentage of total)

	Agriculture	Industry	Services
1960	66	9	25
1965	58.5	12.5	29
1970	50	17	33
1975	42	22.5	35.5
1980	34	29	37

Source: ***World Tables*** 3rd Edition (World Bank)

In addition, and perhaps even more importantly, there is a direct causal link between per capita energy consumption and the productivity of agricultural and industrial labor. This holds in particular for the highest quality and most versatile energy form—electricity. It is clear from **Tables 4 and 5** *that Thailand in the past two decades has made significant progress in this regard. Still, the absolute values*

Table 3

How much has Thai agriculture modernized?

		Fertilizer consumption (kg/ha of arable land)	Rice yield (kg/ha)
Thailand	1970	7.6	
	1981	17.7	1,952
Korea	1970	246.6	
	1981	351.3	5,841

Source: ***World Tables*** 3rd Edition (World Bank)

remain quite low and a most ominous sign is the fact that the energy-consumption growth rate since 1975 has dropped to less than half of what it was between 1960 and

Table 4

Progress made in commercial energy consumption

(kg of coal equivalent)

		Total	Per cap.	Per Km²	Growth rate Total	Growth rate Per cap.
Thailand	1960	$1,703 \times 10^6$	63	3,314	12.3%	9.3%
	1980	$17,371 \times 10^6$	370	33,781		
Korea	1960	$5,202 \times 10^6$	208	52,832	13%	10.6%
	1980	$59,703 \times 10^6$	1,563	606,288		

Source: ***World Tables*** 3rd Edition (World Bank).

Table 5

Electricity production: a decade of growth

(millions of KWh)

		Total	Growth rate
Thailand	1969	3,728	14.5%
	1978	12,644	
Korea	1969	8,150	16.2%
	1978	31,510	

Source: ***Statistical Yearbook Asia/Pacific,*** ESCAP 1979

Table 6

Value added reflects energy consumption

(U.S. dollars)

	Total	Total per cap.	Agric. per cap.	Industry per cap.	Total/Km²
Thailand					
1979	27.24 bn	594	157	117	53,000
Korea					
1979	60.66 bn	1,613	328	430	594,000

Table 7

Pace of urbanization is slow

	Urban population (% of total)		Average annual growth rate (%)
Thailand			
1960	13	1960-70	3.6
1982	17	1970-82	4.3
Korea			
1960	28	1960-70	6.5
1982	61	1970-82	5.0

Source: ***World Development Report 1984,*** World Bank

1975. Highly desirable productivity gains in agriculture, for example, will not be possible unless this recent trend is reversed, since the necessary production inputs (fertilizers, etc.) are based on highly energy-intensive production processes.

Table 6, comparing value added for Thailand and Korea, is interpolated at this point to verify the point made above, i.e., that there exists a close correlation between per capita energy consumption and average productivity. For a tightly fitting correlation, energy consumption for transport and infrastructure would have to be taken into account. Still, the general point can be readily understood by comparing the 4:1 per capita energy consumption ratio to the most relevant 3.6:1 per capita value added ratio in manufacture. The figures for energy flux per area and value added per area also demonstrate a direct scaling of the two quantities.

The relatively slow growth of Thai industry relative to agriculture is not surprisingly mirrored by an equally slow pace for urbanization and by the fact that in Thailand there has been virtually no diversification of urban structure and almost the entire urban growth has been in the already overloaded Bangkok area (**Table 7**). There exists an obvious and urgent need for decentralization of urban development.

Indicated in **Table 8** is one of the weakest and most dangerously inadequate features of Thailand's development. Indigenously, the country is even now producing few—if any—Ph.D.s in natural science, but instead has an overabundance of lawyers and social scientists. Without drastic immediate changes in this regard, there is simply no way for Thailand to build a modern, self-reliant nation as it behooves the 12th largest country in the world in population terms to do.

Table 8

Scientists and technicians

(1975 figures)

	Total	Scientists & engineers	Sci. & eng. in research	Nat. sci. in research	Soc. sci. in research
Thailand	67,632	20,288	6,097	547	3,209
Korea	1,449,372	460,037	6,314	1,652	568

Source: ***Statistical Yearbook Asia/Pacific,*** ESCAP 1979

We conclude with **Tables 9 and 10,** because in a sense they summarize the more detailed account provided so far. The export structure in particular tells the story. In 1960, 98% of Thailand's exports were in agricultural goods and raw materials. By 1981, this figure had been reduced to 73%—only a very modest change in fundamental structural terms. In the same time span, Korea, on the other hand, went from 86% in agricultural and raw materials exports down to 10%, a structure comparable to most average advanced-sector nations. The challenge for Thailand is obvious.

As already mentioned above, it is the firm conclusion of this writer and the FEF study team that the Thai economy

Table 9

Export structure

(% of total exports)

	Fuels, minerals, metals	Other primary commodities	Textiles	Machinery	Other mfrs.
Thailand					
1960	7	91	NA	0	2
1981	8	65	10	5	12
Korea					
1960	30	56	8	NA	6
1981	2	8	30	22	38

Source: ***World Development Report 1984,*** World Bank

Table 10

Import structure

(% of total imports)

	Food	Fuels	Other primary commodities	Machinery	Other mfrs.
Thailand					
1960	10	11	11	25	43
1981	4	30	8	26	32
Korea					
1960	10	7	25	12	46
1981	12	30	15	23	20

Source: ***World Development Report,*** 1984 World Bank

Table 11

Labor force of Peru by category of occupation

(% of total)

	Agriculture	Industry	Services
1960	53	19	28
1980	40	18	42

has come to a watershed point. Resumption of vigorous growth in the existing structural framework will not be possible. Any attempt to do so will fail—with serious social and political consequences. The point can be made more precise by reference to the evolution (or devolution) of some of the Latin American economies. We choose the example of Peru, because the FEF recently conducted a detailed study of the Peruvian economy, under contract from the National Society of Industry (SNI) of Lima.

In 1960, the Peruvian economy, while starting with different absolute values, exhibited a broadly similar "colonial-style" structure to Thailand, with regard to labor force distribution and export/import structure. In the subsequent two decades, labor force distribution evolved as shown in **Table 11.**

The desirable 13% shift out of agricultural employment, rather than going into industry, went entirely into the tertiary (non-productive) service sector. To put it caustically, the economy made the transition from pre-industrial to post-industrial society without the intervening complication of industrialization. The watershed point toward modern industrial development (as in the case of Korea) had been reached by the late sixties, but the wrong economic policy choices (strongly influenced by foreign intervention) instead led to the present almost entirely bleak situation. It is urgent that Thailand avoid traveling down that same road. But the proper economic policy signals implied by the foregoing comparative analysis must be set now. New strategic economic policy impulses aimed at basic structural change rather than tactical measures within the existing framework are required.

The Role of the Kra Canal

These concluding remarks are intended as a brief outline of the Kra Canal's possible impact on the Thai economy, in light of the preceding analysis.

Our evaluation of the canal's impact on the Thai economy proceeds from two points of principle:

1) Successful industrialization, as noted above, has never occurred without the execution of large-scale infrastructure development projects.

2) A look at the world map—in particular a Pacific-centered projection—demonstrates the decisive strategic location of Thailand, and should therefore put to rest the controversy over the competing ambitions of Singapore. Why should a large nation of 50 million people (and 70 to 80 million by the end of this century) abrogate its potential role and economic opportunities in favor of the miniscule city-state (2.5 million inhabitants) of Singapore?

We will concentrate on drawing out the implications of the first point:

- While Korea—for lack of opportunity—engaged in no infrastructure project comparable to the scale of the Kra Canal, total infrastructure spending (energy, transport, urban development) between 1960 and 1975 was massive, being to a large extent responsible for Korea's present indebtedness of close to $30 billion. However, the productivity-producing impact of such infrastructure spending was such that between 1970 and 1982, Korea's debt service as a percentage of exports of goods and services dropped from 19.4% to 13.1%.

In comparison, Thailand's total public external debt in 1982 was only $6 billion, but debt service as a percentage of exports increased from 3.4% in 1970 to 8.4% in 1982. Therein lies the obvious lesson that it is not the total amount of money you borrow that counts, but rather what you do with it. And there is a second point as well: Thailand, even under conservative estimates for its future export potential, is in the position to incur the additional indebtedness implied by the Kra Canal project if that project can be demonstrated to have the potential of

The economic feasibility and future benefits of the Kra Canal project

by Uwe Henke von Parpart

While the justification for building the Kra Canal goes beyond mere financial considerations, it is expected that the canal will more than pay for itself within 10-20 years of its completion under the more favorable options, or in up to 30 or 35 years under less favorable circumstances of total cost and higher interest charges. Compared to projects of comparable relative cost and magnitude during the past century, this payback period is quite modest, even if it is longer than the customary term of commercial bank loans today. The estimates of the financial feasibility of the canal are derived from three principal groups of parameters:

1) estimates of the excavation and construction costs;

2) estimates of the financing costs at various rates of interest;

3) estimates of the expected level of trade, and the level of canal revenues that can be generated from this trade.

Based on several alternative sets of estimates for different sized canals and different interest rates, financial breakeven conditions and dates were calculated. For this study, only direct canal revenues were included, even though revenues from the associated harbor and industrial projects will provide additional revenues applicable against amortization of the accumulated debt incurred in construction of the canal. The calculations show that for the more expensive options, the revenues in the first few years after construction will be below the interest charges on the debt. Therefore, we calculated both the point at which toll revenues "catch up" to interest payments, as well as the point at which the entire debt will be paid off.

The excavation and construction costs of the canal are taken from the "Preliminary Survey Report on the Kra Canal Complex" prepared in September 1973 by the Tippetts-Abbett-McCarthy-Stratton (TAMS) Consulting Engineers firm of New York and the Robert R. Nathan Associates, Inc. Consulting Economists firm of Washington, D.C., and including contributions by the Hudson Institute of Croton, New York and the Lawrence

---

reversing the present unfavorable trend in the country's debt-service ratio.

- We have demonstrated that canal passage revenues alone will, in a reasonable period of time, given the size of the project, offset construction and related financing costs. Any revenue flow to the Thai government from associated port and industrial development would be a net benefit. The sum total of such benefit is difficult to estimate but would almost certainly amount to several billions of dollars per annum within less than five years of project completion.
- While under construction, one conservative estimate is that the canal project would create between 3 and 5 million new and relatively high-skill jobs *directly* and up to 8 million new jobs proliferating through various branches of industry.
- The type of new jobs and industries created and stimulated by canal construction are precisely of the right kind to repair the above-analyzed structural deficiencies of the Thai economy. Stimulation will be primarily in the heavy-industry and machinery production sectors. The energy requirements of the canal zone will also at long last get the nuclear-energy industry in Thailand on its feet. Nuclear energy is certainly the most plausible answer to meeting the energy requirements in the canal zone and the southern region of Thailand in general.
- The canal zone with its port and industrial facilities will become one of the badly needed alternative development centers to the Bangkok region. Comparison figures from the Europort development of Rotterdam in the Netherlands, from the expansion of the ports of Yokohama, Kobe, and Singapore demonstrate that sizeable percentages of a country's total labor force will be attracted to port and industrial development associated with it.
- It would be most desirable to locate in the canal zone certain high-technology industries not presently installed in concentrated form anywhere in the world. We reference here Dr. Willard F. Libby's concept of a nuclear industrial zone ("Thailand's Kra Canal: Site for the World's First Nuclear Industrial Zone," Orbis, Spring 1975). Such a development should provide the necessary and desirable impetus for scientific manpower development in Thailand that is presently sorely lacking.

We conclude with a plea for no lawyers and social scientists in the canal zone, no anthropologists in particular! ■

Livermore Labs of Berkeley, California. The total construction costs of the canal in the TAMS study were put in 1984 constant dollars by, multiplying the mid-1973 costs by the rate of inflation indicated by the U.S. Bureau of Reclamation canal and channel construction index, and adjusting this to allow for inflation and breakthroughs in construction technology. The adjusted 1984 constant dollar costs for the canal, which will be built to accommodate ships with 500,000, 300,000 or 250,000 ton deadweight ton capacity are shown in **Table 1.**

Financing of the canal is expected to come from four principal sources: the so-called multilateral lending agencies such as the World Bank and the Asian Development Bank; the export-import banks of the developed countries whose firms will participate in the construction; the commercial banks; and interested governments, including the United States and Japan, and Thailand itself.

In terms of the multilateral banks, Thailand does not qualify for preferential loans that "fourth world" poorest countries do, and hence is subject to a strict quota, so it is not expected that more than a small proportion of the financing will come from this source. The primary government funding source is expected to be the respective export-import banks of the United States, Europe, Japan, and countries such as Korea which will extend loans at relatively favorable terms to finance all or most of the foreign exchange portion of construction contracts to firms of the respective countries. Based on whatever portion of the total construction costs these two classes of loans will cover, the commercial banks will be invited to finance the remainder of the costs. It is anticipated that the commercial bank portion will be 50% or less. However, as commercial bank loans today average in the seven-to-eight-year range, with occasional longer terms, the structure of the total financing package will establish the commercial loans as the first ones to be repaid, with the export-import and multilateral bank loans to be paid only afterward, as these loans can be made on a much longer-term basis.

Table 1

What different sizes of canals will cost to construct

Canal size (dwt)	Canal type (lanes)	Method of Construct.	Original Cost* (bn US$ 1973)	Cost** (bn US$ 1984)
500,000	2	convent.	11.12	22.48
	2	nuclear	6.22	12.57
	1	convent.	5.65	11.42
	1	nuclear	3.54	7.16
300,000	2	convent.	8.90***	17.99
	2	nuclear	4.80***	9.70
	1	convent.	4.55***	9.20
	1	nuclear	2.89***	5.84
250,000	2	convent.	8.35	16.88
	2	nuclear	4.45	9.00
	1	convent.	4.27	8.63
	1	nuclear	2.73	5.52

* From the TAMS study.
** The TAMS figures multiplied by 2.246 and .9
*** Interpolated from 250,000 and 500,000 ton canal costs.

Table 2

Asian trade volume has grown utilizing the Straits of Malacca,* 1970-1980

(million tons)

	1970	1980	Annual % Change
Eastbound trade:			
Total	263.9	342.5	2.6
Petroleum	217.5	284.5	2.7
Bulk cargo	40.5	50.6	2.2
General cargo	6.0	8.0	2.9
Westbound trade:			
Total	19.2	62.4	12.3
Bulk cargo	11.5	29.7	9.9
General cargo	7.7	31.7	15.1
Two-way trade:			
Total	283.0	403.9	3.6
Bulk cargo	52.1	80.4	4.4
General cargo	13.7	39.7	11.2

*The available figures utilized for this table showed trade to and from major seacoasts of the world which permitted a relatively accurate assessment of which trade must have utilized the Straits of Malacca. In the unfortunate absence of any direct figures on trade or ship traffic through the Straits, such indirect measures as the one used provide the only basis for estimating this traffic.

Source: *Maritime Transport Study, Commodity Trade (By Seal) Statistics,* 1970 and 1980. Statistical Papers, Series D. Statistical Office of the United Nations.

It is expected as well that the United States and Japan will wish to make a $1 billion contribution each to the Canal Authority, either as a straight grant or as an interest-free loan, not to be repaid until all other obligations are discharged. To Japan, the value of the canal will be immediate in economic terms; to the United States, it represents the strategic value of securing the long-term economic growth and stability of the Southeast Asian region and the optimal way of preventing Soviet subversion of the region. It is also possible that the Thai government will participate, up to the $1 billion level, perhaps in the form of 8-12 annual payments of $85 million to $125 million. Such participation may or may not be possible or desirable.

The financing of the canal project will employ a tiering process of loans, as is common practice with such development projects. The initial loans will not be disbursed all at once, but only as needed. Plus, the first years of the project, that is, the construction phase, will be concomitant with a grace period on both the principal and interest of the loans, in which period the interest will be

capitalized. Repayment of the principal plus the capitalized interest will start with the first year of the canal's operation, paid out of the tolls charged, net of operating expenses.

The prevailing interest rate is the dominant parameter affecting the overall cost and time of repayment of the total loan package. For purposes of this study, several different interest-rate levels were explored.

Trade Patterns and Projections

In order to project likely revenues realizable from operation of the canal, a picture of the recent past trade patterns through the Straits of Malacca was required, as a basis for projecting likely patterns in the future. An effort to measure this had been made by Robert Nathan Associates for the original study referred to above for the early 1970s, but trade patterns have changed so much that no simple scaling of their figures could be employed to update their results. In particular their figures for the petroleum trade were calculated before the 1973 oil crisis. On the other side, the growth of manufactured exports by Japan, Korea, and Taiwan has increased the general cargo trade way beyond the pre-1973 calculations.

Consequently, United Nations figures were used to compare volume (in tons) of cargo transported through the Straits in 1970 and 1980. The results appear in **Table 2.**

Since 1980, petroleum imports have actually fallen, while manufactured exports have continued to grow, although somewhat more slowly than previously. Our estimates, assuming a period of general economic recovery, project that total petroleum trade in 1985 would be 255 million tons, 200 million to Japan and 55 million tons to other importers. Bulk cargoes were estimated at 90 million tons, including 25 million tons of iron ore exported by India to Japan. General cargoes were assumed to have risen to 50 million tons.

We show these figures only from 2000 on because the canal itself would not be ready until the late 1990s or early 2000s. It was assumed that all petroleum and bulk cargoes will use the canal, as they will have no reason to prefer Singapore and the Straits, while 70% of the general cargo will prefer the canal, the remaining 30% using Singapore as their primary port of call. This 70% was increased by 1% yearly to 90% by 2020. This scenario envisions therefore a slower, but continued growth for Singapore, as well as a rapid growth through the canal.

Revenue Calculations

Calculations of expected revenues were based on the estimated cost savings to ships not having to use the Straits of Malacca. According to the figures in the TAMS study, the canal will save at least one full day of steaming time for ships now using the Straits of Malacca (two days for Bangkok, somewhat more than one day for Indochina). Average ship operating costs were converted to estimates of cost per day per ton carried, from which total revenues were figured using the tonnage figures in **Table 3**. It was also assumed that profit of 20% was also realizable.

Table 3

Trade through Kra Canal projected 2000-2020

(million tons)

	Petroleum		Bulk	General	
	To Japan	To Others	Commod	Cargo	Total
2000	360	200	135	144	839
2005	418	294	172	294	1,133
2010	499	432	220	428	1,579
2015	561	635	281	733	2,210
2020	651	934	359	1,250	3,194

Source: own elaboration: Japan's oil imports are assumed to rise at 3% per annum, and other countries' at 8%; bulk shipments through the Canal are expected to rise at rise at 5%, and general cargo shipments at 10%.

Seventy-five percent of the resulting cost plus profit saved/earned was assumed to be the toll chargeable by the canal.

During the 1970s, a series of serious accidents resulting in oil spills occurred in the Straits of Malacca. While subsequent safety measures have reduced the incidence of accidents, the growth of trade envisioned in this study is likely to bring congestion in the Straits to a serious level by 2000. At that point, it is expected that the larger tankers will be required to use the much longer route through the Straits of Sunda or Lombok. The Sunda Straits add at least one more day to the travel time through Malacca, and Lombok almost two. It was therefore assumed that for tankers, a savings of two days could be assumed as the basis for a toll structure.

The average price of several sizes and types of ships, as compiled by the U.S. Maritime Administration, was used to estimate the per ton costs of one day saved at sea, as presented in **Table 4.**

Table 4

Daily ship operating costs at sea, 1983

	Tonnage	Daily operating cost
Medium-sized tanker	85,000 dwt*	$25,727
Large-sized tanker	265,000 dwt	$49,751
Small bulk carrier	25,000 dwt	$12,482
Large bulk carrier	50,000 dwt	$21,726
Small containership	12,000 dwt	$15,296
Large containership	42,000 dwt	$32,990

*dead weight tons

Source: U.S. Maritime Administration, Office of Ship Operating Costs, memorandum on ship operating costs.

Revenues from the canal were calculated to be about $275 million in constant 1984 dollars in 1997, the earlier date the canal might open, $335 million in 2000, $461 million in 2005, $650 million in 2010, $1, 390 million in 2020 and $2, 730 million in 2030.

While only direct canal tolls were included in this study, it should be pointed out that other sources of revenue will augment the total funds countable against amortization requirements. The port to be developed at Songkhla, on the eastern terminus of the canal, which will not only provide all the obvious services of bunkering, ship repair, etc., and serve as a transshipment point for the entire region, but which will be the gateway to a major industrial complex, will generate revenues net of its own operating and amortization costs, the excess reverting to the Canal Authority. And the industrial complex itself will generate revenues, in the form of rents and leases for the land, which will also be paid to the Canal Authority.

A review of **Table 1** shows that the options considered fall into roughly five price ranges. The most expensive canal is the two-lane conventional 500,000 dwt capacity option, at over $20 billion. The next is the two-lane conventional 300,000 and 250,000 dwt option, about $4 billion cheaper in the $17-18 billion range. Third is the 500,000 dwt two-lane nuclear and one-lane conventional option, at round $12 billion. Fourth is the 300,000 and 250,000 dwt two-lane nuclear and one-lane conventional options, and the 500,000 dwt one-lane nuclear alternative, in the $7-10 billion range, and the cheapest are the 300,000 and 250,000 dwt one-lane nuclear construction options which cost $5-6 billion.

The one-lane alternatives were not considered attractive because, while much smaller at present, the east to west general cargo trade is the most dynamic, and is expected to continue to be so for the indefinite future. Since a one-lane canal would necessarily go from west to east to accommodate the oil traffic, the added cost of the two-lane options would more than pay for itself over time by the added traffic of this east to west general cargo. Also, the original 500,000 dwt alternatives were considered by TAMS at a time when tankers in the 400,000-500,000 range were foreseen as the wave of the future. Now, only one in that range is still operating, and 300,000 tons is the effective limit. Therefore, the 500,000 dwt size now seems unnecessary, and therefore incurring the added costs will serve no revenue function. The 300,000 option was added to the TAMS options to ensure capturing all of the tanker traffic. The alternatives examined in some detail were therefore the two-lane alternatives in the two smaller sizes.

For the more expensive of these options, the conventional construction, a period of 30 years was calculated for "payback," that is, the date at which revenues would complete paying off the entire principal accumulated in construction and subsequent capitalization of other costs, at a 2.5% rate of interest, assuming 1984 constant dollars. It would take seven years for canal revenues to catch up to interest payments (that is, at a "breakeven" point at which total outstanding debt would stop rising). At 1.5% interest, the canal would "break even" immediately, and reach payback in 26-27 years. For the nuclear construction alternatives, "breakeven" is also reached immediately, but payback occurs in 23 years with 2.5% interest, and in 20 years with 1.5%.

Wider Benefits of the Canal

A report attached to the original TAMS study prepared by the late Dr. Willard Libby of the Lawrence Livermore Laboratory makes clear the benefits of building an industrial park in the zone on either side of the Kra Canal. At minimum, the region of the Kra Canal Zone should be provided the following facilities:

1) A major deep-water offshore harbor and port facility, most likely on the Pacific side at Songkhla, with the possibility for a second port on the Indian Ocean side sometime in the next century as needed;

2) Berthing, loading, unloading, repair, and transshipment facilities for all sized ships, including for the 300,000 dwt tankers and the new 50,000 to 100,000 ton container and bulk ships;

3) Protected "inner" harbors through use of dikes, breakwaters, reclaimed land for container ships, mixed cargo, barges, and specialized vessels;

4) Secondary, tertiary, and quaternary canals for industrial sites, i.e., a system of inland water systems breaking off from the primary canal to facilitate efficient interface of the industrial complexes with the ships passing to and through the canal;

5) Piping and pumping systems for crude petroleum and for petroleum products from ships to refinery and back for export, as well as from refinery north and south to Thailand and Malaysia, respectively;

6) Construction of a major oil refinery center on the model of Rotterdam and Singapore;

7) Large compartmentalized concrete reservoirs as an integral part of offshore facilities, serving possibly as the foundation for power plants, pumping stations, and a central location for all piping systems;

8) Nuclear-explosion-created deep underground storage cavities of from 1-5 million cubic meters for storage of petroleum, toxic effluents, and wastes from shore industries;

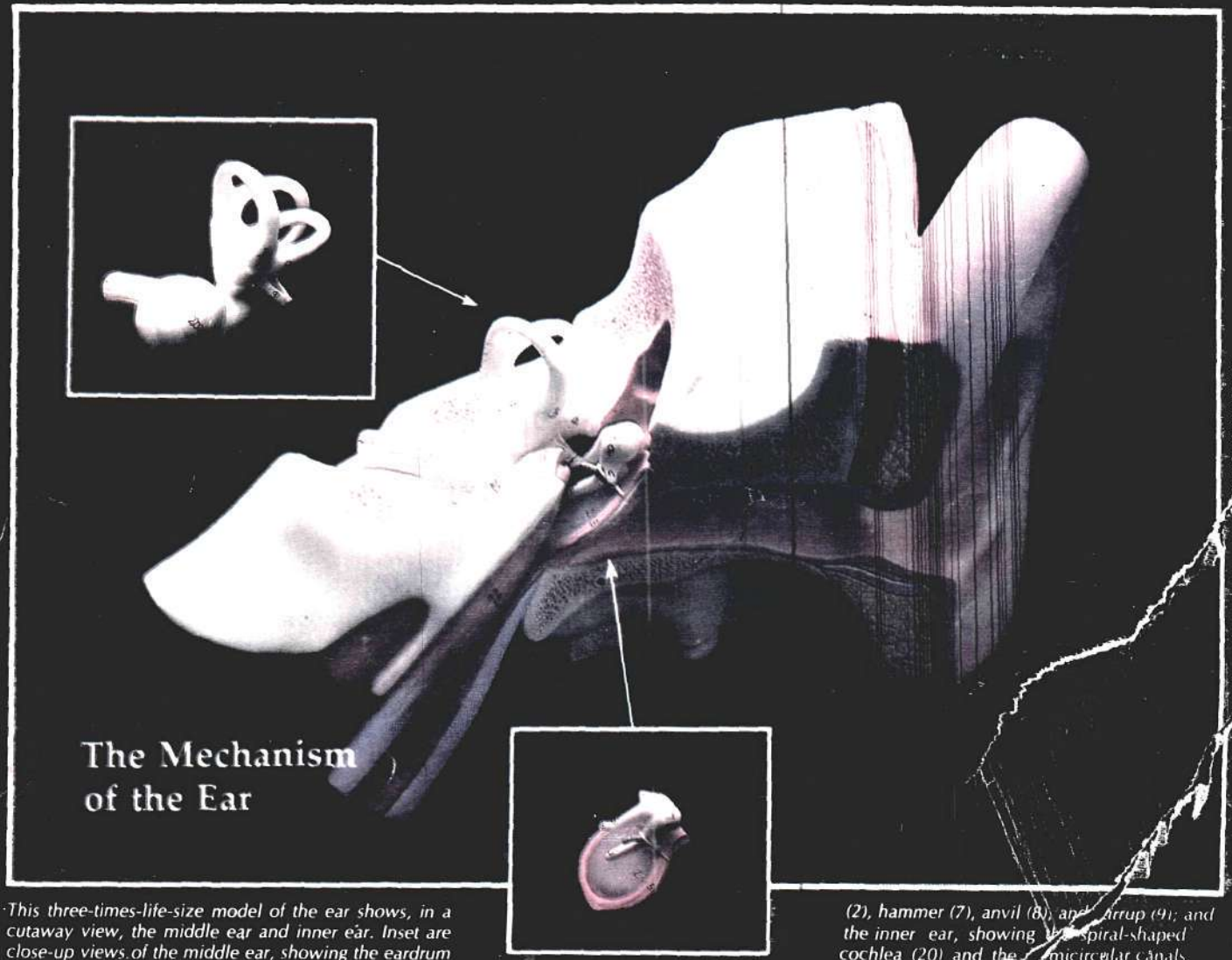
9) Large (1,000-megawatt-size) nuclear power facilities for pumping stations and to provide cheap industrial power to shore facilities. The nuclear power facilities could use the surrounding waters as a heat sink or coolant;

10) The development of heavy industries such as steel and other metals, to utilize the cost benefits of cheap water transport of the large bulk cargoes to and from the factories;

11) An industrial park, including food processing, metallurgy, machine-tool making, machinery-making, etc.,

12) Construction of new towns and cities, rail spurs, hotels, airports, residential areas, commercial facilities, water taxis, etc. By 2020, this zone could support a population of 3-5 million citizens, double the present population of Singapore. ■

R. No. 42931/84



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

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

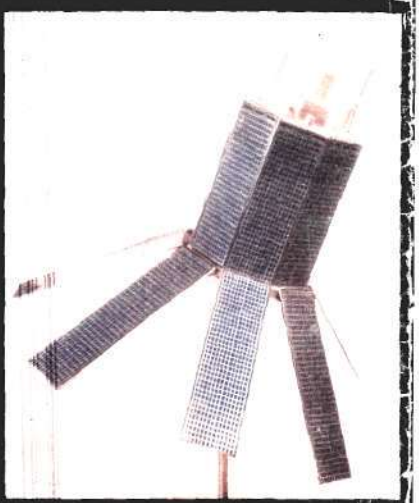
The little bones in the middle ear (see inset) were at the center of a hotly contested scientific battle in the mid-19th century between mathematical physicist Bernhard Riemann and scientist Hermann von Helmholtz. One hundred years later, as two feature articles in the issue discuss, modern biophysics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

INDIA'S SPACE PROGRAMME ACTS AS ECONOMIC 'DRIVER'

Delivering satellites into orbit and technology to industry, India's space programme is shaping up as an important motor for the country's economic development. The investment in the Indian Space Research Organisation's build-up of a self-reliant capability in satellite design and construction, rocketry, and space science is reaching a threshold where returns to the economy as a whole will begin to multiply. Over the next 15 years the growing scale and sophistication of the programme's requirements will place a healthy demand on industry even as ISRO itself is breaking new research ground and creating new technologies, products, and materials for transfer to industry.



Model of the Stretched Rohini Satellite (SROS), a small, versatile, and low-cost satellite now under development at ISRO. The first SROS will be launched by an indigenously designed and built launch vehicle, the ASLV, this year.

Cover photo, courtesy of ISRO, shows India's first indigenously built launch vehicle, the SLV-3.

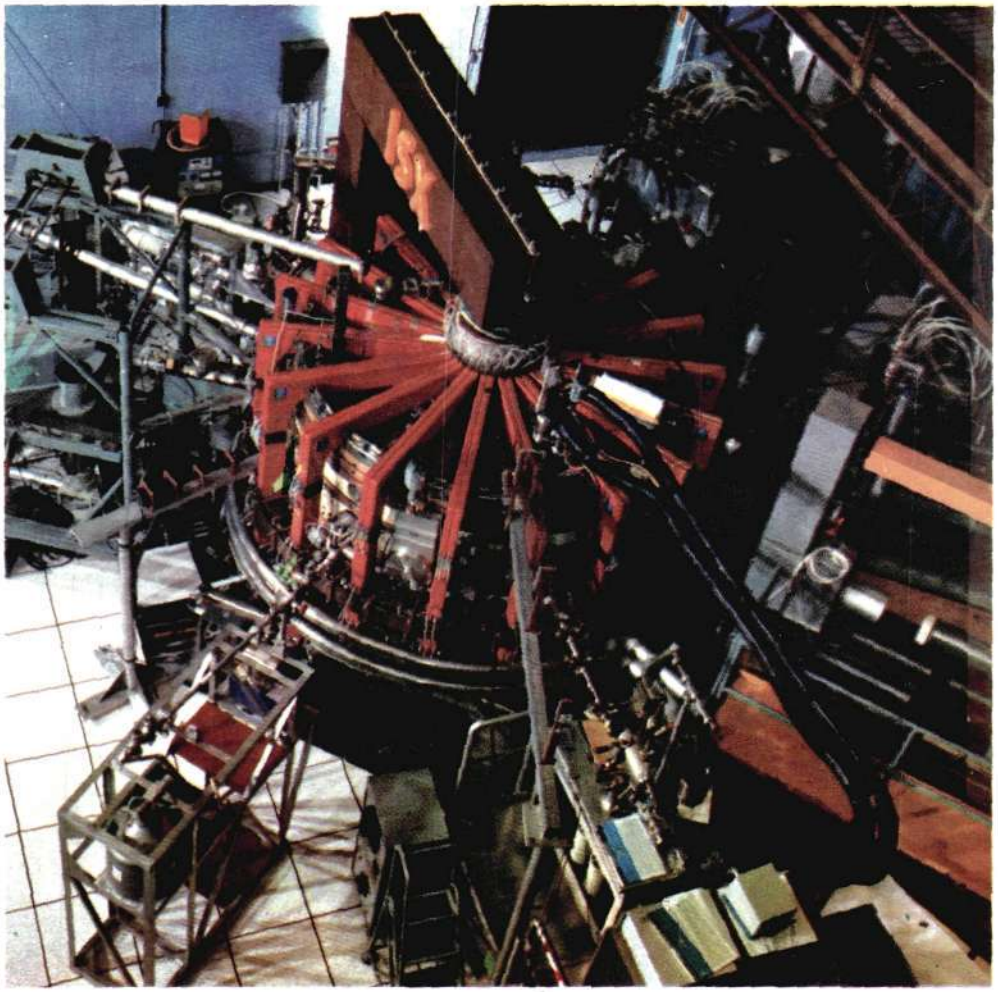
The world will have widespread fusion power by the year 2000.

The only question is whether it will be delivered by an ICBM or a tokamak.

It's up to you!
With your help, the Fusion Energy Foundation can

- put *Fusion* magazine into the hands of 200,000 progrowth Americans
- educate America on the benefits—economic, military, and scientific—of developing directed energy beam technologies
- send speakers nationwide to debate nuclear freeze advocates on campuses and at community meetings
- promote science and technology—specifically the development of nuclear fusion and fission and space exploration—as the most important tools for continuing human progress.

Join the Fusion Energy Foundation and give gift subscriptions to *Fusion* magazine.



Yes, I want to support the Fusion Energy Foundation.
Enclosed is:

- ☐ Sustaining membership $250
- ☐ Individual membership $75
- ☐ Corporate membership $1,000

(All memberships include 10 issues of *Fusion*)

- ☐ 1-year subscription to *Fusion* $20 (6 issues)
- ☐ 2-year subscription to *Fusion* $38 (12 issues)

Make checks payable to Fusion Energy Foundation, Box 1438, Radio City Station, New York, N.Y. 10101

Name _____

Address _____

City _____ State _____ Zip _____

Credit card _____ Card number _____ Expiration Date _____

Contributions to the Fusion Energy Foundation are tax deductible. Visa, MasterCard, and Diners accepted.