PAUL GLUMAS

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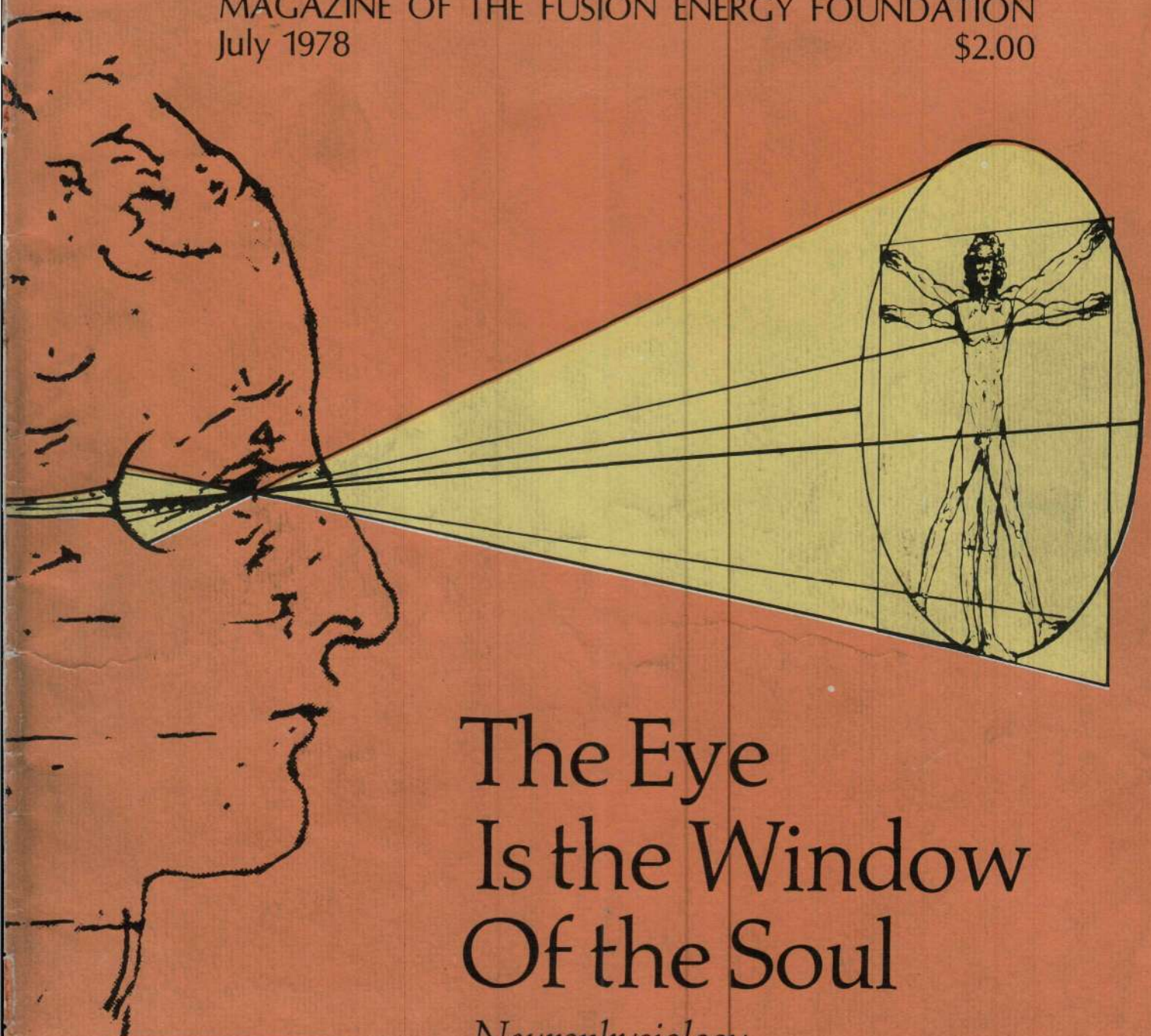

The Eye Is the Window Of the Soul

Neurophysiology And the Geometry of Vision

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Editorial

Full Speed Ahead with The U.S. Tokamak Reactor

The main target of the forces inside and outside the government who prefer conservation and windmills to a vigorous effort to develop fusion power is the mainline tokamak project at Princeton University. Suddenly the cost-conscious energy experts have begun to worry whether the tokamak can be scaled up through its next two major stages—the Tokamak Fusion Test Reactor and the Experimental Power Reactor—into a viable reactor design.

The answer is an unequivocal yes. As recent progress in Grad-Hogan plasma theory at the Oak Ridge National Laboratory in Tennessee underscores, there is absolutely no scientific or technical obstacle now known to stand in the way of tokamak reactor development, a step that would plant our feet firmly in the fusion age.

More than any other U.S. research and development project, the fusion program and the decisions made about it tell us where the nation is heading.

Right now the fate of the fusion program is uncertain. Despite the momentous offers in May from the Soviet Union and Japan for full international collaboration on fusion reactor development and despite the tremendous scientific and technological successes in achieving energy breakeven conditions, there is no national policy commitment to achieve commercial fusion in this century. In fact, there is no national policy commitment even to keep to the government's most conservative timetable that would push fusion off until early in the 21st century.

Ironically, it is the very success of the fusion program that has gotten it into hot water. The recent experiments that demonstrate the feasibility of fusion energy require large-scale funding now to make the promise of fusion a reality.

"Now don't be too hasty!"

The Lightning Rod

My dear friends,

I was recently pleased to receive a visit from my farmer friend Richard, whose whereabouts had eluded me following his tribal conversion several months previous; especially so since he no longer appeared bedecked with the feathered headdress and beaded paraphernalia he had sported during his return to the simple life. Although he now appeared straight as an arrow (forgive me my little irony), my pleasure dimmed as he recounted how missionary zeal had led him from the tribe to California, to join the campaign to abolish taxation.

"No taxation without representation," he declaimed, "especially on us little guys." I had heard the former slogan before, albeit in circumstances more appropriate.

"We've got to cut government down to size—village size," he blustered, grabbing a broomhandle and swinging it woodsman-style in a sweep that sent me to the shelter of the room's opposite end.

Clearly, California had not civilized him. Keeping my distance, I inquired if, in fact, plummeting that state's municipalities and credit institutions headlong into bankruptcy would prove a successful means of regenerating our domestic manufactures?

I would gladly report his thoughts on these matters, if an apoplectic rage had not rendered him incapable of utterance. Broomhandle in hand, Richard flung himself out the nearest doorway, leaving me to ponder what recourse we have when some portion of the populace substitutes hysteria for reason, threatening to take us with them on a journey to oblivion.

This question has occurred to me frequently over recent months. Understandably, the citizens of California distrust the state government ruled by the Zen Buddhist governor Jerry Brown, for it is a government that has refused to build the nuclear plants mandated for their future as an industrious populace. But what if these installations were constructed, only to have several villages on the Arizona and Nevada side of the interstate highways refuse them access to nuclear fuel shipments—as several townfuls of poor Richards in Connecticut and New York have just done to the Brookhaven National Laboratories?

Foolish as such hostilities appear, are they any less foolish than a federal Department of Energy that en-

SLOAN 6-22-78

There is no way to get around the fact of fusion's experimental successes, nor the fact that it will take a major increase in the fusion budget *now* to give the country the safe, clean, and virtually unlimited energy it needs to move it into the 21st century.

Secretary of Energy James Schlesinger and his few cothinkers in the Department of Energy are lying outright when they say that fusion is too distant a possibility to warrant spending larger budget amounts now, or that "fusion has always been 20 years away." They know better. Like informed scientific, industrial, and political figures throughout the world, Schlesinger and his cothinkers know that the enormous progress in experimentally heating and confining fusion plasmas and in theoretically comprehending plasma behavior has put the world at the threshold of fusion power. All that is required to get the first commercial reactor constructed in this century is the *political* commitment to put together an international scientific and engineering effort based on present knowledge.

The argument the cost-conscious experts invoke to cut back the mainline tokamak project is that there is less expensive exploratory work in other fusion research areas and a lack of resources to do both.

The alternative is obvious. If the nation were fully geared up for mass production and export of nuclear plants as part of a comprehensive world development program, there would be ample resources available for a broad-based, scientifically and technologically balanced fusion research program. Such a program would develop in parallel several viable first-generation magnetic and inertial fusion devices, and at the same time it would carry forward research on even more efficient and compact fusion machines based on high-energy-density plasmas.

Until the political forces in the nation decide that a future with unlimited energy is worth the immediate cost of conducting an optimal fusion program, the United States must at least keep its one mission-oriented project, the tokamak, on track. The tokamak is also necessary to hook up the U.S. fusion program into a full collaborative effort with the Soviets and Japanese.

Full speed ahead with the tokamak test reactor!

courages competition among the states for supposedly dwindling energy sources, and that tells local areas to develop comprehensive energy proposals based on locally available "alternate resources"—wood chips for the Pacific Northwest, corn husks for the corn belt, and perhaps wind for the Texas-Oklahoma panhandle (Oklahoma winds being well known from Depression days).

Imagine the legal niceties of policing wind power lest it seep over into bordering states. Or perhaps keeping it from filtering in, if the winds carry a particularly bad odor, as they so often do in Boston.

What innumerable ways can be found to keep us like pent-up and jealous children, unable to harness Reason for the benefit of the entire nation!

Yr. obdt. Srvnt,

Benj. Franklin

Calendar

July

5-7
Int'l Symposium on Energy
Cranfield Institute of Technology
Cranfield, England

10-11
International Cryogenic
Materials Conference
Institut fur Technische Physik
Munich

17-21
General Nuclear Power Reactor
Safety Problems Course
MIT
Cambridge, Mass.

17-22
Nat. Soc. of Professional Engineers
Annual Meeting
St. Louis, Mo.

18-21
IEEE Annual Conference
on Nuclear and Space Radiation Effects
Albuquerque, N.M.

August

20-25
13th Intersociety Energy Conversion
Engineering Conference
Am. Nuclear Soc., Am. Chem. Soc.,
Am. Institute of Aeronautics
and Astronautics, ASME, IEEE
San Diego, Calif.

21-25
6th Int'l. Congress
of Chemical Engineering:
Chemical Equipment Design
and Automation
Prague

23-30
7th Int'l Conference on Plasma Physics
and Controlled Nuclear Fusion Research
Int'l Atomic Energy Agency
Innsbruck, Austria

News Briefs

James Schlesinger

SCHLESINGER: 'WE DON'T NEED BREEDER'

U.S. Energy Secretary James Schlesinger told a Washington meeting of nuclear industry leaders June 14 there are "two reasons we do not need the nuclear breeder reactor: one, we don't need it; and two, we do not need it for budgetary reasons."

A report of the Schlesinger remarks was read into the *Congressional Record* the next day by an angry Senator James McClure. According to the Idaho Republican, Schlesinger told the group that the Clinch River breeder reactor project is "as dead as the B-1 bomber....We can always import foreign uranium" if it becomes in short supply, the secretary said, and "if we need a breeder, we can always import one from France."

U.S. PRESSURES BRAZIL ON NUCLEAR REPROCESSING

U.S. Special Ambassador for Nonproliferation Matters Gerard C. Smith arrived in Brazil June 11 for a week of efforts to persuade the Brazilians to bring their nuclear energy policies in line with the U.S. Nuclear Nonproliferation Act of 1978 and give up their plans for a plutonium reprocessing plant. Smith reportedly will present a proposal for an international nuclear bank designed to discourage developing countries from seeking nuclear fuel reprocessing technology.

According to the Brazilian daily *O Estado de Sao Paulo*, the government is prepared to listen to Smith but will not change its policies. Brazil has contracted a full nuclear fuel cycle system from Kraftwerk Union of West Germany, which will be under the inspection of the International Atomic Energy Agency.

Two weeks before Smith's visit, the head of Brazil's nuclear agency, Paulo Nogeira Batista, posed the reprocessing question as one of progress. "Refusing to use plutonium for peaceful purposes is equivalent to giving up nuclear energy entirely," Nogeira said. "In other words, in the context of the energy crisis resulting from the gradual exhaustion of both oil and economically exploitable hydroelectric resources, it will mean turning one's back on progress itself."

Toshio Doko

JAPANESE BUSINESS LEADER CALLS FOR INTERNATIONAL FUSION EFFORT

Toshio Doko, president of Keidanren, the Japanese business federation, called for an international effort to develop fusion power and to pull the world out of economic depression. In a June 12 article in the New York *Journal of Commerce*, Doko wrote:

"Our hopes for successfully removing the limits to growth imposed by the energy and resources problems and saving the free-enterprise economy from the slow strangulation of low growth lie in the development of new technologies....International cooperation is thus essential in the energy-resources area."

There are some successful instances of international cooperation," Doko said, "such as the highly advanced joint research being carried on by the U.S. and USSR in the field of nuclear fusion technology. Japan must step up its efforts in technological development within the framework of international cooperation, and help lift the world out of its current impasse."

IEA FORECASTS INCREASE IN NUCLEAR POWER

The International Energy Agency released a report in June that gives a country-by-country analysis predicting a rise in the percentage of nuclear energy from the present 9 percent to 22 percent of total energy production by 1985. The Paris-based organization was established by 19 nations after the 1973 oil price rise. Although the figure represents a slight decline from earlier predictions, the commitment of member countries to nuclear energy sources remains strong.

The report also predicts a world oil shortage by 1985 if present consumption trends continue, a conclusion that has been disputed by the Petroleum Industry Research Foundation in New York.

SUPREME COURT BACKS THE SNAIL DARTER

The U.S. Supreme Court ruled June 15 that the construction of the Tellico River Dam, a $100-million project of the Tennessee Valley Authority, must be stopped to protect the only habitat of the snail darter, a 3-inch perch. In issuing its decision, the Supreme Court refused to rule against the 1973 Endangered Species Act, leaving the question up to Congress. Congress will probably pass an exemption for the Tellico River Dam, which is now 90 percent completed, but will avoid dealing with the broader issue of environmentalists using the Endangered Species Act to prevent industrial development.

The endangering species

U.S. ENERGY BILL STILL UNCERTAIN

The heart of the U.S. energy bill foundering in Congress for more than a year, the crude oil equalization tax, has no certain future as of this writing. According to Washington sources, if this part of the bill were voted on today, it would fail to pass. A main obstacle to the tax provision is Senator Russell Long's demand that part of the tax money be earmarked for the development of new energy sources, a proposal to which the administration has responded with a flat "no."

The other controversial section of the bill, phased deregulation of natural gas, is also stalled. A compromise calling for gradual deregulation over the period up to 1985 was passed by House energy conferees May 23 by a slim one vote margin (13 to 12) and is now being discussed with Senate conferees. Although sources estimate that it would take another four to six weeks to put the compromise into legislative form, Senator Howard Metzenbaum and others have vowed to filibuster to stop the deregulation measure from passage.

ROCKY ATTACKS CARTER'S 'GO-SLOW' ENERGY PLAN

Former vice president Nelson Rockefeller told the June 9 meeting of the National Energy Foundation that five years after the 1973 world oil embargo, the U.S. still has "no rational, well-thought out" national energy policy. In his keynote address to the group of industrial and banking leaders, he criticized the Carter administration for indefinitely postponing the Clinch River breeder reactor and delaying nuclear power.

The administration's attitude is: "Don't push ahead on proven nuclear technology....Don't rush ahead on these proven methods of immediately increasing energy....Go slow on government funds for research and development of new forms of energy and particularly the breeder reactor....Any additional funds are inflationary."

Stressing the relationship of a strong national energy base to international security, Rockefeller concluded, "We should start right now to add to our domestic energy production by active encouragement of the energy industry in oil and gas, coal, and conventional nuclear energy."

International

Soviets Present 'Atoms for Peace' Plan

The Soviet Union presented a comprehensive fusion, technology, and disarmament package to the United Nations General Assembly Special Session on Disarmament in May. The policy statement, which elaborated on the detente and development proposals put forward by Soviet Foreign Minister Andrei Gromyko in his UN speech May 26, is the most substantial cooperation proposal by the Soviets since the 1953-1955 period when the Soviets reciprocated the "Atoms for Peace" plan of President Dwight D. Eisenhower.

The proposal, printed in the official Soviet daily, *Pravda*, May 31, outlines the following disarmament measures as "a bare minimum": an international project to develop thermonuclear fusion power, expansion of Soviet uranium enrichment services for other nations, the designation of funds for economic development, the successful conclusion of the Soviet-American strategic arms limitation talks and the European force-reduction talks, and the opening of discussions in other areas of arms limitation. Excerpts from the Soviet plan appear in this news section.

The proposed fusion energy collaboration, which specifies the United States, Japan, and European nations as prospective partners, gives new prominence to the recent offer of Soviet fusion leader E.P. Velikhov to merge the U.S. and Soviet tokamak programs under the aegis of the UN International Atomic Energy Agency. The program also meshes with the $1 billion plan proposed to President Carter by Japanese Prime Minister Takeo Fukuda for the cooperative development of fusion research.

An analysis of the UN disarmament conference appears in the conference section of this issue.

Gromyko at the UN UN Photo by Y. Nagata

Velikhov Offers Fusion Deal

E.P. Velikhov, the vice president of the Soviet Academy of Science and a leader of the Soviet fusion program, formally announced a proposal for an international crash program to develop fusion power at the May meeting of the U.S.-Soviet Joint Fusion Power Coordinating Committee in Moscow. The proposal calls for the United States and the Soviet Union to make the major inputs into a fusion research project, which would operate under the auspices of the United Nations International Atomic Energy Agency.

The main focus of the Velikhov proposal is the construction by the 1980s of a prototype fusion power reactor based on the tokamak magnetic confinement system designed by the Soviets. The tokamak design has achieved breakeven results so far in every country pursuing fusion research.

Velikhov privately had proposed the joint fusion research program to U.S. officials in Washington in April, and U.S. fusion scientists had encouraged Velikhov to pursue the offer. The Soviet Academician told the Fusion Power Coordinating Committee that he would present the proposal to the IAEA Fusion Council in the near future.

U.S. participants at the Moscow meeting commented that Velikhov's attendance at all the Fusion Committee meetings indicated official Soviet circles view the development of fusion as a priority.

The Soviet Proposal to the UN

The following excerpts from the Soviet proposal to the United Nations Disarmament Conference appeared in Pravda May 31 under the title "On Practical Ways to End the Arms Race."

Progress in peaceful uses of nuclear energy is undoubtedly one of the promising ways to resolve the energy problem and the Soviet Union favors broader international cooperation in this area, provided, of course, it is carried out under conditions which rule out its use to increase possibilities for the development of nuclear weapons. At the same time...it can be said with confidence that nuclear [*fission*] energy, however important it is, does not provide the only key to solving the energy problem.

There emerge alternative approaches....These are thermonuclear fusion, solar, and geothermal energy, as well as a number of other sources....

The Soviet Union is prepared to cooperate on a constructive basis with other states in research on new sources and types of energy. We have recently stated our readiness to participate together with the USA, European countries, Japan and other states on a "tokamak" international project—a thermonuclear reactor designed to produce a controlled thermonuclear reaction with an energy yield higher than the energy input.

It will be recalled that the Soviet Union is already providing services to a number of countries in having their natural uranium enriched at Soviet enrichment facilities. To promote a broad use of the peaceful atom in solving energy problems the Soviet Union is prepared to continue rendering such services under appropriate international guarantees.

SALT

Serious difficulties are known to have arisen on several occasions at the talks on limiting strategic offensive arms. At present many of them have been overcome....It is extremely important not to allow new obstacles, new problems to arise in the way of a successful completion of the talks. The agreement can and must be concluded in the very near future....

[*Taking up a standing proposal to channel 10 percent of the arms budgets of the permanent members of the UN Security Council into a development fund, the Soviets proposed a revision that could mean more monies.*]

A Turning Point

The steps proposed are a bare minimum. Without their implementation the arms race will not be halted.

At the same time these would be substantial steps. Their implementation would actually mark a turning point in the entire course of international developments....

And all these steps are feasible....On most of them talks are already in progress and some are nearing completion. With regard to other steps such talks could be started in the near future.

Willingness to move decisively ahead and political will are required to end the arms race. Today the responsibility of each state for the present and the future of the peoples is so great that a state failing to cooperate in meeting this historic challenge would be committing a crime against humanity.

Japanese Gov't Optimistic on U.S. Fusion Role

Japanese Foreign Minister Sunao Sonoda told a United Nations press conference in New York City May 30 that the United States "is holding cabinet-level discussions on the fusion proposal made by Japan with a view to responding to it shortly." Japan, Sonoda reported, is now readying "the administrative mechanisms to make it an effective effort for scientific cooperation between countries."

Although Sonoda was optimistic about U.S. participation, to date there has been no official U.S. response to the $1 billion joint fusion research program proposed by Japanese Prime Minister Takeo Fukuda on his visit here in early May.

Asked at the press conference whether the Fukuda proposal would be open to participation from the Soviet Union, which had made similar offers for fusion cooperation, the foreign minister stated that his nation's offer was "open to all parties....We feel the future of mankind is the concern of all nations," he said.

According to Japanese government sources, several government ministries are now formulating the specifics of the unprecedented offer. The fusion proposal was a major policy initiative by the Japanese cabinet, the sources said, and it had bypassed the usual time-consuming routine of consensus-forming in the government bureaucracy.

U.S. Research Centers Ready

Several U.S. private and public research centers have already approached the Japanese Ministry of Internal Trade and Industry with options for joint research projects. Among the possible projects under consideration by the Japanese are the following:

*Construction of a super-large linear accelerator with Stanford

University Linear Accelerator Center.

*Construction of a prototype nuclear fusion reactor with General Atomic Company of San Diego, California.

*Manufacture of proton collision equipment with Brookhaven National Laboratory.

*Research on nuclear laser fusion with KMS Fusion of Ann Arbor, Michigan.

In a complementary development effort, a prestigious private thinktank in Japan, Nomura Research, Inc., produced a report for the Japanese government that proposed a $20 billion energy and steel development fund for what they termed the Pacific Rim countries—North America, Latin America, Southeast Asia, Japan, the Soviet Union, and China.

Mexico, Soviets Stress Nuclear Cooperation

Nuclear energy cooperation was a central topic of discussion during the 10-day visit to the Soviet Union of Mexican President Jose Lopez Portillo in May. In addition to bilateral agreements providing for Soviet technical assistance in the long-distance transmission of electricity and advanced oil and gas technology, the Soviet-Mexican accords include the training of Mexican nuclear scientists and the transfer of Soviet nuclear technology to Mexico.

The accords will permit advances in all forms of energy, "especially nuclear," Lopez Portillo said.

The Mexican president emphasized that the agreements for the exchange of technology were critical to the creation of a new world economic order. "To us of the developing countries," he told the Soviet nation in a special half-hour television address, "the important thing is not just reducing the risk of war, but winning the peace. This is only achieved if we find the true path toward the new international economic order, which resolves problems of financing, transfer of technology, and basic trade."

Speaking to the Academy of Sciences of the Siberian city of Novosibirsk May 22, Lopez Portillo again emphasized the importance of technology transfer: "The powerful countries which have achieved advanced levels of technology have the obligation, for the future of humanity, of honestly transferring their advances so that backwardness can end, so that tomorrow's humanity will not be as divided as it might otherwise be. ...Technology is the patrimony of humanity."

During his trip the Mexican president toured the fusion and nuclear fission research facilities at the Kurchatov Institute outside of Moscow, accompanied by Soviet physicist Aleksandrov, institute director and president of the Soviet Academy of Sciences.

Nuclear Cooperation

Although the bilateral accords on oil and gas technology were anticipated, the extent of the joint cooperation for nuclear energy development surpassed that of announcements by the Mexican government prior to the president's trip. According to Mexican Minister of Natural Resources and Industry, Jose Andres de Oteyza, negotiations are underway for Soviet enrichment of Mexican uranium, both countries will promptly exchange delegations of nuclear technicians, and the way is open for Mexican scientists to complete their studies in Soviet enrichment facilities.

While the Soviet discussions were in progress, the director of the Mexican Electricity Commission announced from France that that country would provide Mexico with access to the seven years of preparatory studies in the design of the French Superphenix nuclear breeder reactor.

Both the Soviet and French agreements indicate that Mexico is moving rapidly to establish the preconditions for an advanced and integrated nuclear program in the 1980s.

In juxtaposition to banner headlines proclaiming the nuclear cooperation with the Soviets and French, the Mexican press reported that the U.S. Department of Energy had decided to continue to embargo more than 100 tons of uranium that Mexico had sent to the United States for enrichment several months ago. The department has refused to release the uranium unless Mexico agrees to allow direct U.S. inspection of its nuclear facilities.

Saudi Support for Nuclear Energy Is Key to Peace Plan

The Saudi Arabian government publicly endorsed nuclear fusion and fission power for the first time last month, a significant policy turn that occurs amid a number of specific proposals for Mideast peace based on economic development.

In a May 24 interview on New York television, Saudi Minister of Irrigation and Water Resources, Mohammed Ben Faisal, supported nuclear fission power and lauded fusion power as the only viable future energy source. Faisal dispelled the interviewer's charges about the dangers of nuclear energy by stating: "There are two kinds of nuclear energy: reactors and bombs. Only the second category is dangerous." He then said that fusion energy will come on line in the future because "it has to."

Earlier in the same week Saudi state radio promoted research in the development of nuclear technology.

The Saudi turn on the nuclear energy question coincides with several initiatives to build a Mideast peace around a program for industrialization and development, centered on nuclear power. The Saudis are particularly important to these plans, because they have the oil dollars to contribute to three-way development deals. At least one Saudi deal is in the works. Late last year Saudi Oil Minister Yamani signed an agreement with France for joint research in nuclear energy and joint

French-Saudi exploration for uranium on the Saudi Arabian peninsula. The agreement was reaffirmed this month during the visit of Saudi King Khaled to Paris.

Peace Through Development

Hans Friederichs, head of West Germany's Dresdener Bank, issued a call in late May for East-West cooperation to industrialize the Mideast based on the transfer of nuclear energy facilities. "Long-term energy cooperation with the Arab world will prominently involve the development of nuclear energy," Friderichs said in an interview with the West German daily *Sueddeutsche Zeitung*.

This "era of large-scale cooperation with the Arab world" and with the development of a "productive Arab economic region" will clear the way massive "bloc to bloc deals... involving energy and scientific cooperation, marketing, and investment."

As a start, Volker Hauff, the West German Minister of Technology and Research, is currently touring the Persian Gulf and has reopened talks with the Kuwaiti government on the sale of a West German nuclear reactor for desalination research. The reactor would be used as a training center for all the Gulf states.

An equally ambitious development plan was put forward by Robert Abboud, the president of the First National Bank of Chicago, at a meeting of the American-Israel Chamber of Commerce in Chicago May 10.

Other development initiatives have come from Japanese Prime Minister Takeo Fukuda, who told the Lebanese daily *Al Hawadess* that Japan is "prepared to extend unlimited economic aid to developing countries of the Mideast with a view to developing chances of an Arab-Israeli peace accord"; from the Rockefeller Foundation, which issued two policy reports this year urging international cooperation for the promotion of nuclear research and development for worldwide use; and from statements by groups of scientists in both Israel and Egypt supporting nuclear power projects for the region.

U.S.-Iranian Deal On Nuclear Plants Reported Near

The proposal by the Shah of Iran to purchase eight U.S. nuclear-power-generating plants is reaching its final stages after four years of negotiations.

According to an Iranian diplomat, the Carter administration and the government of Iran may announce the agreement as early as July or August, at which time the sale would be submitted to Congress for approval. The Iranian official noted that Congress will scrutinize the details of the agreement and that there will probably be a fight within Congress over U.S. policy on exporting nuclear technology.

Iran has been in the vanguard of the oil producing nations both in pioneering the installation of nuclear-power-generating technology domestically and in waging a political fight internationally to make fission and fusion the new mode of energy, replacing oil reserves. The Shah has expanded his quota of nuclear reactors to be built by 1990 from 22 to 24 or 26, and he has also initiated a small fusion research program.

If the Iran-U.S. deal is approved by the U.S. administration, it will serve as a precedent by which 26 other nations now waiting to purchase nuclear reactors can finalize long-overdue sales, the *Christian Science Monitor* commented June 1.

Congressional approval will be contingent on whether the terms of the sale conform to the nuclear weapons nonproliferation guidelines established by the controversial Nuclear Nonproliferation Act of 1978. Unlike the recently enacted Nonproliferation Act, the Iran deal will be fought out in Congress in the context of mounting international pressure from the Soviet Union, Japan, West Germany, and France as well as the U.S. nuclear industry and other domestic supporters of high-technology exports to force Washington to adopt an energy policy that promotes America's advanced nuclear technology.

Washington

Schlesinger Fights to Kill Fusion

"It is not feasible to develop fusion until late in the 21st century," U.S. Energy Secretary James Schlesinger told a Chicago press conference June 5. Schlesinger's timetable is at the center of his recently escalated campaign to make it impossible for the United States to accept the May offers of Japan and the Soviet Union for joint fusion research programs that would develop commercial reactors by the 1990s.

To buttress this deception effort, both Schlesinger and his Deputy Secretary John O'Leary have circulated two fusion budget stories to the energy press. First a number of articles reported that department sources said the fusion budget for fiscal year 1979 would have to be cut because of demands from the Office of Management and Budget.

Second, a spate of articles has appeared citing department sources who claim that the present fusion program is unfairly centered on the mainline tokamak reactor at Princeton University and that other programs are not getting a chance for development. Among the latter group are articles in *Nucleonics Week* June 1, *Aviation Week* June 12, and—of all places—*New Times* magazine June 26.

OMB for Fusion

Reliable Washington sources have told the Fusion Energy Foundation that the Office of management and Budget has been won over to the idea that the fusion program should be funded, no matter what other budget cuts are made in the Energy Department. In the view of these sources, the leaks from the energy secretary and his deputy to the contrary are just so much black propaganda.

The Schlesinger line on the tokamak, however, is being read into the Foster Committee report, a fusion policy review commissioned by the department and carried out by a committee of scientific and technical experts. The committee is chaired by Dr. John Foster, vice president of the TRW Corporation and the former director of research and engineering for the Department of Defense.

It is clear from a reading of the just-released report and from discussions with committee members that the problems it raises with the tokamak program were not intended as a reason to slow the program down. Nevertheless, this is how the Schlesinger faction intends to use the report.

The fusion issue will come to a head within the department the week of June 19 when the department's fusion review committee is scheduled to meet. The meeting was already postponed a week to give the fusion division some time to make its case before a hostile Deputy Secretary O'Leary. Reportedly lined up behind the tokamak program are the department's research head John Deutch and Deputy Undersecretary Robert Thorne.

— *M. Hecht*

Senate Ctte. Delays Breeder

The Senate Energy Committee voted June 8 to allow the Carter administration to stop the Clinch River plutonium breeder-reactor project if it agrees to pursue a non-plutonium breeder instead. Since the White House had indicated earlier that it would not favor a compromise requiring commitment to anything beyond a *study* of an alternate breeder design, the Senate vote is a serious setback for the U.S. breeder program.

Clinch River is the nation's only nuclear breeder project, and political delays in its construction have put the U.S. well behind Europe, Japan, and the Soviet Union in breeder technology.

According to a committee spokesman, the vote gave several options to the Department of Energy. If Energy Secretary James Schlesinger decides to go with the Clinch River program (which he has said he will not do), then the committee would authorize the same level of funding authorized last month by the House Science and Technology Committee—$174 million. If Schlesinger decides, as expected, to kill Clinch River, then the Senate vote requires the department to design and construct a new breeder project.

Sen. Frank Church

When finalized in written form, the Senate committee recommendations will go to the full Senate for final vote. Senate sources have not predicted what that vote will be, but it is generally felt that the full Senate is more strongly in favor of proceeding with the breeder project than is the Energy Committee.

The committee breeder plan was worked out between Democratic Senators Frank Church (Idaho) and John Melcher (Montana).

FEF's Gilbertson to Testify On Nuclear Licensing Bill

Nuclear safety expert Jon Gilbertson, the director of nuclear engineering for the Fusion Energy Foundation, will testify in June before the House Committee on the Interior and Insular Affairs, on the Nuclear Siting and Licensing Act of 1978. Excerpts from the Gilbertson testimony are reprinted here. A full copy of the speech may be obtained by sending $1 and a self-addressed envelope to the FEF.

"....The only way that the proposed Nuclear Siting and Licensing Act can be competently judged is to determine how well it supports and assists in the rapid implementation of a progrowth U.S. energy policy....What defines a growth-oriented energy policy?

"This can be determined by considering three criteria that enable us to define in detail the interrelation between economics and energy: quantity of energy, energy density, and the capability for developing superseding energy technologies. If these three criteria are not simultaneously met when comparing different energy resources or combinations of energy resources, the United States will not have an adequate energy program....

"As the Fusion Energy Foundation has thoroughly documented elsewhere, nuclear energy is the only source that meets all three criteria. . . .

"Nuclear energy is therefore the only policy that makes any economic sense for the nation and is the only way out of the economic disaster we are now facing. This proposed legislation must be judged on how well it promotes and assists this energy policy. In that light, there are several positive features of the bill that tend toward decreasing nuclear plant construction time. However, other sections of the bill introduce clauses that will negate any of these positive features with the probable result that the bill will do more harm than good....

"There are four major features that will make [decreased construction time] *impossible* to achieve. These are (1) the transfer of environmental statement approval from the federal agencies to states; (2) the requirement for consideration of alternative energy sources including conservation; (3) the subsidizing of intervenors in nuclear licensing and rulemaking hearings; and (4) making the public hearings and decision-making process even more open to harassment and delays by intervenors. All of these 'new' features will, without exception, cause further delays in nuclear plant construction and allow the intervenors to continue the obstruction of new plant construction.

NEPA and Growth

"Most, if not all, of the above four features recently have been judged by the U.S. Supreme Court to be in contradiction with the correct interpretation of the National Environmental Policy Act (NEPA) and should be taken out of this proposed legislation on that basis alone. In that decision, the Supreme Court in the *Consumers Power* case made clear that NEPA was meant to *uphold a progrowth energy policy for the United States* rather than prevent it....

"However, the four cited features to this bill should be...removed because they will prevent the U.S. from attaining its essential and necessary energy and economic growth....

"In a republic such as the United States, a small minority does not have the right to jeopardize the well-being of the United States as a viable nation. The economic and strategic consequences of the United States *not* having a growth-oriented energy policy are already only too obvious. It is the responsibility of Congress to see that this *is not* the case. A good place to start is with this bill, modified to include the changes recommended here by the Fusion Energy Foundation."

National

Antinuke Group Targets UN Disarmament Conference

"Ban nuclear power" was one of the slogans on posters put up to advertise the antinuclear demonstrations targeting the United Nations Special Session on Disarmament in New York City this month.

The antinuclear campaign was organized by the Mobilization for Survival, a group pulled together last year by the Institute for Policy Studies out of an assortment of 40 old "ban the bomb" groups, pacifists, environmentalists, and terrorist support groups. The Mobilization has tried to build support for their antinuclear position by equating the issue of nuclear energy with nuclear weapons and by getting as much publicity as possible from civil disobedience actions. The environmentalist agenda for disarmament includes no plan for economic development—just zero growth, conservation, and deindustrialization.

The leading figure in the group is Daniel Ellsberg, a protégé of Henry Kissinger and a member of the London Institute for Strategic Studies, one of the chief Cold War thinktanks. Ellsberg and 380 other demonstrators were arrested at the United Nations June 13 on charges of disorderly conduct.

Turn to Violence

The environmentalists have already turned to violence to try to accomplish what they were not able to do around the May 3 Sun Day event because of a lack of mass support. Near Seattle June 1, a group calling itself the November 13 Faction destroyed a 200-foot meteorological tower, at the site chosen by Puget Sound Power and Light Company for construction of two nuclear plants. The group's name reportedly is taken from the November 13 death of Karen Silkwood, an employee of a nuclear-fuel reprocessing plant in Oklahoma. Silkwood was said to have been on her way to turn over evidence of safety violations to a reporter when she was killed in a car accident.

One of the inspirations for the environmentalist attack on the tower is Sam Lovejoy, the avowed nuclear terrorist who was the feature attraction at the Crabshell Alliance's celebration of the November 1977 anniversary of Silkwood's death. Lovejoy, who was convicted for destroying a weather tower at a nuclear reactor site in Massachusetts three years ago, showed a film to the group documenting his raid, "Sam Lovejoy's Nuclear War."

Other demonstrations against nuclear sites are planned for this month by the Crabshell Alliance in Seattle, the Clamshell Alliance in New England, and the Keystone Alliance in Pennsylvania.

Antinuclear warriors Ellsberg (above) and Lovejoy.

Press Distorts NAS Policy on Orlov Case

Reports in the *New York Times* and other national press that the U.S. National Academy of Sciences had canceled a scheduled visit to the Soviet Union to protest the trial and sentencing of Soviet physicist Yurii Orlov were "distorted," according to an NAS spokesman. Howard Lewis, NAS information officer, said that the cancellation was "strictly a decision made by the individuals" involved in the trip and was not academy policy as the news reports had claimed.

The decision of the individual NAS members to cancel the scientific trip culminates a three-year effort on the part of Jeremy Stone, the head of the Federation of American Scientists, who claimed credit for the NAS-Orlov affair in a recent interview. After a trip to the Soviet Union in 1975 where he met with Orlov and other dissidents,

Stone said: "I wrote a newsletter which was sent to all members of the National Academy of Sciences. It raised a big uproar . . . . The academy did not want to get involved but we kept the pressure up . . . . My purpose is to harass the Soviet government."

Under Stone's directorship, the federation has worked closely with Ralph Nader and other antinuclear environmentalist groups associated with the Institute for Policy Studies. (The federation, however, also contains many prominent supporters of nuclear development and East-West detente.)

The reaction here to the Orlov affair has been mixed. Although Joseph Califano, Health, Education, and Welfare secretary, canceled a scheduled visit to Moscow for a cancer research meeting and several scientists, including NAS President Philip Handler, have issued statements against the Orlov sentencing, other U.S. scientists have made it clear that they want to continue cooperative work with the Soviets. The *Washington Post* reported that American scientists are enthusiastic about continuing an agreement to collaborate with the Soviets on their unmanned lunar missions, in spite of Orlov's sentencing. The *Post* quoted one of the U.S. space delegation: "We want to keep as many doors open between the two countries as we can."

Nat'l Energy Forum:

Sen. McClure Defines Moral Basis For a Nuclear Energy Policy

Participants at the National Energy Forum of the World Energy Conference in Washington, D.C. May 18 repeatedly scored the Carter Administration for backing a dead-end energy program and the wrong nuclear policy. The forum included 300 industrial and trade union leaders, scientists, engineers, international energy experts, and policymakers from the Republican and Democratic parties.

In his keynote conference address Senator James A. McClure told the group that unless "the supporters of a rational energy policy" based on nuclear technology are certain of their moral position, they cannot succeed. The Idaho Republican called the Carter "no-growth" energy policy "the equivalent of war," discussed the oil question, and developed at length the moral basis for a U.S. energy policy.

McClure's Speech

Excerpts from McClure's speech appear below.

". . . We realize that many of the opponents of nuclear energy genuinely believe that it is evil and must be stopped. But, we must not allow their fears to overshadow the facts regarding nuclear energy. Current nuclear technology represents a major hope that future generations may enjoy the standards of living available to all too few today. In addition, nuclear energy offers us assistance in increasing present day productivity, thereby improving the lives of people already living. We must not concede the *moral* issue to the *opponents* of nuclear energy. . . . With the advent of the Carter administration, the antinuclear movement finally discovered a winning combination: (1) stop the breeder program, using phony press releases concerning plutonium; (2) stop spent fuel reprocessing, while making vague threats about terrorists who somehow are immune to radiation; (3) create serious doubts as to the future availability of spent fuel storage facilities; and (4) cripple the opportunities for our domestic nuclear industry to survive through exports, using the threat of nuclear weapons proliferation while ignoring the reality that such prohibitions actually *increase* the threat of proliferation. . . ."

"The *proponents* of nuclear energy have surrendered the moral issues involved. The opponents have wrapped themselves in the invisible Emperor's Cloak of righteousness and good. They have assumed the role of good, while casting their adversaries as evil. . . .

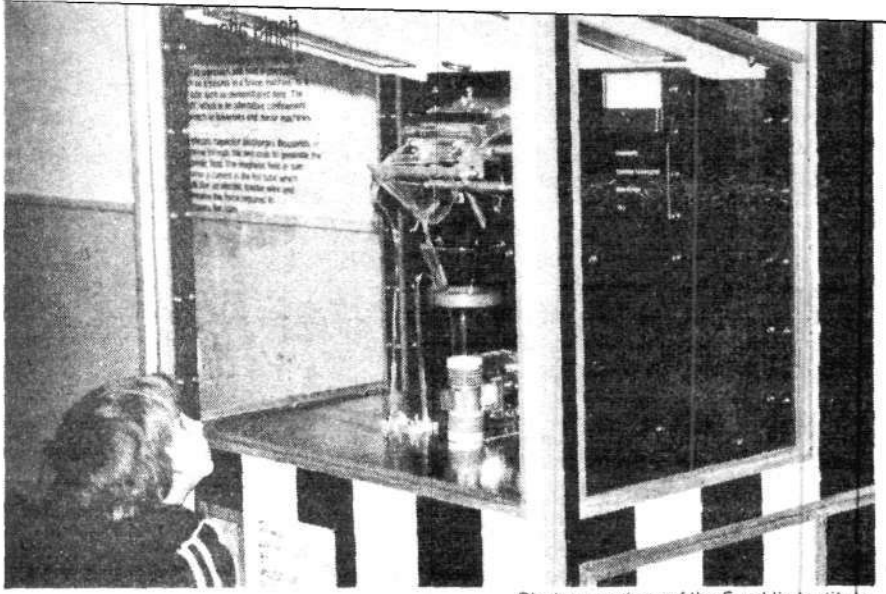
A Moral Test of Will

"It is time that the record be set straight. We cannot win this battle for the survival of nuclear energy while conceding the moral position to our opponents . . . .

"These individuals [Amory Lovins, Ralph Nader] have one major advantage over the supporters of nuclear energy: They are embarked on a quasi-religious crusade to rid mankind of the atom. This provides a strong moral position, which will easily override the factual arguments and logical presentations of a nuclear energy supporter *UNLESS* he too believes that his position is morally correct. The supporter of nuclear energy must truly believe that nuclear energy is a moral necessity for mankind and that without it, future generations will sink ever deeper into poverty and, eventually, dictatorship. Shortages of energy will result in shortages of jobs, housing, and food. And, shortages of necessities—even when caused by government action—always result in increased government controls. And, increased government controls will always lead to increased shortages. And the tragic culmination of such a chain of events is war, as those who are without seek to take from those who have! . . .

"The issue is now that of a moral test of will. Our opponents know clearly where they stand. The National Council of Churches, for instance, has decided that plutonium should be excluded as a future energy source. They have made this decision based on their moral beliefs.

"If you do not believe just as strongly that exclusion of plutonium as an energy source is immoral, then your arguments for breeder reactor development and commercialization of spent fuel reprocessing are lost at the onset. . . ."



Photos courtesy of the Franklin Institute

Educating the Population for Fusion

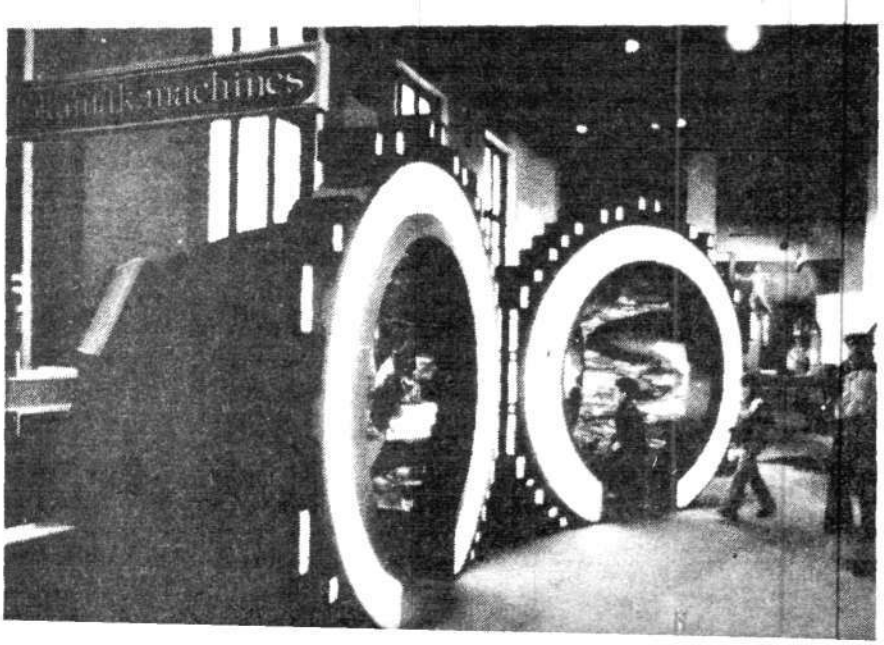
Can nonscientists understand the advanced scientific concepts involved in controlled thermonuclear fusion processes? Not only can they, they must! For a fusion-based economy to become a reality in the next 10 to 15 years, the nation must increase the number of scientists and technicians involved in fusion research and ensure that the general population knows enough about fusion to bring the U.S. to the fusion era.

The nuclear fusion exhibit at the Franklin Institute in Philadelphia, the only major exhibit about fusion in the country, is exciting precisely because it fulfills its purpose of making fusion understandable to the population at large and motivating further study. Since October 1977, nearly 300,000 persons have seen the exhibit, and a second exhibit is planned for the West Coast.

Project Director Jack Miksit, the museum staff, and Department of Energy representatives have developed a permanent, comprehensive display covering every major area of fusion research. The models, movies, slides, games, and demonstrations range from an explanation of the basics of a fusion reaction showing how atoms of deuterium and tritium collide and release energy to models of the most advanced machines used to create fusion. One of the most fascinating demonstrations is a working model of a magnetic pinch machine. The machine [see photograph above] produces a magnetic field that crushes a metal tube to show how a magnetic field can compress deuterium and tritium atoms so that fusion can take place.

The fusion exhibit is open seven days a week and class trips can be arranged.

—Ken Mandel



Conferences

UN Session On Arms Misses Point

by John Sigerson

The UN Disarmament session

UN Photo by Saw Lwin

UNITED NATIONS, N.Y.—The United Nations Special Session on Disarmament, which opened here May 26, was the launching ground for a handful of new initiatives toward curbing the production and deployment of world arms. With few exceptions, however, the key ingredients for realizing this aim were either ignored or left unrecognizably vague. Symptomatically, out of the hundreds of thousands of words that have come out of the conference proceedings, the need for expanded fusion research was mentioned only once—by Soviet Foreign Minister Gromyko.

The special session has been fraught with difficulties since it was conceived at the 1976 meeting of nonaligned countries in Colombo, Sri Lanka. More ambitious plans were eventually reduced to the present format of addresses to the General Assembly by delegation heads, to be followed by a broad declaration of principles.

Even the presentations got off to a bad start when President Carter declined to attend. This, in turn, put to rest speculation that Soviet President Brezhnev would put in an appearance.

Instead of Carter, Vice President Mondale addressed the session with an abrasive speech that contained dark warnings about the "continuing buildup of Warsaw Pact forces." Mondale's comments were later seconded even more forcibly by Chinese Foreign Minister Huang Hua, who claimed that Soviet global strategy is "to weaken and squeeze out the influence of the other superpowers in all parts of the world."

Gromyko Proposal Ignored

Soviet Foreign Minister Gromyko's proposal "On Practical Ways to End the Arms Race" [see international news, this issue] went largely ignored, despite the fact that it is the most far-reaching Soviet "Atoms for Peace" proposal since the 1950s. The U.S. press, especially, made little mention of the Soviet call for technological cooperation.

However, another series of constructive proposals from French President Valery Giscard d'Estaing received support from West German Chancellor Helmut Schmidt and a few other leaders. Giscard proposed the creation of a new mechanism for disarmament negotiations, in the context of the Helsinki agreements on European security and cooperation, which would include arms currently not covered by the Vienna talks on Mutual and Balanced Force Reduction. Such a new forum would permit France to participate actively in European disarmament negotiations without at the same time being obliged to reenter the North Atlantic Treaty Organization.

Giscard's proposals were firmly rejected by the Soviet side, which has more to do with a similar proposal from the Chinese than with the merits of the French plan. As the belligerent anti-Soviet speech of Huang Hua made clear, the Chinese have their own reasons for becoming further involved in disarmament negotiations.

Under the rubric of "peaceful uses of nuclear energy," other world leaders addressing the session stressed the necessity of a worldwide development effort and warned James Schlesinger's U.S. Department of Energy against trying to halt the process.

As Veselin Djuranovic, president of the Federal Executive Council of Yugoslavia, put it: "Disarmament measures should be conceived in such a way as to ensure respect for the principle that the achievements of technology and science constitute a common heritage of the whole of mankind and cannot be the privilege of one country or a group of countries."

West Germany's Chancellor Schmidt was more blunt: "To many countries not possessing sufficient sources of energy, nuclear power is indispensable." According to delegates working on the final resolution draft, the "peaceful uses" clause is one of the few that have gone unchallenged, even by those countries who disagree with it.

John Sigerson is Fusion magazine's correspondent at the United Nations. FEF coverage of the UN special session is part of the foundation's ongoing effort to promote technological and economic cooperation for world development as the only effective strategy for disarmament.

The Historical Quest for a

by Judith Wyer

Courtesy of the New York Public Library, Rare Book Division

Science of Vision

FOR CENTURIES the most outstanding scientific minds have probed the relationship of visual perception to cognition, a problem that remains a challenge to the limits of human knowledge today.

The two basic approaches to this question—the Aristotelian and the Platonic—in fact, still characterize the current research in the neurophysiology of the brain, as the following article by Dr. Ned Rosinsky demonstrates.

At the center of the debate between the contending intellectual traditions of Plato and Aristotle is the question of human mentation. To the Aristotelians, the senses are primary in the process of thinking. They describe the mind as a *tabula rasa* to which the senses transmit the raw data that cumulatively form ideas. The Platonists, on the other hand, assert that there are innate qualities to the human mind that distinguish it from the animal mind, which is dominated by its senses. This quality enables the human mind to know itself as a unique creative force in the universe.

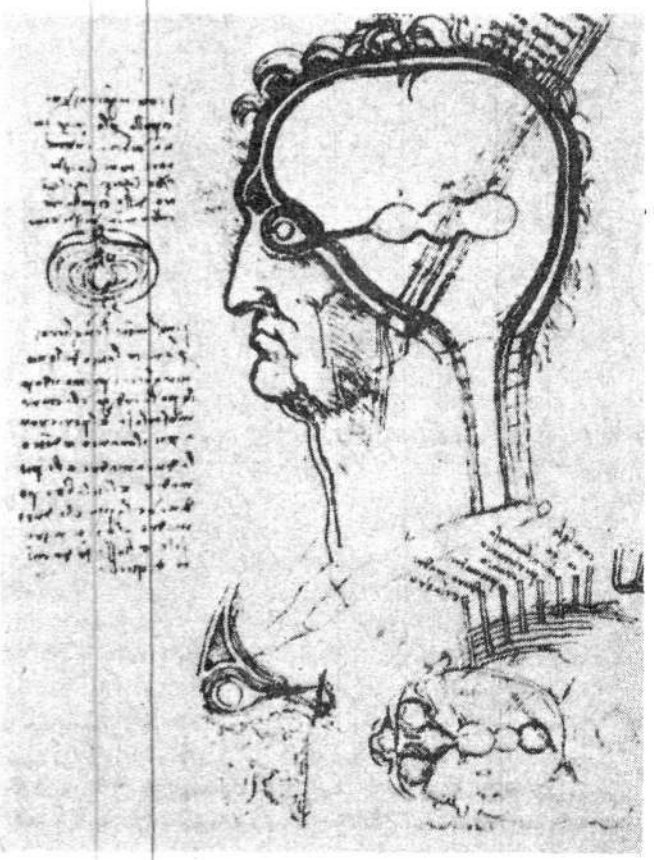
Historically, the Platonic tradition has examined the question of vision from the standpoint that the laws that govern the physical universe, in particular the behavior of light, are coherent with the laws of the human mind. The "truths of the mind" are the "truths of nature," G. W. Leibniz wrote.

Posing the Question

It is from this perspective that the noted 10th century Islamic astronomer and physicist, Al Hazen (Ibn al Haitham) was devoted to solving the question: What happens to impulses of light once such impulses traverse the eye and enter the brain?

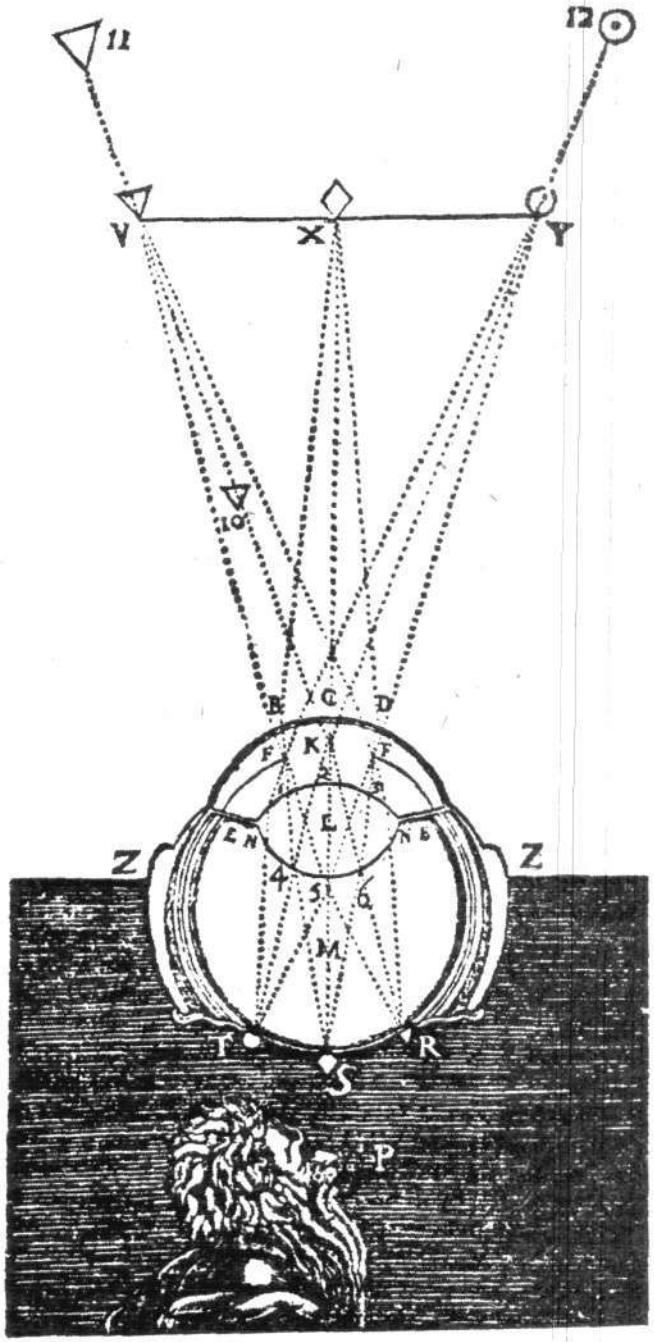
Al Hazen did not pose the question as if the transformation of visual data into ideas was a linear, mechanical operation. Like other thinkers of his time who were systematically working in the tradition of Plato, he was seeking to locate the coherence between the complex process of human cognition and perception and the laws that govern the self-expanding universe.

In his masterwork, the *Kitāb āl-Manāzir* (thesaurus on optics), Al Hazen set out to construct a unified theory of physical, physiological, and geometrical optics. Although he failed in this bold endeavor, he formulated a problem within the domains of physics and human physiology that remained unsolved for 600 years, until the major contribution of Johannes Kepler in his *Paralipomena*. Al Hazen asked how the eye could receive and order light if light behaved in a nonlinear fashion as radiation in a field (a continuous phenomenon of simultaneous diffusion in all directions) and not in the tidy rectilinear rays prescribed by Euclidean geometrical optics. The fundamental



The frontispiece is from a 16th century translation of Al Hazen's major work on optics and demonstrates the science of optics as it was known then. The foreshortening of the bridge, the elephants and the boats show perspective. Refraction of light can be seen in the rainbow, and in the pool of water in the foreground (notice the man's legs). The reflective property of light is shown being used to burn ships with mirrors in the city and to produce a mirror-image reflection (foreground).

Right: Sketches from Leonardo da Vinci's notebooks showing the anatomy of the eye.



Rene Descartes's diagram of the eye illustrating the retinal image, from his La Dioptrique, *which was published 30 years before Kepler's* Paralipomena. *The visual cones originating from points V, X, and Y are refracted through the crystalline lens at L and converge to apexes R, S, and T.*

difficulty in Al Hazen's system was his failure to identify the seat of vision at the back of the eye in the retina; instead, he located the seat of vision in the crystalline lens.

Kepler's Answer and Further Question

In the next few centuries, the research work of several scientists—most notably Leonardo da Vinci and the 16th century anatomist Felix Platter—contributed to the young Kepler's capability to refute the theory of the crystalline lens as the seat of vision.

Among the most important earlier contributions to the science of vision was the work of Roger Bacon, who wrote nearly 400 years before Kepler and was most likely made known to Kepler through Leonardo. Bacon waged a serious investigation into the secrets of perception, which he recorded in his *Opus Maius*. His discussion on optics is methodologically correct, because it begins with an anatomical description of the optic nerve and those sections of the brain that were thought to be responsible for completing the process of perception. Like Al Hazen and Kepler, Bacon confesses the immense limitations he faced in his quest to master the perception-cognition process. Bacon wrote that he was able to define all the various categories of the way in which light multiplies itself by means of mathematics, except for the category concerned with light's entry into the mind:

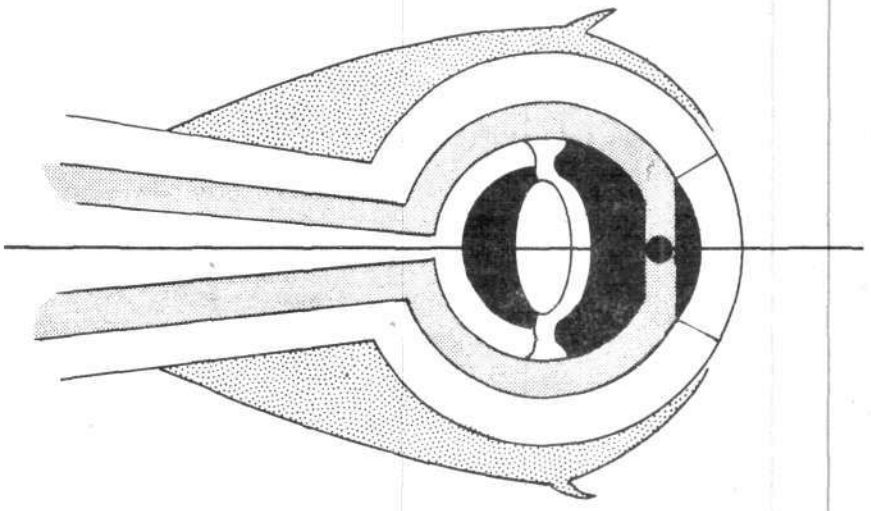
> .... For it violates the common laws of nature and claims a special privilege for itself. And this multiplication occurs only in an animated medium as in the nerves of the senses; for a species follows the fortuitous path of the nerves and does not concern itself with rectilinear passage. And this takes place by the power of the mind directing the passage of the species, as the operations of an animated being require....

Kepler was able to solve the problems posed by Al Hazen and Bacon and, for the first time, to devise a theory that explained the process by which the eye receives and orders infinite rays of light moving in all directions in a field.

Kepler's research on the passage of light through a small aperture like the pupil (using a *camera obscura*) demonstrated that the double convex crystalline lens ordered this untidy mass of light onto the retina by means of refraction.

Like all significant scientific work, however, Kepler's answer posed a higher-order problem that he could not solve, given the technological limitations of his era. Kepler's reflection on the inversion of the image projected back onto the retina from the crystalline lens prompted him to seriously pose the fundamental question: How is the image then reinverted to produce what we perceive as objective reality? This dilemma was not resolved within the confines of physiological optics of that time, but awaited the advancements in medical research and the development of neurophysiological science.

In his *Paralipomena*, Kepler revealed the raison d'être



Left: A reproduction of Al Hazen's cross section of the eye. There is no depiction of the retina, since Al Hazen believed that the crystalline lens at the center of the eye was the seat of vision.

Below: The emblem of the 15th century art theorist Alberti showing the eye with wings. The Platonic notion of wings symbolizes the ascendency to godliness. For Alberti, the study of perception and cognition through the science of optics was the pathway to perfection.

for his investigations into perception and cognition—ongoing efforts to master the heavens through astronomical research.

> Since the diameters of the [celestial] luminaries and the quantities of the solar ellipses are given a fundamental place by astronomers, [it must be recognized that] some deceptions of sight intrude, arising partly from the art of observing through small apertures . . . and partly from simple vision itself, and this deception, so long as it is not taken into account, creates great difficulties for investigators and detracts from the ability of the art to judge [properly]. And so the explanation of error in sight is to be sought in the structure and functioning of the eye itself.

The Perception Question and the Renaissance

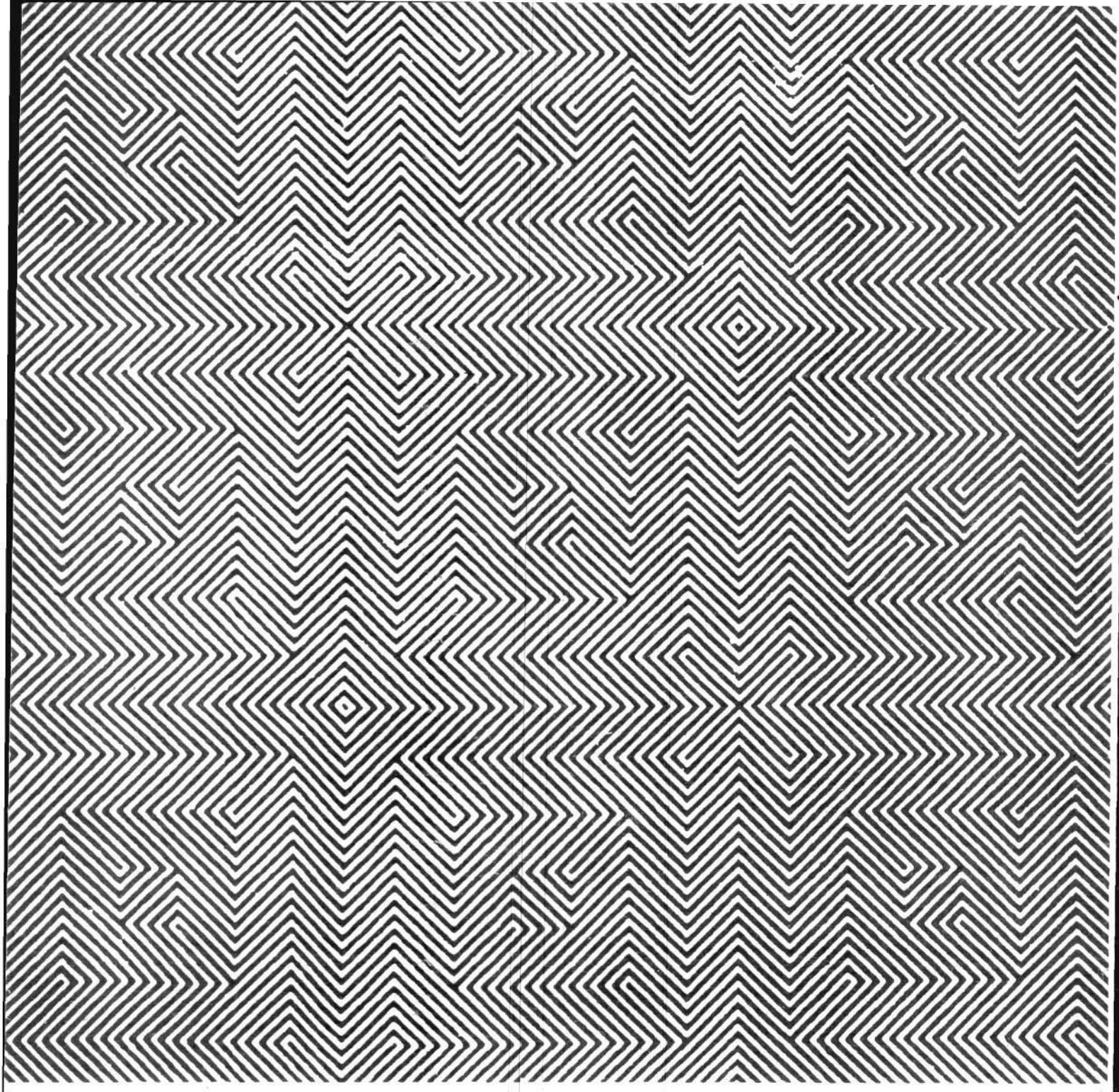
From this early work in geometrical and physical optics, the science of perspective evolved to serve as the theoretical basis for the development of painting in the European Renaissance. The Platonic school conceived of the art of painting as the necessary visual proof of the creative qualities of the human mind for which the eye is its most esteemed sensory servant—"the window of the soul."

In this spirit, the great Florentine art theoretician Leone Battista Alberti wrote that "there is nothing more powerful, nothing more rapid, nothing more worthy than the eye. What more can be said? The eye is such that among the members of the body, it is first, the chief one, and as it were, God."

From the time of 15th century Renaissance Europe onward, the crucial experiments launched by a handful of painters made perception the vehicle for proving the coherence of the laws of human mentation with the laws of the universe. This is explicitly why Leonardo da Vinci equated painting with physics and emphasized that "the limit of vision is simultaneously the limit of comprehension." Working in the tradition of Leonardo, Rembrandt van Rijn declared that he considered himself to be a "mathematician" whose work is proof "in the vegetable material" of paint that his "postulates" could be proven.

Today's quest for a science of vision is unfortunately not being pursued along Platonic lines. As discussed in the Rosinsky article, the neurophysiological work of Eric Schwartz is among the first to adequately describe the geometrical interface between vision and the brain. As such it is a major contribution to the historical understanding of vision as the mediation between the process of creative thought and the laws of the physical universe.

Judith Wyer, an artist and art historian, is currently engaged in a study of the science of perspective.



Vision is inherently geometrical, yet there is no current theory of vision based on geometric concepts. Researchers have long known that the visual scene, as it appears on the retina of the eye, undergoes a number of profound distortions, or transformations while it is conveyed back through various parts of the brain. Dr. Eric Schwartz of the Brain Research Laboratories at the New York University School of Medicine is the first to formulate a concise geometric description of these transformations. This geometric notion is closely related to concepts of fluid flow in hydrodynamics and potential flow in electromagnetic theory, and represents an initial inroad into the discreteness-continuity problem in the field of neurophysiology.

Optical illusions demonstrate "field" phenomena in visual perception, and for that reason they were frequently used by gestalt psychologists like Kohler. In the example here, the impression of motion implies that the viewer is associating the lines with a number of contradictory gestalts, hence the motion from one to another. This article tackles how the geometry of the visual system is associated with higher visual functions and field effects in embryology and evolution.

The Physical Geometry of Vision

by Ned Rosinsky, M.D.

INTRODUCTION

VISUAL PERCEPTION is inherently geometrical. Shapes, forms, motion, size and distance are all inherent qualities of any notion of a visual scene. Yet there is no current theory of vision based on geometric concepts. In fact, there is almost no current theory of vision.

Any theory of vision must address itself to several fundamental questions. First, how does the visual system process both stabilities and motions in the visual scene? Second, the visual system is characterized predominantly by discrete elements, the nerve cells and their connections; what is the coherence between these individual entities and the apparent continuity of perception? Third, even elementary psychological data demonstrate that vision is subsumed by higher psychological processes; how is this brought about? Finally, within the broader context, what is the relationship of the visual system to the underlying invariants that unite the physical universe and mental processes?

Writing in 1947, the gestalt psychologist Wolfgang Kohler posed the problem of "psychophysical isomorphism" (physical and psychological processes whose internal relations are closely related) in the following way:

> Dynamic distributions are functional wholes. Take, for example, a single electric circuit. The differences of potential and the densities of the current distribute themselves along the conductors in such a way that a steady or stationary state is established and maintained. No part of this distribution is self-sufficient; the characteristics of local flow depend throughout upon the fact that the process as a whole has assumed a steady distribution.
>
> If a similar conception is to be applied to the processes which underlie sensory experience, we must avoid a mistake. In his protest against psychological atomism William James once said that in the sensory field local experiences are interwoven with their neighbors in a manner which is beyond the grasp of pure intellectual theory. He also thought that original sensory experience is uniformly continuous, and that all cuts and boundaries are later introduced into the field for pragmatic reasons.
>
> From the point of gestalt psychology, such a statement does not correspond with the facts. Notwithstanding the general dynamic interdependence throughout the field, there are boundaries in it at which dynamic factors operate toward a measure of segregation rather than uniform continuity. For this there are good examples in physics. Everything favors the assumption that the same happens in the nervous system . . .
>
> The fact that organization depends on the relations among the local stimuli makes it entirely clear that sensory organization cannot be understood in terms of local processes as such. Independent local facts are entirely indifferent to any formal relations which may obtain among them. On the other hand we have no difficulty in understanding the role which such relations play in organization, if we assume that the organization of sensory fields pictures the self-distribution of processes in corresponding areas of the brain. Dynamic self-distributions maintain themselves by interaction among the local events. But we have seen that in all parts of physics interactions depend upon the "conditions-in-relation" as given to the various parts of a system. Since the same holds for visual organization, we have every reason to believe that this organization results from the self-distribution of certain processes in the visual sector of the brain. As a matter of fact, a careful study of visual organ-

ization may sooner or later tell us quite specifically what physical processes distribute themselves in the visual cortex.

This article presents the first work in neurophysiology to conform with Kohler's principle that there is a lawful relationship between physical and psychological science. Kohler was initially trained in physics within the tradition of Bernhard Riemann and Felix Klein, and so he had direct access to the most advanced conceptions concerning higher manifolds and solutions to the discreteness-continuity question. His lifelong work in psychology was aimed at producing a theory of the mind based on the invariant of the physical universe: *the fundamental principle of self-development*. As Kohler's work makes clear, there is no simple, one-to-one correspondence between physics and psychology; rather, psychology is a higher expression of this invariant operating in the physical universe.

Disproving the Neurophysiological Dogma

In contrast to this notion, current neurophysiological dogma asserts that the brain functions like an extremely complex computer. Each of this computer's approximately 10 billion nerve cells is connected to an average of 100,000 others, forming the possibility for a virtual infinity of circuits that could "encode" things like thoughts, emotions, memories, logics, and so on. And if it is found that these circuits do not control the encoding, researchers have offered equivalent notions using proteins, RNA molecules, or even individual cells as alternative possibilities.

Although all these ways of viewing the brain are patent reductionist nonsense that has produced nothing better than the nerve-cell circuit diagram of the sea-snail, such paradigms have dominated the field for the past 100 years. Only recently have several neurophysiologists—like Kohler originally trained in physics—begun investigations along more productive lines. In the forefront of these investigations is the Brain Research Laboratories of the New York University School of Medicine (formerly of New York Medical College), chaired by Dr. E. Roy John. This article focuses on the recent research of one of John's coworkers, Dr. Eric Schwartz.

Schwartz's work deals with visual perception in primates, cats, and goldfish, and directly associates the higher-ordered and self-organizing geometry of neural elements, nerve cells, with specific aspects of vision.

In order to understand his work, it is useful to have an initial distancing from one's own visual system. When many European scientists were experimenting with lens systems 400 years ago, Johannes Kepler asked this question: If the lens in the eye inverts the image of the visual scene that appears on the back of the eye on the retina, then why don't we see the world upside down? This problem, although simple to answer with a "What difference does it make?" raises the profound epistemological

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GLOSSARY

afferent: traveling toward the central nervous system, such as a nerve or nerve impulse.

analytic function: a continuous and differentiable function of a complex variable that creates a "smooth" mapping; that is, although the mapping may change the overall shape of the plane relations, the angle and size ratio relations are preserved in any small area of the map—except for points of singularity.

axon: a lengthy extension of the body of a nerve cell that transmits electrical signals away from the cell to other cells.

binocular disparity: the difference in images of the two eyes due to the difference in location of the eyes in space.

boundary conditions: the limiting conditions of a varying process, such as the shores of a river.

complex variable: a number composed of two distinct parts that vary independently and of the form $x+iy$, where i is the square root of -1.

concatenated: linked, connected.

Laplace equation: a second-order partial differential equation that can be interpreted in fluid-flow dynamics as specifying that flow in one direction is always compensated for by flow in other directions; that is, no net fluid is introduced or lost.

linear function: a straight line relationship or constant proportion between two varying quantities; for example, one yard is 36 inches, two yards are 72 inches.

neuron: a nerve cell.

neurophysiology: the science of the activity of the nervous system, including the brain, the spinal cord, and peripheral nerves.

retina: a structure in the back of the eye composed of light-sensitive cells and other elements. The eye's lens, in the front of the eye, focuses an image, the visual scene, on the retina (as in a camera). The retinal cells connect to the brain by way of axons from the individual cells, and these are carried back to the brain through the optic nerve.

transformation: equivalent to mapping; a correspondence between points on one plane and points on another plane. "A maps to B" means that each point on A has a corresponding point on B. In general, the relative location of points on A changes when these points are mapped to B.

viscosity: the frictional force experienced by a blunt object as it is dragged through a fluid.

visual receptive fields: the retinal area that projects to a given area (or cell, etc.) of cortex.

vorticity: the amount of twisting motion, such as in a fluid.

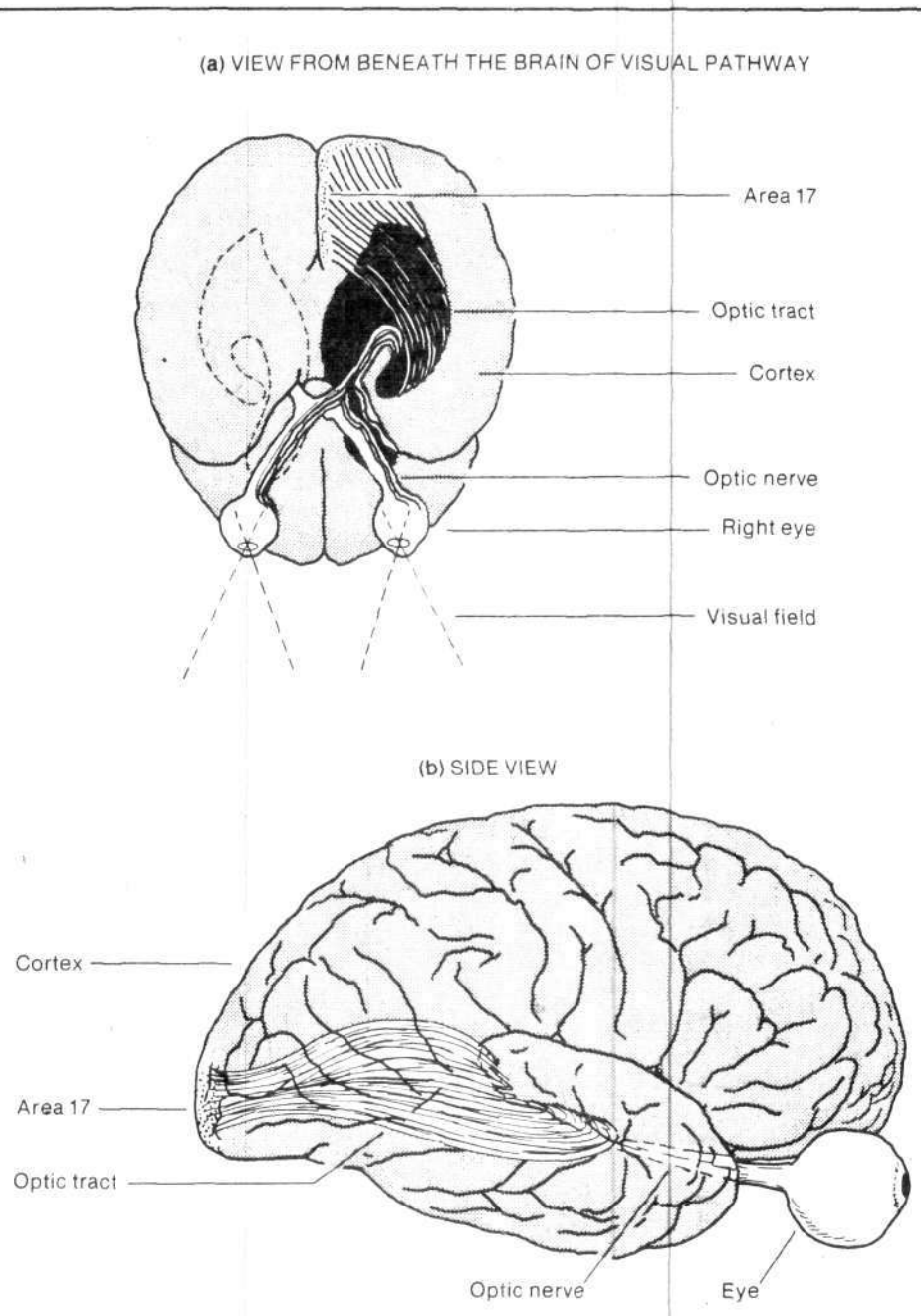

Figure 1
THE RETINO-CORTICAL PATHWAY

Shown in (a) and (b) are the eye, the optic nerve and optic tract, and visual cortex area 17 of the brain. Only the right side of the visual pathway is shown. The lens in the front of the eye focuses an image (the visual scene) on the back of the eye, where the retina is located, much like the film in the back of a camera. Various parts of the image stimulate light-sensitive nerve cells in the retina. These cells have embryologically established connections to the brain via long thin extensions, axons, which are carried like a cable back to the brain within the optic nerve and optic tract. The axons end up in the primary visual cortex area, where they electrically stimulate cortical cells to recapitulate, although in somewhat changed form, the image-relations of the retinal visual scene. This change in form, which results from redistribution of fiber positions within the optic tract as it grows back from the eye during embryological development, is the main focus of the article.

Illustrations by G. Genazzio

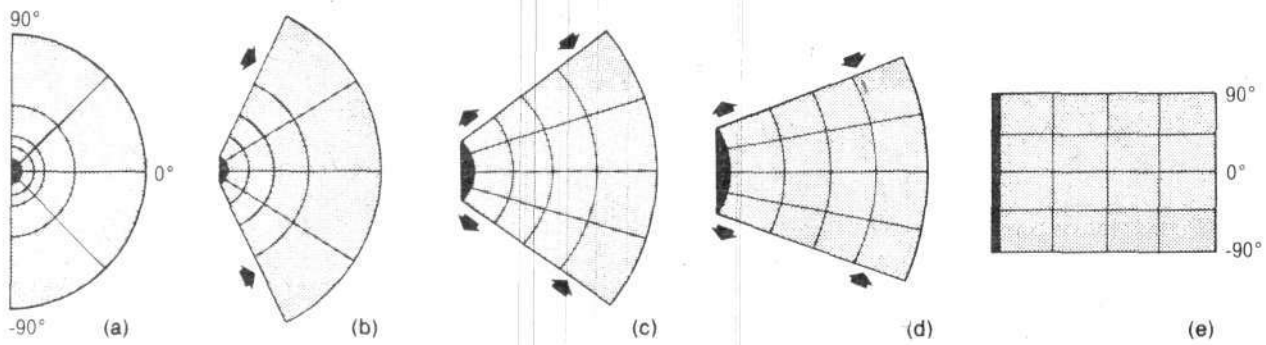

Figure 2
MATHEMATICAL REPRESENTATION OF THE COMPLEX LOGARITHMIC TRANSFORMATION

The complex logarithm transforms a radex in the visual scene into a rectangular grid on the cortex. The radex (left) is composed of exponentially spaced concentric circles and radii emanating from the common center of the circles. Only half of the circle is shown in this mapping. In the transformation, the center of the circles, the heavy black dot, is stretched out to form the entire left border of the rectangular figure (right) as a small wad of gum could be stretched out to form a line. Simultaneously the entire figure is "unwrapped" so that all of the radii become parallel horizontal lines, while the concentric circles become parallel vertical lines.

A heuristic series of transition figures is shown. Note that not only the central dark area is stretched out, but also the entire center portion of the radex.

question of the relation between cognition and perception.

Although this problem seems trivial, Schwartz shows that the visual system introduces several initial changes in the visual scene that are far more radical than simply inverting it. Furthermore, Schwartz shows that these changes, or *transformations*, make all the difference in the world with respect to the possibility for three-dimensional vision, the stability of the visual scene with eye motion, and other complex visual functions. Unlike the inversion referred to by Kepler, which occurs within the globe of the eye, Schwartz's transformations occur as the image from the retina is carried back through the optic nerve to the brain, specifically to the primary visual area of the brain, cortical area 17 (Figure 1). The transformations depend on neural geometries originally set up in the embryo, which are related dynamically to a self-distribution of developing neural elements.

The image is "carried" by the optic nerve as follows. The retina consists of millions of light-sensitive nerve cells or *neurons* that are variously stimulated to electrical activity, depending on the visual scene. During embryological development, each of several million neurons grows a long, threadlike extension, termed an *axon*, back through the optic nerve sheath to the brain (Figure 1).

This "cable" of axons is capable of carrying the retinal image (through their individual electrical activities) in an approximate point-to-point fashion, back to the visual cortex area of the brain.

If there were no rearrangement of the relative positions of the axons within this cable, then the image impinging on the cortex would be a faithful replication of the retinal visual scene. In fact, however, as this fiber bundle grows back toward the brain in embryological development, the fibers change their relative positions, progressively and in an ordered way, producing a very specific distortion in the visual scene as it is presented to the cortex. Although the overall shape of this distortion has been known for some time—researchers have derived the distortion experimentally by individually stimulating a sample of retinal cells and then recording from electrodes placed in the cortex*—neurophysiologists have been unable to explain how this distortion could be useful for vision.

Visual Transformation and the Complex Logarithm

Schwartz initially approached the problem of visual transformation by assuming that the geometry had an important functional significance. His initial contribution was to elaborate on the significance of the formulation by Fisher (1973) of a concise mathematical description of the transformation of the visual scene to the cortex based on the complex logarithm (Schwartz *1977a*).** The general form of the complex logarithmic approximation to the transformation from the visual scene to the cortex is shown in Figure 2.

Schwartz noted that although the complex logarithmic transformation profoundly distorts a visual image, the cortical image is not changed *but simply shifts sideways when the visual scene changes by either rotating or* symmetrically changing size (as in motion toward or away

from the viewer). Presumably this sideways shift makes these common changes in the visual scene readily recognizable on the cortical level.

Schwartz then related the properties of *size and rotation invariance* to the dynamics of depth perception and other functions, and associated the transformation with a *fluid-flow dynamic* in the embryology that could account for how each growing axon eventually impinges on the correct cortical cells. It should be noted that this dynamic explains the retina to cortex transformation without the necessity for postulating a reductionist, cell-to-cell recognition factor for each of the millions of connections formed.

To recapitulate: points on the retina (for purposes here, actually cells that approximate points) map to points on the visual cortex (again, cells), by mediating fibers carried through the optic nerve. These fibers change their relative positions as they grow back through the nerve during embryological development (as the wires in a support cable may be twisted around each other, although the specific rearrangement involved here is not simply a symmetric twisting), producing in its final form a transformation of the visual scene. Once this transformation has developed in the embryo it changes very little after it is set up. Within the context of this permanent transformation, if specific images on the retina rotate or dilatate, then the transformed image on the cortex will be *invariant* except for sideways motion.

Before proceeding, it must be noted that area 17 subsequently maps to the secondary visual cortex, area 18; then to area 19, and so on, all very likely before any conscious perception of the image occurs. A multitude of higher-level transformations and other functions are involved in vision, about which very little is known at present. Many of these higher activities involve greater degrees of freedom than the mapping with which we are here concerned (for instance, the capacity of the mind to actively create new geometries in conceptions) and are intimately influenced by deliberative activity. For experimental reasons and because of the lagging theoretical state of the art, these higher activities at present are beyond the reach of experimental neurophysiology.

This work, however, aims to make inroads toward solving these more difficult questions. In fact, as I shall show, the implications of Schwartz's work for embryology and evolution, more than its implicaitons for visual physiology per se, bear directly on the question of the higher cognitive functions.

THE SCHWARTZ FINDINGS

Schwartz has found that several aspects of the visual system are remarkably accessible to investigation along geometric lines—particularly the spatial mapping of the retina onto the cortical area 17.

In order to treat these aspects in mapping terms, they must be treated as though they were *planar structures*, so that points from one plane map to points in the other. There is good justification for making this initial approximation. The retinal surface is only several layers of cells thick, and the axonal projections to the brain come from only one of these layers, the *ganglion cell layer*.

Similarly, the cortex of the brain is called the cortex because it is the *outer layer* surrounding the cerebral hemispheres of the brain. Within the cortex itself there are several layers, and here we are mainly concerned with *layer 4*, the layer that receives direct stimulation from the retinal fiber bundle. One objection to this planar representation might be that the cortex has a convoluted appearance over the surface of the brain. However, if these convolutions are smoothed out, it changes the internal relations over the area 17 only slightly, so that the two-dimensional approximation is justified for our purposes here.

Although so far only the overall or global form of the mapping connection has been referenced, a number of aspects of visual physiology in the small may be explored along similar geometric lines. These are the properties of *feature extraction*, the experimental finding that individual cells in the cortical area 17 apparently are variously "tuned" to respond to aspects of a visual stimulus. This is true not only if that stimulus simply occurs at a certain point in the retina, but also if the stimulus has one or more of the following complex attributes: is a straight line or edge at *a certain location, inclining at a certain angle*, moving with a certain velocity; has a certain binocular disparity (a difference of appearance of the image in the two eyes because of the different locations of the eyes in space); has certain light-dark contrast; and so on.

Current reductionist dogma postulates that these properties are somehow inherent to the individual cortical cells, although this has never been verified or explained. However, Schwartz shows that if one assumes that small patches of retina each map logarithmically to small patches of cortex (with the size of the patches on the cortex being approximately 1 mm by .5 mm and with each patch within its own mapping resembling the general form of the global mapping), then most, if not all of the feature extractor properties can be derived as *geometric qualities* from this local mapping. Furthermore, the fluid-flow concept also explains this higher-ordered local cell-to-cell connection pattern, although the dynamics would be somewhat different from those postulated for the global map.

Boundary Conditions

In both the global and local mappings the fluid-flow dynamics imply that *boundary conditions*, such as the shape of the boundary of the retina, the optic nerve sheath, and the visual cortex, are determining the pattern of neural flow in setting up anatomical connections and the resulting physiological implications. If this is true, then the changing of these boundary conditions within the nervous system could be an appropriate point of intervention for the rapid evolution of visual systems.

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*See, for example, Daniel and Whitteridge 1961.

**The complex logarithm is an analytic function (equation) frequently used to describe the dynamics of fluid flows; for example, the pattern of fluid flow in different shaped pipes.

Figure 3
THE HOMUNCULUS OF MAN

A map of the body is drawn over the primary skin-sensation area of the brain, showing the area of the body that corresponds to the area of the cortex. Equal areas of the body are not represented by equal areas of the cortex, which results in a distortion of the proportions of the figure. The figure is called a homunculus. Note that the stretched parts are also the parts of the skin that have the greatest concentration of perceptivity or ability to discriminate sensations: the hands and mouth area. Intensity of perceptivity is transposed into cortical space, just as in the visual mapping the central part of the retina is allotted an increased cortical area in the projection.

Reviewed below are some data that show a tendency within vertebrates progressively to set up the logarithmic analytic structure in the visual mapping by an *evolution of boundary conditions* rather than by the reprogramming of millions of individual cells.

Vision is not the only type of sensation that maps in a "smooth" surface-to-surface fashion, or topographically, to the brain. Touch and pain on the skin surface of the body map topographically to the primary cutaneous sensory cortical area (Figure 3); the basilar membrane, the hearing receptor surface in the inner ear, maps topographically to the auditory cortex and other areas; and even in the sense of smell, the lining of the nose, the olefactory mucosa, is mapped topographically to the olefactory cortex. All of these mappings are complex nonlinear transformations whose functional significance with respect to the sensations is largely unexplored. More generally, Gaze and his coworkers (French et al. 1976) have stated that the entire embryo is composed functionally of interacting surfaces or layers of cells, folded and arranged in complex formations, so that the mathematics of surface relations may be an appropriate initial tool for describing development. The mathematics of surface relations in physical processes is predominantly the mathematics of Riemannian surfaces, or analytic functions.

The Retino-Cortical Mapping

The complex logarithm mathematically transforms a radex (a pattern of concentric circles and radii) into a rectangular grid, as shown in Figure 2.* Figure 2a, representing the z plane in complex variables, has a radial grid consisting of radii and concentric circles for identifying points on the plane as (r, θ). The points on the z plane (the visual field) map to points on the w plane, (the cortical area), shown in Figure 2e.

The polar coordinates on the z plane are chosen because this simplifies the computation of the complex logarithm: In complex variables, points on the z plane are generally represented by $(x + iy)$; here, using the (r, θ) notation, $(x + iy)$ becomes $r(\cos \theta + i \sin \theta)$, which also can be represented as $re^{i\theta}$, so that the log function becomes $\log r + i\theta$. Since r and θ are real, the rectangular coordinates on the w plane represent $\log r$ and θ, respec-

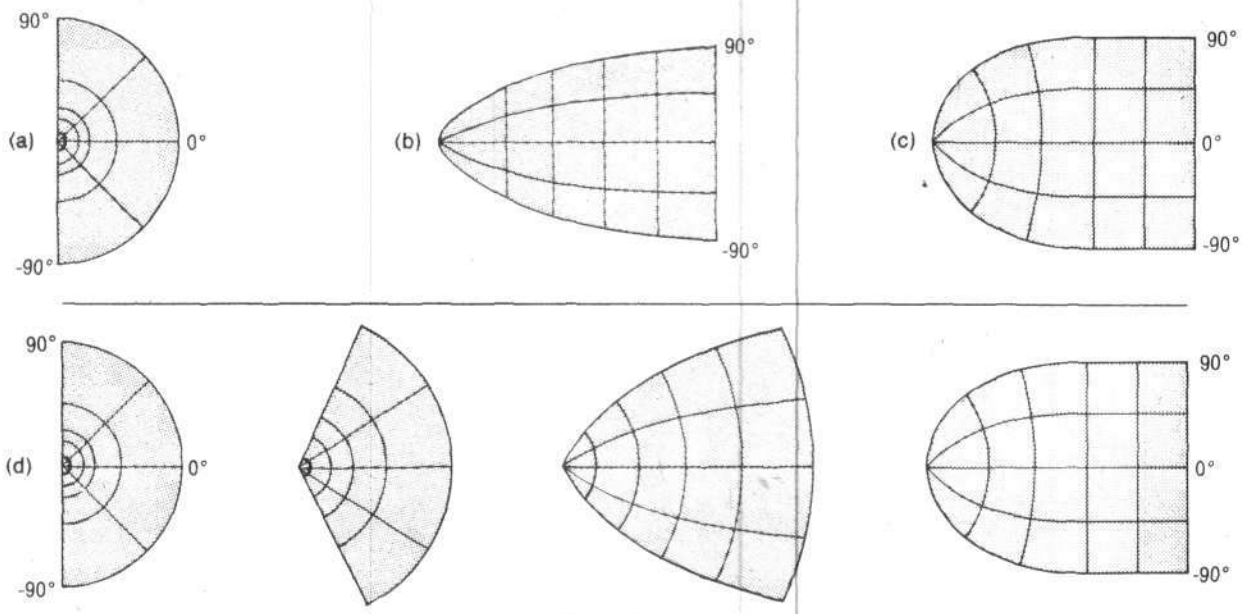


Figure 4

MATHEMATICAL MODEL OF MAPPING FROM THE VISUAL AREA TO THE CORTEX

The retina is shown in (a), *indicating the landmarks that appear in the cortical representations. Note that only half the retina is shown because there are actually two cortical areas 17, one on each side of the brain* (or cortical hemisphere). *Half of each retina maps to the corresponding area 17; that is, the right half to the right area 17, and similarly on the left.*

The actual area 17 is shown in (b). *The shape of the visual cortex is not a perfect rectangle, but is rounded on the end that represents the center of the visual field.*

Represented in(c) *is log* $(z + 1)$. *This is a better fit to the shape of the actual visual cortex than the log z shown in Figure 2, which was a heuristic approximation. Log* $(z + 1)$ *is rounded for small values of z, on the left, small portion of the figure and nearly rectangular for the rest of the figure.*

Shown in (d) *are heuristic transition figures for the mapping log* $(z + 1)$.

tively. Thus, radii on the z plane map to horizontal lines on the w plane, with angle size changed into vertical distance. Exponentially spaced concentric circles map to equally spaced vertical lines, as shown in the figure.

Turning now to the actual data, there is one respect in which the physiological retino-cortical map differs significantly from the complex logarithm. The logarithm has a singularity at $z=0$, because the function goes to infinity as z goes to zero. Physiologically, the central 1 degree of visual field (degree is used here as in astronomy, meaning a measure of area of field on a sphere, not as used above in polar coordinates) has not been mapped in detail. However, limited measurements indicate that it maps to a linear function or straight line relationship on the cortex. Outside of this central area the mapping closely follows the complex logarithm (see Figure 4).

One degree is approximately equal to the image of 1 square centimeter at a distance of 57 centimeters from the eye. This 1 degree does represent the central retinal fovia area, which is extremely important for vision. However, compared to the usable visual field it is small—only several percent of the total area. A better formulation that represents the entire visual mapping, including the fovia, is log $(z + 1)$, shown in Figure 4c, which is approximately linear at small values of z and very close to logarithmic at large z. It is also free of singularities** over the domain of the function. The right half of each retina maps to the right hemisphere's cortical area 17, and similarly, the left half of the retina maps to the left cortical area, so that θ goes only from $-90°$ to $+90°$. Thus, z can be taken as always greater than or equal to 0 (except for some small overlap of bilateral representation of the central fovial area), and so $(z + 1)$ is always greater than 0. Figure 4 shows data

*For those who are not familiar with the following notations, the diagram of transformation will be sufficient to provide all the required notions. *Complex variables*, z or $(x + iy)$, are used to identify points in a plane, just as a real variable, x, identifies points on a line. Thus, a function of a complex variable, w or f(z), takes the points from one complex plane, the z plane, to another, the w plane; if it is applied to all the points in the plane then it maps the z plane onto the w plane.

**The term singularity is used here in the mathematical sense, the point at which the function blows up. A true physical singularity, on the other hand, such as a discrete molecule, cell, and so forth, represents a potential inflection point within the ongoing development of the manifold.

from the actual physiological map, demonstrating a close correspondence with the log(z + 1) mapping.

The overall effect of the complex logarithmic mapping has a close psychological correlate. The center of the visual field is the area in which vision is most intense, in which the perception of detail and other qualities are most concentrated, while the peripheral visual fields are frequently described subjectively as fuzzy. This relative intensity of visual perception on the retina becomes represented by a *spatial* allottment on the cortex—the central visual area is greatly expanded in its mapping, while the peripheral area is contracted. Psychological data suggest that this retinal-intensity/cortical-spatial relation holds over most of the visual field.

Size and Rotation Invariance

The size and rotation invariance properties of the logarithmic mapping now can be easily demonstrated (Figure 5). If an object in the visual field rotates around the visual center, at $z=0$, then every point of the object will travel in some circle whose center is at $z=0$. Since all such concentric circles are mapped to vertical straight lines in the mapping, the mapped figure simply will move in a vertical direction.

If the object symmetrically dilatates, for example, as the object gets closer to the eye, then all points on the object will travel along radii away from the point $z=0$. Since these radii all map to horizontal lines, the mapped figure simply will move sideways in the map. Thus, dilatations and rotations are converted into simple translation motion in the map.

The same conclusion can be shown more rigorously by using the $z=re^{i\theta}$ notation: A symmetric dilatation introduces a real constant, k, such that any point z_i now equals $kre^{i\theta}$, and log z equals log k + log r + $i\theta$, which simply adds a real constant (log k) to the map or a translation of the figure to the right by the distance log k. A rotation introduces a real angular constant, c, such that any point z_i now equals $re^{i(\theta+c)}$, which maps to log r + $i(\theta+c)$. This adds an imaginary constant (ic), resulting in a translation of the mapped figure in the vertical direction. These same considerations apply to the area in the physiological map which is logarithmic; that is, everywhere except the mapping of the central fovia area.

Appropriateness of the Complex Logarithm

Size and rotation invariance are crucial for depth perception. Three-dimensional vision depends on the fact that the two eyes are located in different spatial positions (that is, have different points of view), so that the retinal image in one generally will be different from the other. These two images must be compared and correlated to produce the basis for a three-dimensional image. The differences to be correlated can be quite sizable. In the course of normal eye movements, the eyes may differ in their relative angular positions (both horizontally and vertically) producing as much as a 20-degree rotation difference in the two images. Also, objects close to the viewer may differ in the size of their retinal images by as much as 10 percent because of the different distances of the two retinas.

A recent paper in the optical pattern recognition literature (Casasent and Psaltis 1976) points out that if one is restricted to the generally used mathematical cross-correlation techniques (the equivalent of placing one image on top of the other and seeing how well they match up), then if one image is rotated only 1 degree, there is a tenfold drop in the ability to compare images. In other words, things rapidly become extremely blurry. Similarly, with a 1 percent enlargement of one of the images, there is again a tenfold drop in the ability to compare images.

This means that under normal conditions of stereopsis (3D vision), size changes and rotations may be much larger, by an order of magnitude or more, than the amount that, according to generally used mathematical techniques, has been shown to destroy the ability to compare images.

Yet, the visual system can handle these image differences easily. In fact, evidence from experimental psychology shows that humans quickly can cross-correlate and usefully compare images presented separately to the two eyes even when these images differ in size by considerably more than 10 percent or are rotated by more than 20 degrees (Casasent and Psaltis 1976). This strongly implies that the anatomically determined logarithmic mapping plays a central role in ongoing visual activity.

By normalizing for size and rotation changes, the complex logarithm also should be useful for determining that an object in motion—either rotating or moving toward or away from the viewer—is not changing its shape while that motion is going on. Similarly it should be useful for maintaining the stability of the visual scene while the eyes themselves move.

Consider the following as an example of the difficulties posed by even a small rotation. Place the palms of your hands together and spread the fingers of each hand. Now rotate one hand so that when looking at the two hands (with the back of one of the hands toward you), the left and right fingers alternate in space. If these were two flat, identical superimposed images, without any other clues, extricating two hands from the image of 10 fingers could be difficult.

As an example of the size and rotational invariants, Figure 5 shows how the image of a square on the retina (half the square for each half of the retina) would map to the cortex. The distortion introduced by the mapping bends the straight sides of the square into curved lines, although, significantly, the continuity of the perimeter of the figure remains intact. (This is related to the continuous property of the mapping.) Dilatation and rotation of the square, as shown in the figure, produce images that are identical to the original mapping, except for vertical or horizontal translations.

Note that the right angles in the square map to intersections of curves that locally are perpendicular; that is, the tangents to the curves at the "peaks" of the waves in the mapped figure would intersect each other at right angles. The preservation of angle relations in the small (that is, in the small neighborhood of the peak in question) could aid in object recognition, in spite of overall

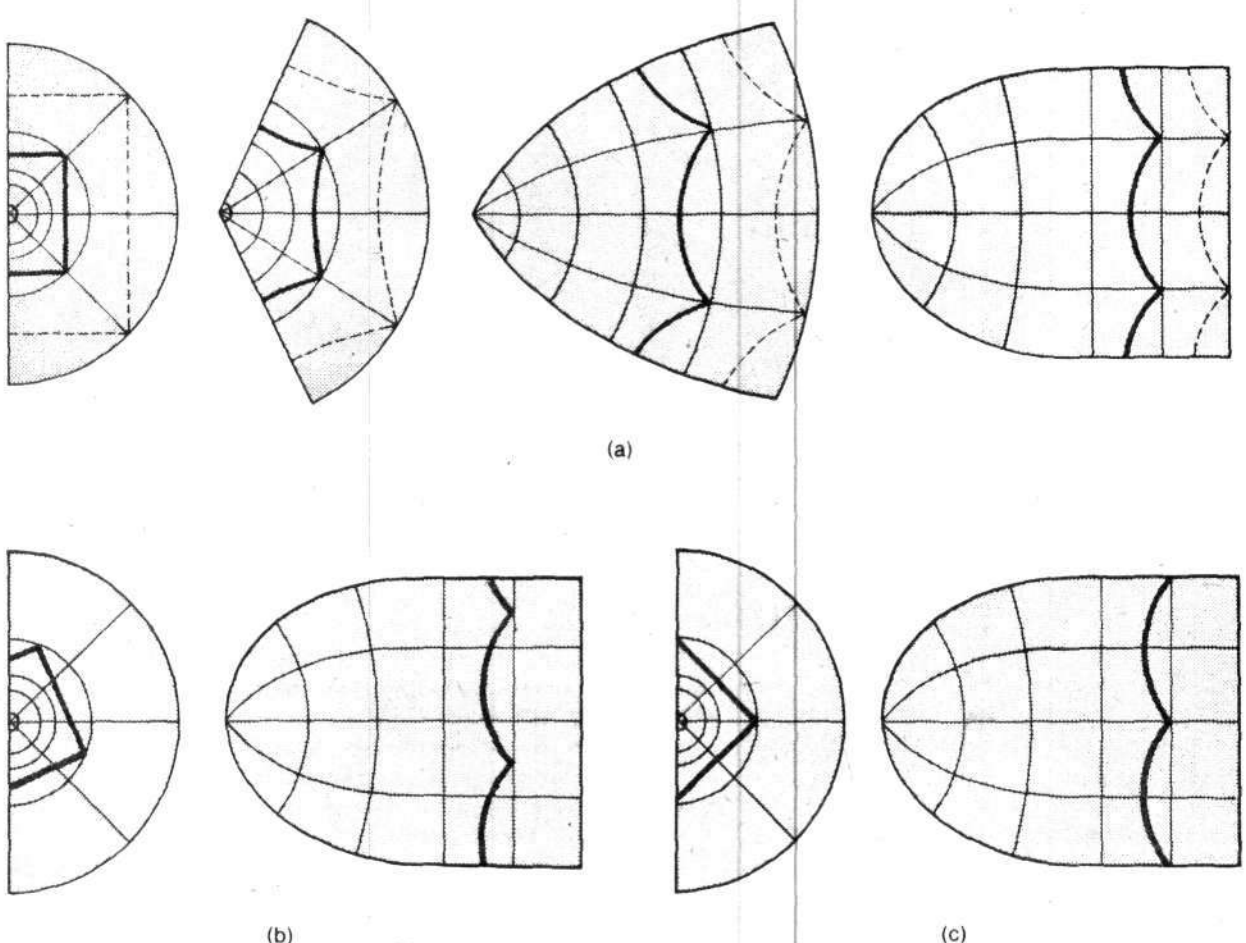


Figure 5

THE MAPPING OF A SQUARE IMAGE TO THE CORTEX ACCORDING TO THE COMPLEX LOGARITHM

These three series of mappings show size and rotation invariance. Series (a) depicts both the mapping of the image of a small square on the retina to the cortex (solid line) and the mapping of a symmetrically enlarged square (dotted line). The initial image in each case is followed heuristically as it would be progressively distorted by the complex logarithmic transformation to the final image shown on the cortex. Note that the transformal figure on the cortex of the enlarged square is not enlarged, but simply moved to the right. It is size invariant.

In (b) the square is rotated 22.5° and in (c), 45° to depict rotation invariance. The transformed figure that results on the cortex from this rotation on the retina is not rotated but simply moved in an upward direction.

Some kinds of continuous intermediary distortions occur within the optic tract as the image is carried from the retina to the cortex, but the details of the distortions progressively introduced by the shifting of the axons in their anatomical pathway back to the brain have not been experimentally determined. This series represents one possibility.

Notice that the initially straight sides of the square are progressively bent as the concentric circles (which are introduced here only as a means of keeping track of points on the retina) straighten out. Also the corners of the square remain corners, and the 90° angles are preserved in the small neighborhood of the corner. This angle-preserving quality of the map is a general property of analytic transformations and "smooth" fluid or potential flows. The mapping is also continuous; that is, points near each other on the retina map to points near each other on the cortex. In the mathematical model this "nearness" would extend to the infinitesimally small.

distortion of proportion. This preservation has been documented experimentally (Daniel and Whitteridge 1961).

The maintaining of angular relations in the small has a more fundamental importance. Mathematically, this property is necessary and sufficient to prove that a mapping is *analytic*; that is, it can be interpreted as potentially representing a fluid-flow situation. This lends confirmation to the logarithmic characterization of the retino-cortical mapping originally proposed on the basis of global landmarks (Figure 4), since the complex logarithm is an analytic function.

Another piece of confirming evidence is the measurement of the cortical magnification factor—the amount that the mapping lengthens or shortens a small-line segment on the retina. This magnification factor depends only on the distance of the given small-line segment from the center of the visual field and is proportional to 1/r, the inverse of the distance from that center (Daniel and Whitteridge 1961).

And the unique analytic function whose derivative (the magnification factor is the equivalent to the derivative of the mapping) is 1/r and which transforms an annulus-shaped area (the circular retinal area minus the central circular fovial area) into a rectangular strip (the cortical area, in this approximation) is the complex logarithm (Ahlfors 1966).

The preservation of angles in the small, the analytic or conformal quality of the mapping, suggests that the embryological neural fiber growth, or "flow," follows a fluid-type of motion. The next section shows that the 1/r derivative implies a precise dynamic for how this fluid flow could proceed, given the fact that the neural fibers are a discrete rather than continuous medium.

To visualize the angle-preserving quality in smooth fluid flows, imagine several small boats floating near each other, motionless in the middle of an extremely calm ocean. If the shorelines of the ocean slowly change shape and size, the overall distribution of water will be changed. But as long as no turbulence is created (that is, if the shorelines move so slowly that there is no turbulence), then even though the boats may find their geographic positions shifted, the angular position of the boats with respect to each other will remain virtually unchanged. This is the case even if the entire ocean surface expands or contracts leaving the boats farther apart or closer together.

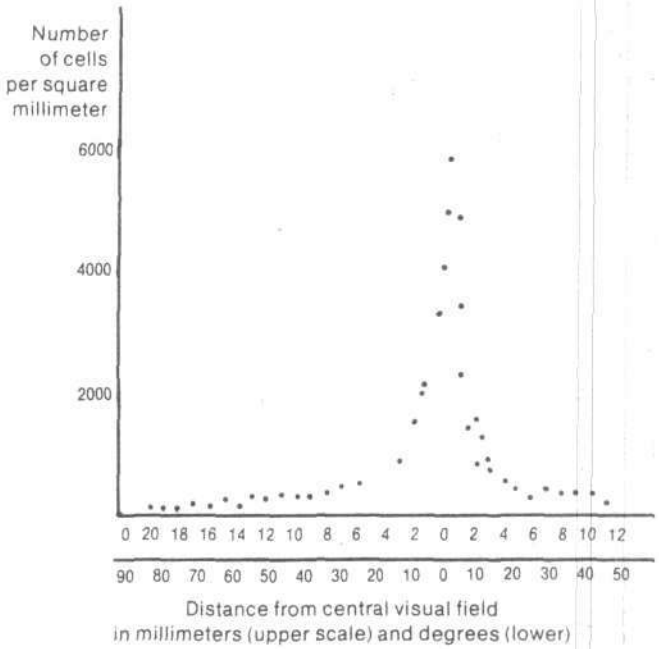


Figure 6
RETINAL CELL DENSITY

The graph plots cell density, the number of cells per unit area, against the distance from one side to the other of the retina. The rising and falling curve indicates that most of the cells are concentrated at the visual center and decrease progressively toward the periphery. This is in correspondence with the psychological experience of having more "intensity" of visual acuity and other functions in the central area of vision than at the edges of the visual field.

THE GEOMETRY OF DEVELOPMENT

How is the global geometric transformation of the visual scene produced embryologically; that is, how is the mapping originally set up?

During development, each of the retinal ganglion cells sends an axon, a thin fiberlike extension, back through the optic nerve to the brain which (after a relay in an intermediary brain area, the lateral geniculate) connects with cells in the visual cortex. How does each of the millions of retinal cells know which cortical cells to connect to in order to produce the precise mapping that has been found experimentally? Current neurophysiological dogma asserts that the retinal cells must be programmed individually (that is, genetically) to hook up with the correct cortical cells, presumably by some kind of cell-specific identification chemical. This supposedly gives rise to specific chemical "handshaking" between cells, reminiscent of the chemical specificity in the antigen-antibody reactions of the immune system. For both experimental and theoretical reasons, reviewed below, this reductionist idea can be thrown out.

The cell density and boundary conditions of the retina and cortex strongly imply the fluid-flow dynamic referenced above. Except for several degrees of central visual field, the retinal cell density* follows an inverse square law with respect to the center of visual focus; that is, it is proportional to $1/r^2$ (Daniel and Whitteridge 1961). In other words, most of the cells are located near the center of the retinal field, and taper off toward the periphery (Figure 6). This coheres with the psychological experience of high density of visual activity and general perception in the central part of the visual field, compared with the periphery.

In contrast, the density of cortical cells in area 17 is constant.

If the retinal cell density is proportional to $1/r^2$, then the number of cells along a small line segment is proportional to

$$\sqrt{1/r^2}$$

or $1/r$. (An area measurement is the square of a linear measurement, so the linear measurement is the square root of the area measurement.) A cell *potential function* can be written as the integral along a line path that is proportional to the integral of $1/r$ (that is, adding up the cells encountered along a path). Using the techniques of calculus, this is proportional to log r. This is entirely analogous to the calculation of potential around a line charge in electrical field problems, in which the field, E, equals $1/r$. (In both cases, a vector notation is necessary to be entirely correct.)

The constant cell density in the cortex is matched by the impinging fibers from the retina which, by the time they reach the cortex, also are distributed equally. A *mapping function* of cell potential from the cortex to the retina, therefore, can be constructed mathematically and is also proportional to log r (equal distribution, or no change in potential, goes to the $1/r$ distribution, or log r potential). The cell potential mapping function is thus mathematically the *inverse* (it goes from the cortex to the retina rather than from the retina to the cortex) of the actual spatial mapping function found to be proportional to log r in the direction of retina to cortex. In other words, the spatial distribution in the cortex, the amount of space allotted for each small portion of retina, is equal to the amount of density of cells in the corresponding part of the retina, as mathematically expressed in the cell potential function.

As a result of these mathematical relationships, the retinal annulus and its cell distribution is termed *conformally equivalent* to the cortical strip and its cell distribution. (The retinal annulus, a circular disc excluding the central several degrees of visual field, is used because of the linear relation of cell density in the central fovial area.) As in the case of electrostatic or gravitational fields, the logarithmic potential function used here is a solution to the Laplace equation, $\nabla^2 u = 0$, which is the general condition for *smooth* potential or fluid flow.

The implication of this demonstrated conformal equivalence is that the geometric considerations of boundary conditions and cell densities are sufficient physiologically to define in detail the mapping and to determine the developing embryology, as follows: If one begins with the assumptions that retinal axons are targeted generally to terminate within area 17 and that a global orientation is established (to prevent the entire mapping from turning), then *only one additional assumption is necessary to produce the fine detail of the map. The remaining assumption is that the axon fibers, as they grow back within the optic tract, try to get out of each other's way, and repel each other as smoothly as possible, subject to the changing boundary conditions (the shape of the brain).*

Included in this notion of smoothness is the stipulation that as the fibers rearrange themselves while growing back through the tract they do *not* twist around each other, which would be the equivalent of vortex motion in a fluid. *In other words, the system is irrotational. The question of* how targeting and orientation are produced remains open, but these could be accomplished easily by generalized chemical attraction (chemotaxis) or other common biological processes.

To help visualize this process, consider the following. Remember that most of the retinal cells are concentrated near the center of the retina. Imagine that these push against each other and expand their area of space until their concentration has thinned to the level of the concentration of cells in the peripheral part of the retina. While this is going on, the boundaries simultaneously are changing appropriately, so that the precise mapping shown in Figure 4 is produced. The equalization of cell densities could occur within different boundary changes, or even within a constant boundary (if the cortical area were shaped like the retina), but this would produce a completely different rearrangement of the cells, a different mapping. Thus, both the density change and the boundary change are determining aspects of the mapping.

To take the ocean as an example again, assume that it is now filled with rowboats, 10 feet apart on average but more densely packed on one side of the ocean than the other. As the shoreline slowly begins to change, people in each of the boats simultaneously start using their oars to push against all of their immediately neighboring boats until, in the final state, the boats are all equally distributed within the new boundary. Their final distribution, compared to the original, therefore, will depend on the initial asymmetry of their location (more at one end of the ocean), the fact that they end up equally spaced, the initial shoreline or boundary, the final boundary, and the dynamic of each boat pushing against all surrounding boats. Again, this assumes an overall smoothness to the process, so that no rotations of relative boat positions occur.

In general, smooth transformation can be defined more precisely as the minimization of the average *magnification factor of the map* (the ratio of the length of a small line segment on the retina to its mapping in the cortex), which is a variational problem and is an example of the Dirichlet principle operating in a biological context.

Dirichlet's principle is used in a wide variety of basic physical processes to explain the geometrical findings. For example in reflected or refracted light, and in collision kinetics, the principle asserts that the time of travel is minimized; in other instances, energies are minimized. In all of these cases, however, the minimal principle is an oversimplification of a higher-manifold situation in which the physical singularities mediate a developmental condition that subsumes the minimal principle. Recent work on superfluidity and superconductivity (Levitt 1978) shows clearly that this is the case with these phenomena.

*The term density is generaly used with reference to volumes. Here it is identified as a term designating area because the cells are arranged in layers, and thus the third dimension is constant.

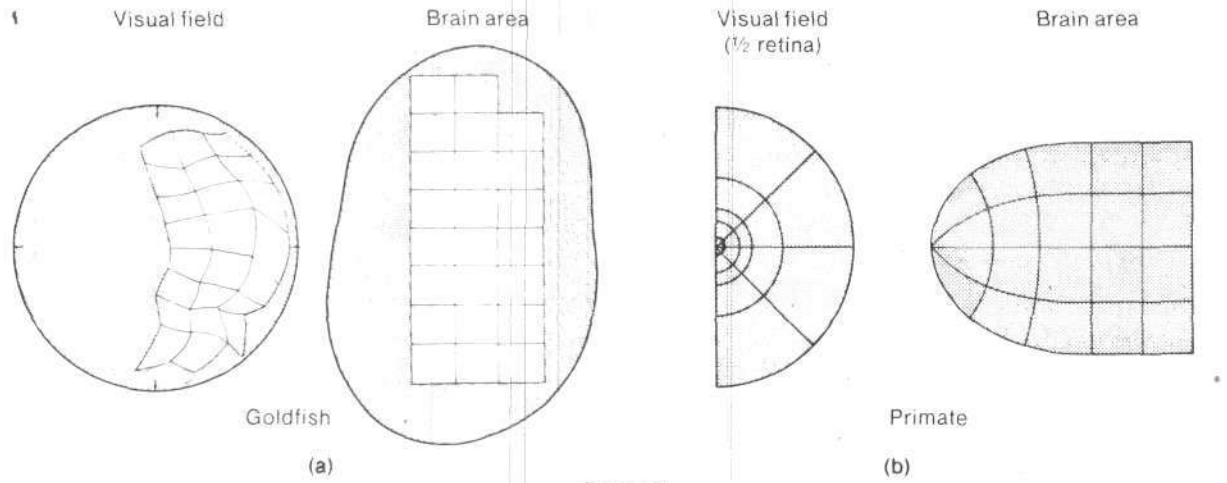


Figure 7
GOLDFISH AND PRIMATE VISUAL MAPPINGS

Shown in (a) is a mapping of the goldfish retina to the primary visual area of the goldfish brain, called the tectum. A rectangular pattern of reference lines is marked out on the tectum and these are traced back to the retina. The pattern still resembles the rectangular formation, although somewhat distorted. However, there is none of the pattern of circles and radii, characteristic of the complex logarithm in the primate mapping, shown in (b) for comparison.

The changes that occur in the goldfish can be related to the boundary condition changes, as in the primate, but the goldfish system is simpler because the initial cell density distribution on the retina, like the tectum, is uniform. The boundary of the retina is roughly circular, while that of the tectum is elliptical, and an analytic function describing fluid flow between two such boundaries gives a good approximation to the actual data. The underlying fluid-flow dynamic, therefore, is the same in both goldfish and primate, but the mappings differ because of an evolution of cell density distribution and boundary changes in the higher vertebrates.

As confirmatory evidence of the fluid-flow dynamic, the optic nerve of the goldfish can be severed and the retina will reestablish connection to the tectum. If part of the tectum is simultaneously removed surgically, then the entire retina fiber bundle will be crowded onto the remaining portion of the tectum, as determined by a pattern of fluid flow into the new boundary. (Data are now in preparation for publication.)

and the same holds for the succession of higher-ordered states in energy-dense plasmas.

Evolutionary Implications

This more general standpoint has powerful implications for biological evolution. If one assumes that boundary conditions are in some sense dependent on genetic content (although cortical area 17 is certainly also a product of previous embryological geometries or *epigenetic* development, such as the initial formation of the embryological neural crests), then new mappings, with the implied new visual physiologies including computational geometries, could result from what otherwise would appear to be only marginal genetic changes. Also, a change in retinal cell densities would effect a mapping change. This mode of evolution would be far more rapid than mapping changes set up by individual cell markers. In the latter case, evolution would require each of millions of cells to be reprogrammed in a way coherent with visual necessity.

Vertebrate evolution shows a progressive tendency for the logarithmic mapping to be formed. The primate has the kind of logarithmic mapping referenced above. In the cat, the radii and concentric circles on the retina map to lines that are approximately straight and perpendicular, but the mapping is not as precise as in the case of the primate. In the goldfish, the retinal cell density is constant, the brain area is the shape of an ellipse, and there is no indication of logarithmic structure (Figure 7).

The goldfish supplies further confirmation of the fluid-flow hypothesis. If the optic tract of the goldfish is severed, then, unlike higher animals, the retinal axons will regenerate the mapping to the brain. If the brain simultaneously is changed surgically by a partial removal of the visual area, then the regenerating fibers will crowd onto the remaining visual area and form an analytic map defined by the new boundary, a process that lends strong confirmation to the general hypothesis advanced here.

In experiments on the subsequent mapping areas, area 18 and area 19, the logarithmic character introduced into the visual image by the mapping to area 17 persists through these higher mappings. In these experiments, straight line trajectories of points stimulated in the brain mapped back to logarithmic spirals on the retina, the general condition

for the logarithmic mapping. The concentric circles and radii described above are actually limiting cases of logarithmic spirals when the cortical lines are at 0° or 90°. At other cortical angles, the actual spiral is produced.

HIGHER-ORDERED GEOMETRIES

Like Kohler's isomorphisms, many of the concepts introduced into the study of neurophysiology here rely on the conceptual tools developed in physics. There is good reason for this. As currently constituted, biology is not a theoretical science. There are no tools within biology for systematically describing the notion of coherence, for example. In spite of the overwhelming evidence from evolution, embryology, and virtually all biological phenomena, that development and progress are the determining invariant of the subject under study, almost every writer on evolution pays homage to Darwin, while those writers in other biological fields get by on a daily basis by putting the question of evolution out of their minds.

Although most practicing physicists are no better off, there is a positive tendency in physics represented by the Leibniz-Riemann-Cantor tradition, which has provided all of science with the initial tools for representing higher manifolds and notions of the transfinite. In germinal form, these are the concepts Schwartz is struggling to develop within what is undoubtedly the most difficult area in all of biology, neuroscience. Ironically, although Schwartz's hydrodynamic models for embryological development may seem esoteric to most biologists, his underlying assumption of a simple continuum barely hints at the higher-ordered singularities within the neurological manifold. The beauty of this work, however, is that Schwartz has been able to productively approach the question of coherence in physiology, development, and evolution by using notions from classical hydrodynamics and field theory. By doing so, he is helping to break ground for a total reconstruction of biology.

Mapping in the Small

A series of further investigations of visual physiology, outlined below, suggests that the retino-cortical mapping contains a higher-ordered geometry more advanced than the one described so far. These higher orderings occur on the small level, in the mapping of small patches of retina (involving several thousand cells each) to cortex.

The details of the experimental evidence and the implied mapping are not easy for most readers to grasp. But these ideas are necessary in order to develop a broader perspective on the question of qualitative advances in evolution and embryology. As with the global mapping, the figures should enable the non-mathematically-trained reader to understand the main ideas.

To begin with, recall that the spatial mapping of the visual field has been treated as if that field were composed of a continuous medium. As noted, however, these structures are not actually flat planes or ideal fluids. They are composed of discrete elements—nerve cells, axons,

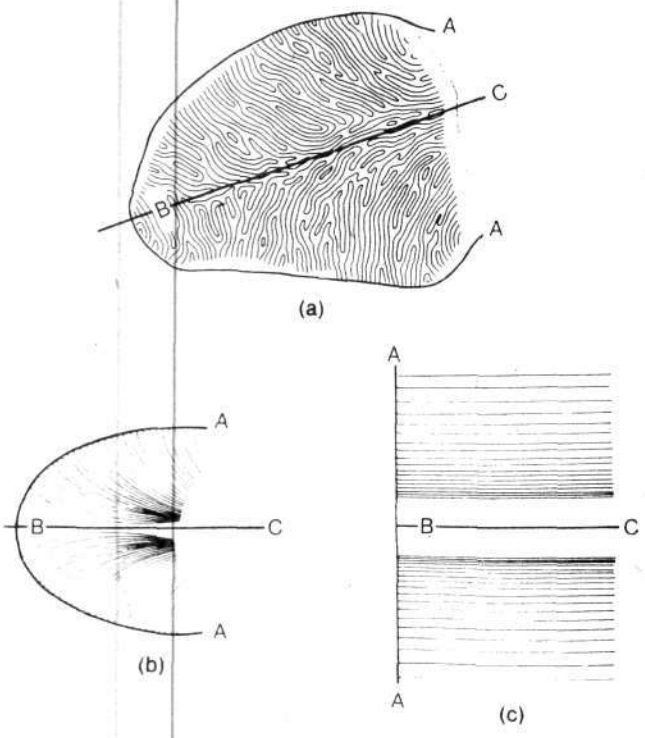


Figure 8
OCULAR DOMINANCE COLUMNS

Each of the two cortical areas 17 has representation from both eyes. The right cortical area 17 receives input from the right half of each retina; the left cortical area 17 from the left half of each retina. The input from both eyes does not mix completely, but follows a well-ordered pattern (a), alternating left and right eye strips called ocular dominance columns. The columns are visible on the surface of the cortex. The pattern of these columns can be approximated by the mathematical model as shown in (b), which then maps back to the retina as exponentially spaced horizontal straight lines (c).

and many other components—which probably help determine the overall mapping by changes in their packing densities in conjunction with boundary changes. The existence of these discrete entities raises the possibility of their mediating higher-ordered geometries, for example, on the small scale of the map.

When test microelectrodes are used to monitor individual cells in the cortex, evidence is found for such higher-ordered geometries. However, this evidence is indirect, centering on the feature extraction properties of cortical cells, because for experimental reasons the geometries in question cannot be mapped directly. Such mapping would require simultaneous electrode recordings from many neighboring cells, and recording technology is not far enough advanced for this.

There are two main feature extraction properties relevant here: *line tuning*, the ability of individual cortical cells to respond selectively to a line or edge in the visual field if the line or edge is inclined at a certain angle; and

binocular disparity tuning, the ability of individual cortical cells to respond to simultaneous input from both eyes when the difference of location of the two eyes in space has produced a specific disparity, or difference, in the two images. Like angle tuning, the property of disparity tuning has a specific direction or vector quality: each cell is tuned to a disparity or image shift at a specific angle.

How does this come about? A diehard ultrareductionist might assert simply that the cells are tuned, and that's all there is to that. A slightly more sophisticated reductionist might come up with a simple-minded geometrical explanation as follows: For any individual cortical cell, a summation geometry of retino-cortical connection could result in both properties. Line tuning could be explained by having a linear string of retinal cells arranged at a particular angle and all sending axons to impinge on the given cortical cell. In this case, the cell would respond maximally if a visual line simultaneously stimulated the entire line of retinal cells. Similarly, for the disparity property, if retinal cells from one eye, and cells from the other eye that were slightly shifted (with respect to the two retinal fields) impinged on the same cortical cell, the cell would be maximally stimulated only if an image with a certain degree of binocular disparity were present on the two retinas.

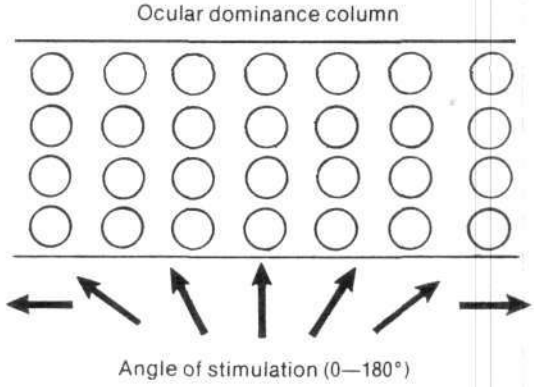


Figure 9
SEQUENCE REGULARITY OF THE ANGLE OF LINE TUNING

If a recording electrode is placed to monitor individual cortical cells, it can be shown that these cells will be activated when light falls on a particular part of the retina. Similarly, when an edge or straight line, inclined at a specific angle, is in the visual scene, it will stimulate certain cells. Other cortical cells when tested by the electrode will respond or be "tuned" to lines inclined at different angles. The amount of change in the angle of the cells are tuned to is directly correlated with the distance the electrode has moved along the direction of the ocular dominance column borders. If the testing electrode is moved perpendicular *to this direction (that is, moving across a column), there is no change in the angle tuning. The angle goes through a full 360° turn in a 1-millimeter cortical area. (The entire area 17 is several centimeters in length and width.)*

The series of arrows below the figure shows the angle tuning as a test electrode moves along a line parallel to the borders of the ocular dominance column. This change of an angular property on the retina to a linear property on the cortex is a strong intuitive suggestion that the retino-cortical mapping follows a complex logarithmic mapping within the millimeter patches of cortex, similar to the global mapping experimentally determined by the change of location of global landmarks. In order to directly establish the form of the local mapping, a similar landmark study would have to be done within the small patches of retina and cortex; this is not technically feasible now because of inadequate recording techniques.

Although this arrangement still requires the explanation of how the individual summations were determined embryologically, the more devastating problem here arises if one tries to imagine not just one cortical cell so arranged, but all of the millions of cortical cells in area 17. The tangle of interpenetrating and crossing afferent fibers to provide these properties would be incredible, especially given the fact that the angle of line tuning and the angle of disparity tuning vary continuously across the cortex.

A far more straightforward, although higher-ordered, pattern of geometric connection on the level of small groups of cells can explain these properties, and this explanation is remarkably similar to the geometry for the global retino-cortical mapping. In addition, the local geometric pattern can be treated in functional embryological and evolutionary terms along lines analogous to the global mapping, and, in fact, represents a qualitative evolutionary leap with respect to that mapping.

Ocular Dominance Columns

As in the case of the global mapping, the proposed local pattern of retino-cortical connection is closely related to dynamics with respect to boundary conditions, the shape of the cortex. As the existence of binocularity tuning implies, both the left and the right portions of the brain denoted as areas 17 (each in its corresponding cortical hemisphere) receive input, or axonal fibers, from both eyes. Specifically, the left area 17 receives axons from the left side of *both* retinas, the right area 17 receives axons from the right side of both retinas. When these inputs arrive at the cortex embryologically, they do not completely mix. As it reaches the visual cortex, the input is arranged in long thin strips, which alternate between input from the left and the right retinas (see Figure 8).

These strips are termed *ocular dominance columns*. The boundaries between the strips form a series of observable lines across the surface of the visual cortex, as in Figure 8a.

This set of boundaries is associated experimentally with the feature extraction properties, and Schwartz proposes that it is causally related to a retino-cortical mapping geometry that can explain those properties.

The most striking aspect of both line tuning and binocular disparity tuning is that when test microelectrodes are moved across the brain surface in a direction *parallel* to the boundaries, the angles of line tuning and binocular disparity tuning rotate in direct proportion to the distance moved. For example, if the microelectrodes move .25 mm, the angle of line tuning turns 90 degrees; if they move twice the distance, .50 mm,

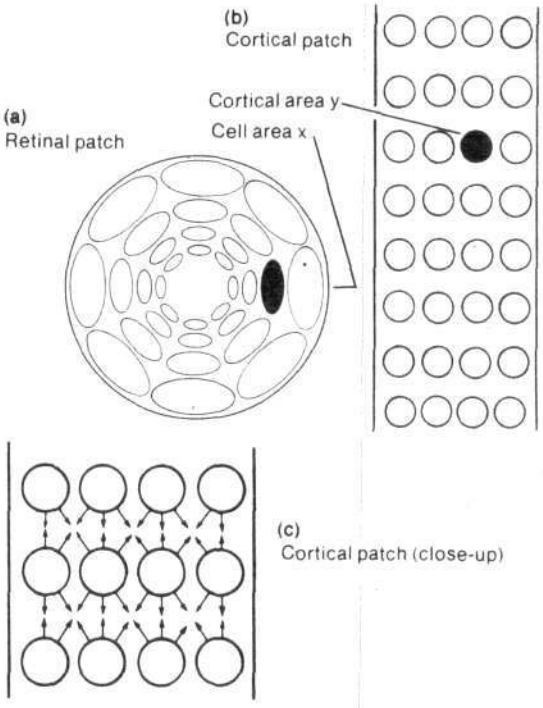


Figure 10
LATERAL INHIBITION

To explain the fact that cortical cells are individually "tuned" to respond to a visual line on the retina that is inclined at a certain angle, Schwartz proposes a lateral inhibition interaction among cortical cells. In lateral inhibition, a stimulated neuron inhibits its neighboring neurons.

In the Schwartz model, the retina is divided into small patches, and each patch (a) maps to a small patch of cortex (b). The mapping follows the complex logarithm, with radii of retinal groups of cells mapping to parallel lines of cortical cells, as in the global mapping. The circles shown are used here to represent areas of retina and cortex that each contain many cells. The boundary of the hypothesized retinal patch is not visible anatomically, but the vertical ocular dominance boundaries are. Let us take for example the retinal area x and its mapped cortical area y.

The proposed pattern for lateral inhibition interaction within the cortex is shown in a representative sample (c), with arrows indicating connections of inhibition. A cell stimulated by the incoming retinal fiber bundle will go on to inhibit the cells it connects to, as the arrows indicate. Notice that the lateral inhibition is not the same in all directions, but that it points generally parallel to the ocular dominance column boundaries and that there is no inhibition in the direction perpendicular to these boundaries.

Lateral inhibition in line tuning is shown in (d) and (e). If a line in the visual scene falls across retinal area x, there are two possibilities of response, depending on the angle of the line. The first, shown in (d), has the orientation of the line toward the center of the patch, so that it intersects a "radius" of retinal areas, stimulating all of the area in a line perpendicular to the ocular dominance columns on the cortex. The cortical cells stimulated then produce lateral inhibition on the cortex, as shown.

In the second case, shown in (e), the line across area x is arbitrarily turned to another angle, stimulating the retinal areas and corresponding cortical areas as shown. In contrast to the first situation, the directional lateral inhibition in the cortex results in the inhibition of area y despite the fact that area x was stimulated. *This entire process produces an apparent individual cell "line tuning" of the cortical cells in area y to retinal line stimulation* only at the angle shown in (d), *but this property is the result of the collective activities of many cortical cell areas.*

the angle turns through twice the angle, or 180 degrees. (As can be seen from these measurements, the period for a full 360-degree rotation is approximately 1 mm. To better visualize the context, the ocular dominance columns are approximately .3 mm wide; and the total area 17 is several centimeters wide and long, depending on the species of animal under consideration.)

In contrast, if one moves *perpendicular* to the ocular column boundaries, the cells encountered all have the same angle tuning. In an analogous fashion, the binocular disparity tuning direction, or vector, of cortical cells also turns through equal angles if equal distances are traversed across the cortical surface.

Since the ocular dominance column boundaries are approximately straight lines, particularly over the small distances considered here, the angle tuning and binocular disparity tuning represent an angular quality in the retina becoming associated with a linear dimension in the cortex. Intuitively, this suggests a similar role on this level for complex logarithmic structuring, as on the global level, where the logarithm converts angles or rotation into linear distance. (Recall that the radii of the radex map to equidistant parallel straight lines.)

This notion is strengthened further by the experimental finding that the two properties are even more closely related: the angle of line tuning is always perpendicular to the binocular disparity vector.

Schwartz brings all of these findings together by proposing that the entire visual mapping is a patchwork of small maps, each of which contains the complex logarithm. Schwartz defines a patch in the cortex as the area within an ocular dominance column that rotates the retinal angle-tuning property through a full 360 degrees. Since the ocular dominance columns are .3 mm wide and the period for a 360-degree rotation is 1 mm, these are the dimensions of the cortical patches. The sizes of the retinal patches are the corresponding areas of visual field.

Within the corresponding retinal patch, groups of cells located along radii map to groups of cells located along lines perpendicular to the ocular dominance column boundaries (that is, the cells in each group are all line tuned to the same angle). As one turns within the retinal patch, cells located along the sequential radii map to successive parallel straight lines of cells located sequentially within the ocular dominance column.

To complete this part of the model requires one further point. Careful mapping of small light stimuli shows that the receptive retinal field of individual cortical cells is roughly circular. The elongated field characteristic of line tuning, therefore, must arise from interactions among cells, either on the retina or on the cortex, in which a given cell that is stimulated will inhibit its neighbors on two opposite sides, but not the neighbors in directions perpendicular to these sides (Figure 10). This *lateral inhibition* creates an artificially elongated receptive field. If this occurs on the cortex and the direction of lateral inhibition rotates as the line tuning rotates, this would produce a highly tangled series of cell interactions.

However, if the lateral inhibition occurs between the successive lines of cortical cells that receive input from cells along successive radii within each logarithmic patch mapping, then the direction of lateral inhibition can proceed only in one direction, parallel to the ocular dominance column boundaries, thus giving the required line-tuning property. The simplicity of this possibility is another strong argument in favor of the presumed logarithmic structuring in the small.

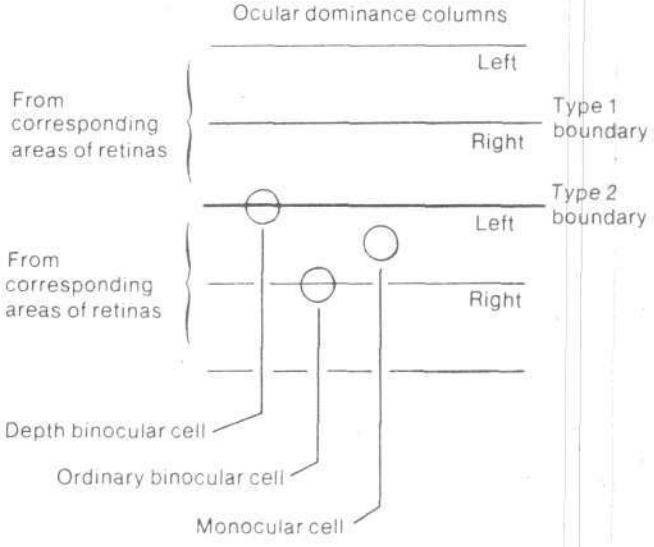


Figure 11
BINOCULAR DISPARITY

The figure shows the alternating left-right pattern of ocular dominance columns, where successive pairs of columns represent correponding parts of the two retinas. Binocularity arises if a cortical cell straddles the boundary between columns and thus receives input from both eyes. Two types of borders are evident, type 1 between columns representing corresponding parts of retina and type 2 between pairs of such columns.

A binocular cell straddling the first boundary would receive identical input and thus have no disparity, while a cell straddling the second boundary would have a disparity between retinal inputs. The first type is called ordinary and the second type depth cells.

Binocular Disparity

Schwartz's experimental data give more details for the property of binocular disparity that argue for the logarithmic structuring in the small. According to the model discussed above, binocularity would arise when cortical cells are located straddling the boundary of two ocular dominance columns and thereby receiving stimulation from both eyes. However, just because a cell gets input from both eyes does not guarantee disparity in input; the input may be from corresponding areas of the two retinas (for example, the right side of the two retinas), resulting in no disparity.

To clarify this apparent difficulty, it may be helpful to the reader to make a model of the left eye-right eye representation in the ocular dominance columns. Imagine that the right half of the right retina is represented by the right hand, and the right half of the left retina by the left hand. As stated above, strips from the right halves of the two retinas alternate in setting up the ocular dominance columns in the right area 17. To model this situation, place the palms of the two hands together, separate the fingers within each hand, and then rotate one of the hands slightly so that the fingers of the two hands alternate or interdigitate with each other. The fingers should line up as follows: left thumb, right thumb, left index finger, right index finger, left middle finger, right middle finger, and so on.

Notice that the boundaries between the fingers are of two types. Thumb is next to thumb, index finger is next to index finger, and so on; but at the same time, the right thumb is next to the left index finger, and the right index finger is next to the left middle finger, and so on. Let us call the first type of boundary type 1, the second type 2. Now, let us apply this to the ocular dominance columns (Figure 11). Just as there are pairs of corresponding fingers which come from corresponding parts of the left and right hands, so there are pairs of corresponding ocular dominance columns, each of which comes from the corresponding part of the left and right retinas, separated by a type 1 boundary. As in the example with the fingers, there are type 2 boundaries between succesive pairs of ocular dominance columns.

If binocularity arises because cortical cells straddle these boundaries, thereby receiving input from both eyes, then there should be two types of binocular cells: those that straddle the type 1 boundary and have no disparity because they receive input from the corresponding parts of the two retinas; and those with disparity because they straddle the type 2 boundary. Experimentally this is exactly the case; there are disparity and nondisparity binocular cells, and their relative proportion is, as expected, roughly 50-50, although because of the technical difficulties noted above the precise locations of the cells are difficult to map.

The rotating angle of disparity tuning (Figure 12) comes directly out of this model. A cell straddling a type 2 boundary is line tuned at a certain angle, but it is line tuned to two line segments at that angle that are displaced on the retinas, perpendicular to the ocular dominance column boundary, as in Figure 11. Theoretically the direction of this displacement always should be perpendicular to the ocular dominance column boundary, and therefore in the same direction within a patch area. However, the elongated receptive field shape (due to lateral inhibition) gives the subjective impression visually that the disparity is *perpendicular to the direction of the receptive field*, or to the line-tuning angle.

Global and Small Mapping Compared

If this logarithmic patch model is correct, what is its relation to the global complex logarithmic mapping? Referring back to Figure 8, it is evident that the ocular

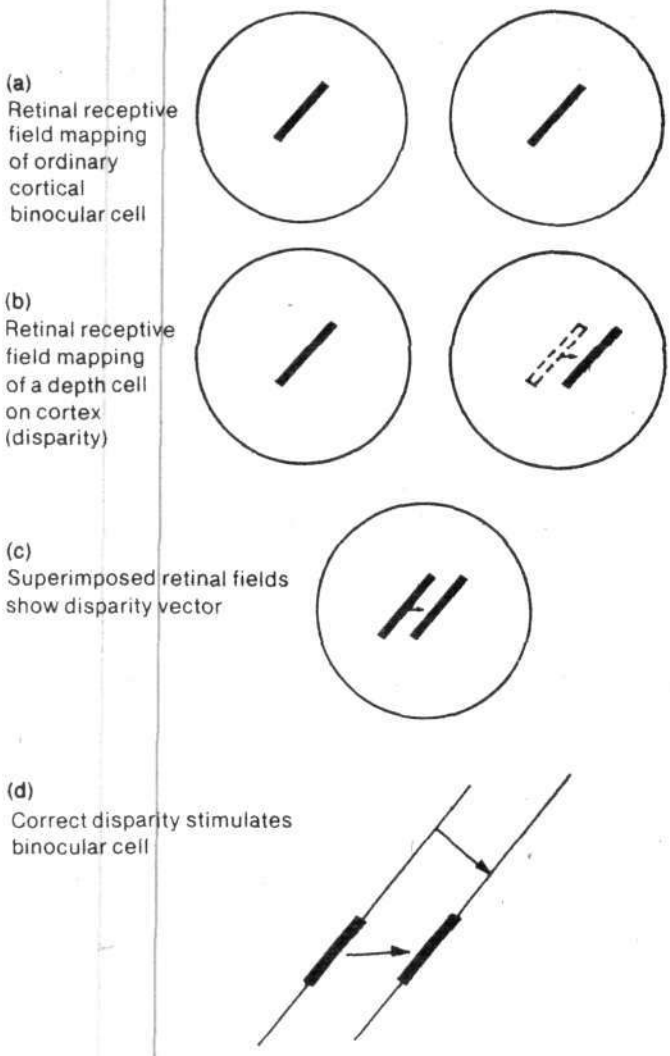
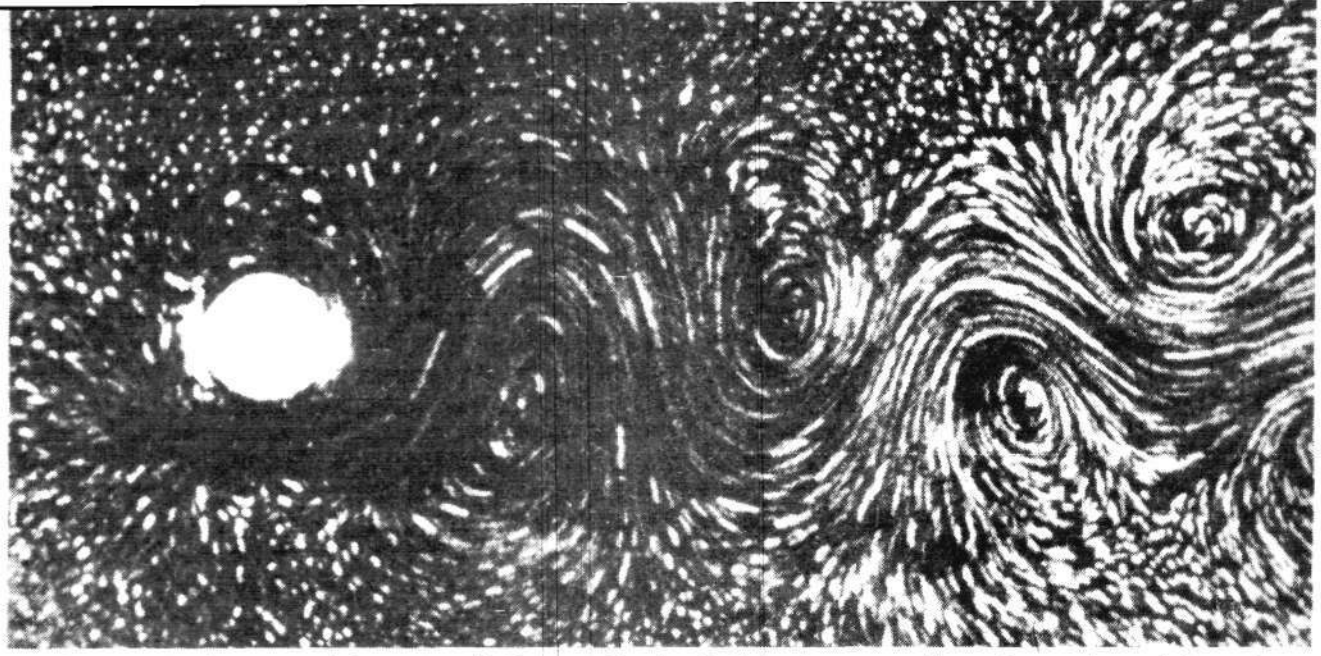


Figure 12
THE RELATION OF LINE TUNING TO DISPARITY TUNING

Shown in (a) and (b) are schematic representations (greatly enlarged for clarity) of two receptive fields, areas in the retina that functionally map to a depth cell and an ordinary cell on the cortex, in the two retinas. In (a), which maps to an ordinary cell (no disparity), the fields are identical. In (b), which maps to a depth cell (disparity), they are shifted, as indicated. The two retinas can be superimposed, showing the vector of disparity (c). In general, these fields will not be stimulated by a line the length of the fields, since the actual receptive fields are very small. More often, the field will be activated when a larger line in the visual scene comes to lie along it, and the binocular cell will be stimulated if that line has the correct disparity, as in (d).

The distance between these long lines is measured by the perpendicular between the lines. This perpendicular is the actual functional disparity of the receptive fields, and is thus perpendicular to the line-tuning angle.



A photograph of vortex turbulence in a fluid caused by the fluid flowing past a blunt object. The turbulence is not random motion, but a highly ordered set of vortices that are stable for a considerable time. This stability is related to the relative distances between the vortices. The ratio of the distance between the two sets to the distance between two adjacent vortices from one of the sets is 0.28. The mathematical description of this hydrodynamic situation is identical to the model of periodic logarithmic structuring within each pair of ocular dominance columns in the retino-cortical mapping. The measurement of the period for 360°-receptive field rotation, compared to the width of the ocular dominance column, is 300 microns/1,000 microns, or 0.30—in good agreement with the predicted value. The rotating motions in the fluid represent a higher order of geometric structuring than that described for the irrotational complex logarithm in the original discussion of global mapping.

dominance column borders do bend over the course of the global mapping, in general conformity to the overall complex logarithmic structure. Therefore, the small logarithmic mappings are embedded within this larger logarithmic mapping, and the entire visual projection may be described as a *concatenated logarithmic mapping*.

The proposed concatenated structure would divide up the retina into small patches, each containing thousands of cells. Each patch would project to a patch of cortex (neighboring patches projecting to neighboring patches) and each patch-to-patch mapping would contain the complex logarithm.

Each patch of cortex would be represented by that tissue within an ocular dominance column that must be traversed to complete a full 360 degrees of rotation of angle tuning (or, equivalently, of binocular disparity tuning). By incorporating other aspects of the neurophysiology, such as lateral inhibition in line tuning and type 1 and type 2 boundary effects in binocularity, the model would be capable of explaining a wide variety of aspects of vision. In particular, such a model would demonstrate how line tuning can be connected intimately to binocularity as a *geometrically determined property*.

Embryology in the Small

The small patch mappings are fundamentally different from the global mappings in terms of embryological dynamics. While the overall map is irrotational or nonturbulent, the recurring small logarithmic maps imply a vortical or rotating structure on the level of each patch, both with respect to neighboring patches and to the mapping as a whole. In terms of the growing embryological fiber bundle, this rotation implies that the fibers are twisting around each other as they grow back from the eye to the brain. This turbulence can be specifically related to the effects of the left and right eye fibers brushing against each other and thereby "whipping up a turbulence" in the region of the boundaries, or interfaces, between the ocular dominance columns.

To describe this dynamic more rigorously, we can construct an analytic function (equation) that is both globally and locally logarithmic. Schwartz has chosen as a function the standard electrical field description of a set of line charges placed between two concentric charged cylinders. The field potential between the cylinders is logarithmic, and the presence of the finite number of line charges modifies the field in local logarithmic patterns. The function is ln(cn[ln z,k]), where cn is a Jacobian elliptic function (Ahlfors 1966). (Again, for those with limited mathematical training, the necessary ideas are expressed in the photograph above.)

In fluid mechanics this function would describe a series of vortical motions, each vortex corresponding to one of the electrical line charges. The hydrodynamic interpretation of this function is known as a *von Karmen vortex street*, the series of alternating left-handed and right-handed vortices produced in the wake of a blunt object moved through a viscous fluid, as shown in the photograph. The question of viscosity, or "drag" in a fluid, arises because we are now dealing with rotational motions in fluids, and fluids that have no viscosity cannot be made to rotate (Levitt 1978).

The Laplace equation previously used to describe the

conditions in the global mapping is now no longer applicable. It is necessary to introduce the more general Navier-Stokes equation, which contains a nonlinear field term relating to the effects of viscosity. This equation is extremely difficult to solve, but it can be simplified by assuming that *the main source of vorticity will be discontinuities in flow along boundaries, here along the boundaries of the ocular dominance columns*. In other words, the fluid will not produce vortices within itself, as a jet of water into a lake does, but only with respect to the surface effects of the boundary. (Technically, we can say that the fluid has a low Reynolds number.)

The equation then reduces to: $\nabla^2 \omega = 0$, where the vorticity is ω and $\omega = \nabla \times V$. Here it is the vorticity, not, as previously, the potential, that satisfies the Laplace equation.

The Hydrodynamic Model

In the actual hydrodynamic situation, the von Karmen vortex street is stable only for certain arrangements of the vortices. Specifically, the ratio of the distance between the two diverging series of vortices at any point and the distance between two vortices within a series at that point is 0.28. This spacing relation implies that the various vortex structures in this arrangement are dynamically stabilizing one another and that they will do so only within certain arrangements.

This ratio in the actual hydrodynamic situation is consistent with the ratio derived from the dimensions of the cortical patches: .3 mm for the width of an ocular dominance column and 1.0 mm for the period of a 360-degree rotation of the receptive field give a ratio of .30. Each pair of ocular dominance columns would correspond to the two series of vortices shown in the photograph.

The dynamic of afferent fiber twisting in the retino-cortical projection now can be approached as a boundary-determined phenomenon similar to the complex logarithm on the global scale. However, the occurrence of the ocular dominance column boundaries is yet to be accounted for. A suggestion by one group of investigators (Levay et al. 1975) that the fibers from the two eyes appear to be competing for space on the cortical area is along the lines of a minimal principle, but this clearly is not sufficient to define the precise geometry involved.

The twisting of the fibers could follow the more elaborate turbulent fluid dynamics as indicated, given the pattern of the ocular dominance columns, resulting in the higher-order mapping. Again, this type of explanation does not require specific cell programming and has the potential for further evolution as discussed in the case of the global mapping.

The evolutionary transition to the turbulent dynamic in fiber twisting from the retina to the cortex, which occurs only in the higher vertebrates, represents more than just a more complex mapping. The patch mappings signify the development of *a higher order of discreteness, or singularity within the map*, and thereby a leap to a higher manifold. This discreteness results from an internal reordering within the mapping of lower levels of discreteness, the nerve cells. Simultaneously, it is connected to a differentiation of the global structure into the binocular cortical representation through the ocular dominance columns.

Each neuron is highly ordered and has been shown to sum up input individually in highly nonlinear ways (Freeman 1976). But even more useful, the local logarithmic mappings have a specific internal geometry where ordering of the newly evolved level of discreteness is potentially immediately accessible for direct study.

The Implications for Biology

The simultaneous *physiological, embryological, and evolutionary* aspects of the cortical mapping, therefore, represent an ordered, interpenetrating *tripleness*, which is actually present in every biological entity or feature.

From this tripleness it is clear that Kohler's psychophysical isomorphisms cannot be built up merely from the direct implications of the form of the sense organ anatomies, even if these involve complex geometrical qualities. Rather, the lessons of biology for psychology revolve fundamentally around the questions of self-development in evolution and secondarily in the linked examples of development such as embryology. These aspects of Schwartz's work—the focus on the question of discreteness and continuity, the role of boundary conditions, and so on—and their link to the physiological questions are what will provide insight into the capacity of biological forms to advance in qualitative and discontinuous ways.

The advanced standpoint of a properly formulated neurophysiology must be applied to all of the basic problems confronting biology, most particularly the question of evolution and the genetic material DNA.

Ned Rosinsky is a practicing physician in New York City and works with the Fusion Energy Foundation biological sciences division.

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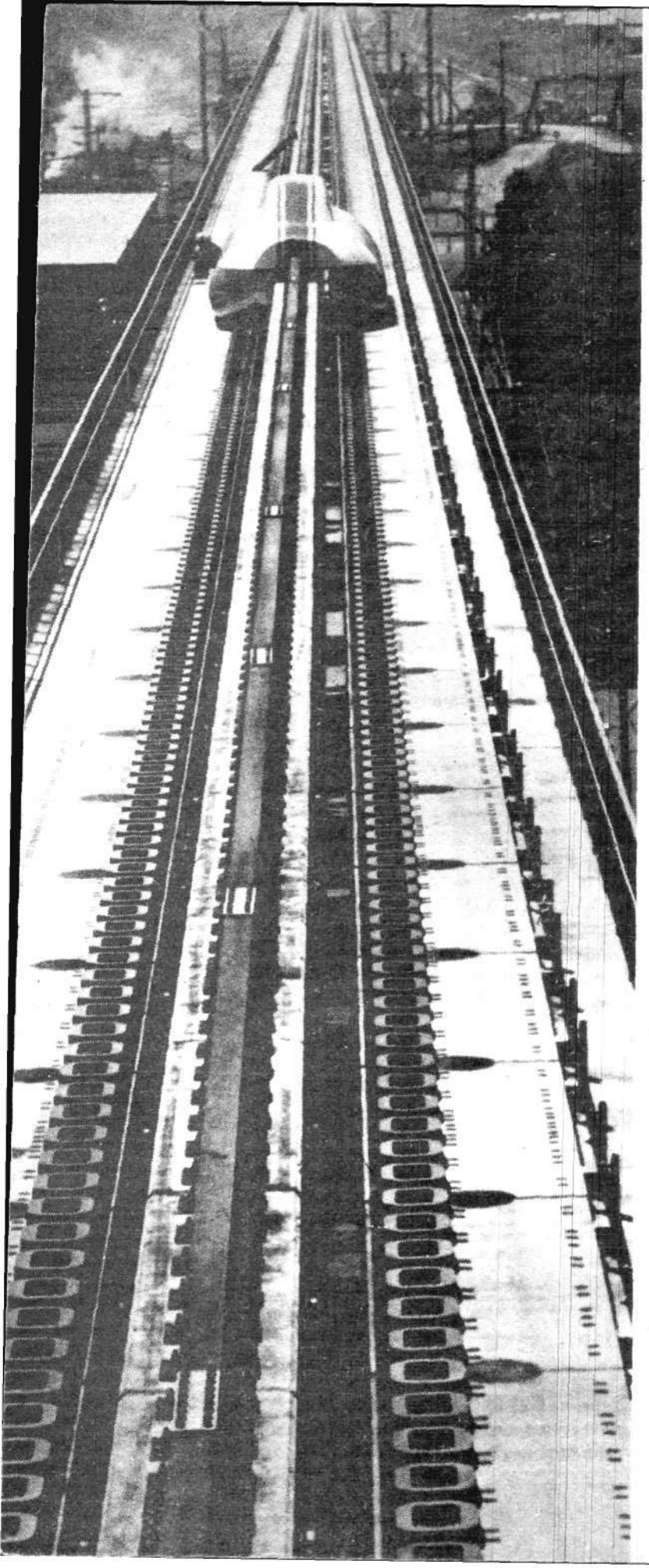


Beyond the Wheel:

by Marsha Freeman

A TRIP FROM NEW YORK to Los Angeles in 21 minutes for $50 or less?

Science fiction? No, the technology that could make such a trip a reality within 10 years already exists. The use of superconducting magnets for the movement of people and materials can take us out of the "wheel age" and put us into an age of magnetically levitated trains.

Using electromagnetic fields to levitate and propel passenger trains has been under consideration for more than 10 years here and in other countries. The problem scientists addressed in looking for a technology beyond the wheel is that conventional wheeled trains cannot operate at more than 150 to 200 miles per hour because of traction and frictional heating. At higher speeds, transmission of electric power by rail to wheel contact becomes increasingly difficult and energy efficiency lessens because of aerodynamic drag losses.

Ford Motor Company, the Massachusetts Institute of Technology, the Rand Corporation, and the Mitre Corporation have worked on various systems designs for magnetically levitated trains. At least three systems have been studied seriously, but only the one using superconductivity technology is feasible for high-speed, long-distance transit. The other systems relied on conventional magnets, both for levitation and propulsion, but these proved limited for mass transit because of space, weight, and energy-efficiency considerations.

The use of conventional electromagnets for levitation of a vehicle is most applicable to an *attractive* magnetic system; that is, where the vehicle is pulled to the track by magnetic force. In this design, conventional magnets are placed in the vehicle and fit between the bulk of the train and the steel rail track (Figure 1a).

Since clearance between the vehicle and the track is only about 3 inches, the guideway must be in near-perfect condition at all times. Another drawback is that the attractive magnetically levitated, or maglev, system is inherently unstable because the attractive force is compounded by the gravitational force and increases with speed. To prevent vehicle contact with the track requires a complex high-powered electronic feedback system. The clearance and instability problems would limit top speed to about 300 miles per hour.

It would not be possible to employ repulsive magnetic force using conventional magnets because the size and weight of the magnets needed on the vehicle would be prohibitive. The same problems arise when considering a conventional magnet system to propel the vehicle.

Researchers have considered two types of electric rotary motors ("unwrapped" into linear structures) for maglev systems. The motor is essentially a cylinder or rotor that is subjected to a rotating magnetic field produced by coils

Japanese high-speed, no-wheels test train
Japanese National Railway

Magnetically Levitated Trains

supplied with alternating current. If the cylinder is a conductor, the motor is called an induction motor because it is driven by currents induced in the cylinder from the rotating magnetic field produced by the alternating current.

The linear induction motor, or LIM, was the obvious candidate for levitated trains, since it had been successfully applied in other areas, and it uses conventional magnets and has a high tolerance for variations in speed.

In the LIM system, the magnetic field from the on-board motor induces eddy currents in the passive (nonelectrified) steel rail and this, in turn, produces a magnetic field around the rail. The guideway current and magnetic field move in the opposite direction to the current and magnetic field on the train. The repulsive force between the two fields thus propels the vehicle forward.

The Limitations

There are two major difficulties with LIM that parallel the difficulties in attractive levitation that is not superconducting. First, because the motor on the train has to induce an actual current in the rail, the vehicle must be relatively close to the guideway, leaving little clearance between vehicle and rail. Second, the amount of alternating current necessary for the on-board magnets in the motor requires either a live rail to transmit continuous power to the LIM, which is unfeasible at 300 miles per hour, or an on-board generator, which would be quite cumbersome. (It could end up comprising one-fourth of the weight of the entire vehicle.)

As a result of these difficulties, scientists at MIT and Rand decided to investigate the application of superconducting magnet technology to high-speed ground transportation. Dr. Henry Kolm, the senior scientist at MIT's Bitter Magnet National Laboratory, initially reasoned that for such a revolutionary concept—replacing physical-contact transport with electromagnetic fields—only the most advanced scientific ideas and engineering applications would be appropriate. Kolm later remarked that superconductivity represents a "breakthrough comparable to the wheel in its potential impact on technology."

Superconducting Levitation

For a number of reasons, *repulsive* levitation, which is possible only with high-field superconducting magnets, is far superior to attractive levitation with conventional magnets. Most important, the repulsive levitation adds stability to the system, because of the configuration of the magnetic field generated (see Figure 1b) and the fact that repulsive interaction is counterbalanced by the gravitational attraction. Also, the clearance between guideway and vehicle, close to 1 foot, eliminates the need to maintain a microscopically perfect guideway and provides ample flexibility of movement for banking on curves.

The repulsive maglev vehicle has two sets of superconducting magnets near its bottom. As the train moves over a *nonconducting* aluminum guideway, the on-board magnets induce a small current in the guideway. This current then generates its own magnetic field, which repulses the vehicle, because it has the same directionality as the train's magnetic field.

Since the second required magnetic field is produced only as a function of the motion of the on-board magnet system, the vehicle can be supported by wheels similar to airplane landing gear, until it reaches a speed of 20 to 30 miles per hour.

At the initial period of acceleration there is significant magnetic drag on the vehicle, as some of the magnetic field energy generated by the moving magnetic vehicle penetrates into the guideway. As the vehicle moves faster, however, it reaches a speed at which the field becomes strong enough so that none of the magnetic flux penetrates the aluminum guideway; the guideway becomes a shield with very little magnetic drag.

Compare this situation with aerodynamic drag, which *increases* with an airplane's speed. The magnetic drag in maglev reaches its peak relatively quickly, and then *decreases* with speed. If air resistance is eliminated, magnetic drag is the only energy loss in the system. Therefore, the only limit on the vehicle's speed would be the length of the trip and its corresponding amount of acceleration time. Given the relatively small circumference of the earth, the vehicle probably would reach only 14,000 miles per hour before it would have to begin decelerating to stop at its destination.

Superconducting repulsive levitation also has important economic benefits, mainly because the guideway can be fabricated easily and unrolled from spools. Since the

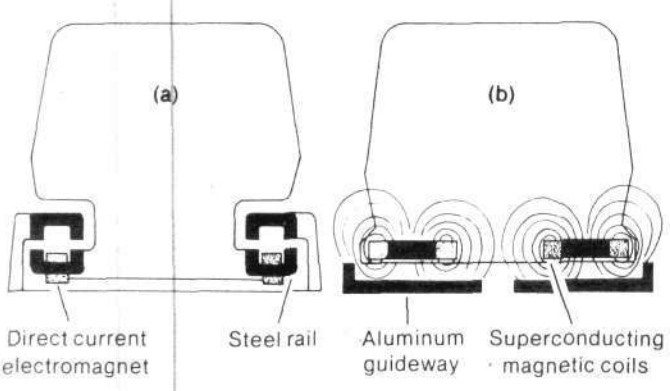


Figure 1

In attractive levitation (a), the pull between the steel rail and the train's electromagnet propels the vehicle. In repulsive levitation (b), powerful superconducting magnets create a repulsive force against current induced in a nonconducting aluminum guideway.

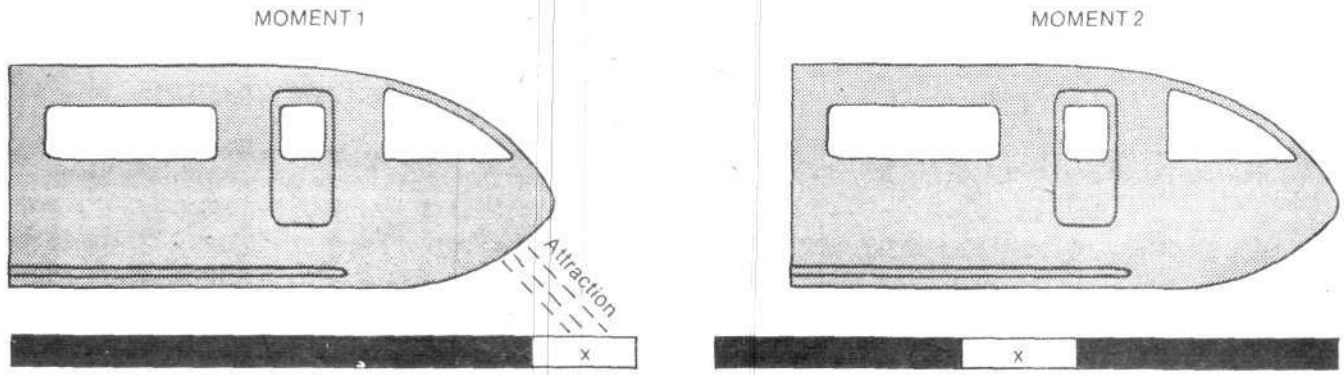


Figure 2

In a maglev system with a linear synchronous motor (LSM), two magnetic fields are generated independently, one created by the superconducting magnet onboard the vehicle, and the other created by current fed independently through the guideway.

The guideway is excited with alternating current in small sections at a time, always ahead of the approaching train. The vehicle is attracted by the magnetic field in the guideway ahead of it. Then, as the vehicle is directly overhead, the guideway current is alternated (its direction is changed), and in that instant there is effectively neither attractive nor

guideway does not have to be magnetic, any light, electrically conductive material like aluminum can be used. In the nonsuperconducting attractive maglev system, the rail itself has to be magnetic to attract the vehicle, which limits its material to ferromagnetic steel.

Superconducting Propulsion

The limitations of the linear induction motor, described above, led researchers to experiment with superconducting linear synchronous motors, or LSM. In LSM the cylinder in the motor is a magnet, and the motor is driven by the current produced by the synchronization of the magnetic fields of the cylinder and the coil. Rather than relying on large amounts of electrical input, as the induction motor does, the LSM depends upon large magnetic fields, which can be produced effectively only with on-board superconducting magnets. These magnets are separate from the superconducting levitation magnet system and are placed in a parallel series on the vehicle.

Unlike the LIM system, the LSM requires an electrically active guideway, but only a weak current is necessary. The power in the track is not transmitted to the train; it simply provides a moving field with which the on-board magnetic field interacts (see Figure 2). As the vehicle moves, small sections of the guideway are activated sequentially with current, generating a field that *pulls* the vehicle forward. This split-second activation is then reversed in direction. As the vehicle passes over the activated section, the fields repel and the vehicle is *pushed* forward. The effect is similar to a surfboard riding a wave.

Sophisticated Electronic Feedback System

To activate small sections of the guideway for this split-second coordination requires wayside power conditioning units placed approximately 18 feet apart. Changes in voltage, using transformers in the conditioning units, also keep the magnetic field around the train and guideway constantly changing, and thus provide continuous propulsion. The vehicle itself contains a computer unit that monitors the position of the vehicle's magnets relative to the magnetic waves from the guideway and brings the wave speed into synchronization when necessary by adjusting the frequency of the track current. It is a very sophisticated electronic feedback system design.

The major advantage of the LSM design is that it maintains a 1-foot vehicle-to-track clearance, since the interaction is between magnetic fields without the need to induce a current. The vehicle needs no on-board generation or power system; its superconducting magnets simply get recharged every 400 hours, or after approximately two weeks of continuous operation.

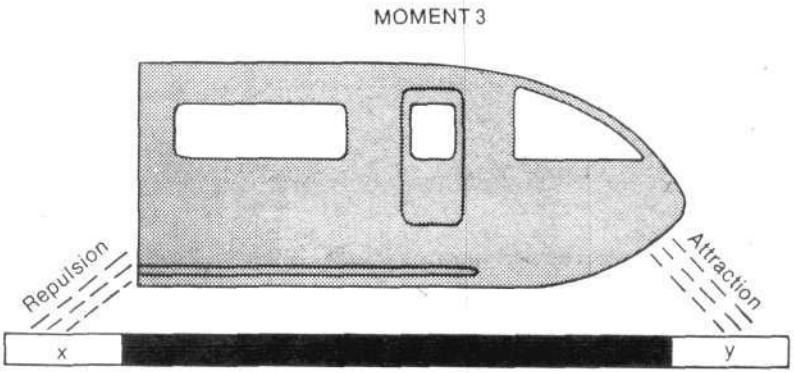
Also important is the fact that about 10 percent of the thrust from the LSM system is vertical. Since the train is moving in three directions at once—levitated vertically, propelled horizontally, and shifting slightly from side to side—this 10 percent vertical thrust allows easy guidance control through variations in the guideway current and magnetic field.

Electromagnetic Flight

Magnetically levitated trains are being experimentally developed now in Japan, West Germany, and Canada. The Japanese are the closest to commercialization, and are considering a maglev rail link from an airport to the city.

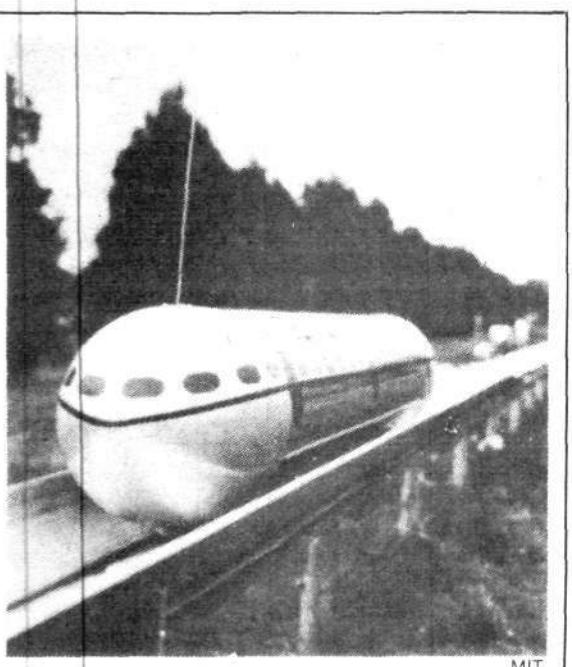
The real potential of a superconducting system, however, is for long distances, such as transcontinental passenger transport, where the system could attain speeds way above the 300-mph limit for ground transport (Ground transport is inherently limited by aerodynamic drag.)

Using above-ground semievacuated tubes that would create an environment of little or no air resistance, a



repulsive force. As the current is changing its direction and the train is moving forward to the next section of the excited guideway, however, it creates a repulsive force that pushes the vehicle along. The vehicle, therefore, is always moving in coherence with the alternating magnetic field.

Right: The MIT scale-model magneplane.



MIT

maglev vehicle could accelerate at 1 g, approximately the same forward thrust as the force of gravity (about 32 feet per second squared). For a very comfortable acceleration of .5 g (like the "fasten your seatbelt" time on an airplane), the acceleration time on a New York to California trip could be about 10 to 12 minutes. At an increase in speed of about 500 miles per minute, passengers would cruise at 6,000 miles per hour for about 15 minutes, then decelerate for another 10 to 12 minutes. Coast-to-coast in about 40 minutes, and even faster speeds are feasible!

The maglev system, of course, would be connected to urban subways for convenience. The trip across the country would take less time than it now takes to get from the center of town to the airport.

Underground Advantages

The technology to build this superconducting maglev system is already available. The most demanding technical problem is that of lateral acceleration; a vehicle traveling at 500 mph or more cannot take sharp turns. At 5,500 mph, in fact, the radius of bend of the track must be greater than 400 miles. The requirement imposes strong constraints on the guideway design and would create great difficulty if built above ground.

Other drawbacks to above-ground evacuated tubes are the ravages of climate and weather, interference with already existing transport and other above-ground infrastructure, and an unpleasant visual presentation.

For an underground system, the main obstacle is the cost of tunneling. According to research conducted by the Rand Corporation, however, an underground maglev system could be profitable, even though tunneling would be about 90 percent of the cost of the total system.

The cost of the guideway in the superconducting maglev system, including the electrical equipment for the LSM, would range from $6 to $8 million per mile—about the same as a major highway. The vehicles would be a minor aspect of the investment, probably costing $600 million each. As noted, the major cost is the tunneling, which would bring the total price up to approximately $30 million per mile.

Rand projects that rapidly occurring breakthroughs in tunneling technology could lower the cost per mile by about 50 percent if there were a demand for it, and could increase the tunneling advance rate by 200 to 300 percent. Furthermore, the tunneling cost is also balanced off against an above-ground system, because no right-of-way real estate has to be purchased.

In order to ensure that the tunneling cost would not make the system prohibitively expensive to amortize, Rand suggests the development of a companion freight transport system. The freight guideway could be located alongside the maglev tunnels and share power and service installations. Conventional electric trains that do not require evacuated environments could travel at 100 mph, and they would be designed to interface with existing railroads and other freight modes.

Other companion facilities under consideration to balance the cost of tunneling are pipelines, communications links—including channels for lasers and microwave waveguides—and superconducting electrical power transmission cables. However, initial analyses have shown that underground long-haul domestic travel can pay for itself, *even without the economic benefits of sharing the tunnel complex* with other underground systems. The figures are startling.

Table 1 summarizes the system design of the underground maglev system that Rand considered, a less conservative system than the one described above. The headway between vehicles refers to the time-space between departing flights. The increased acceleration of 1 g

Table 1
DESIGN PARAMETERS OF THE RAND MAGLEV SYSTEM

VEHICLE DESIGN	
Capacity	100 passengers
Average speed	14,000 mph
Acceleration	1 g
Levitation	16 superconducting magnets
Propulsion	Linear synchronous motor
Number of vehicles	800
SYSTEM DESIGN	
Total miles	500
New York—Los Angeles travel capacity	264 billion miles per year
Annual trips (N.Y.—L.A.)	106 million
Headway between vehicles	1 minute
Travel time (N.Y.-L.A.)	21 minutes
ECONOMIC PARAMETERS	
Travel fare	$50 one way
Overall capital cost	$40-60 billion

Table 2
MAGLEV COMPARED TO AIRPLANE TRAVEL

	MAGLEV	AIRCRAFT
Energy consumption (kWh/passenger-mile)	0.03	1.57
Travel time	21 minutes	347 minutes
One-way fare cost	$50	$125-200
Capital investment over 10 years	$40-60 billion	$50 billion

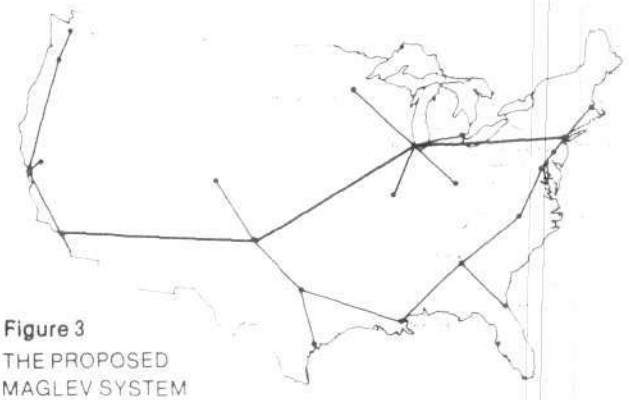


Figure 3
THE PROPOSED MAGLEV SYSTEM

and the resulting higher cruising speed of 14,000 mph account for the fantastic 21-minute trip time. This is absolutely feasible.

Maglev Versus Jets

Table 2 indicates how the maglev system would fare against its only competitor, the airplane—no contest.

Rand estimated that the entire cross-country system with the secondary lines indicated in Figure 3 (about 5,000 miles total) could be built in a decade if tunneling were carried on simultaneously in a number of locations.

A glance at Table 2 shows that the maglev system would have to cost only the same as conventional air flight to begin to take over the market in long-haul passenger transport, given the great savings in time. On the basis of total system cost amortized over 30 years, Rand found that a drastic decrease in fare to $50 one way would make coast-to-coast travel possible for so many more people that the system would be profitable even at that reduced fare.

There is no need to restrict the system to transcontinental travel. Since there is virtually no difference between tunneling at 200 feet versus 5,600 feet, it is possible to consider tunneling under deep water. An intercontinental system, for example, following the great circle route from Seattle to Paris would not require going under any deep oceans; and, in fact, would be under land masses most of the distance. The maximum depth requirement generally would be less than 1 mile. For any European country, such a system would naturally require an international effort.

Maglevs in a Decade

The technology is not an obstacle to building a commercial maglev system. The Japanese are currently testing a 310-mph superconducting 10-ton, 45-foot-long maglev vehicle on a 5-mile test track and they plan public service maglev transportation within the next decade. A test facility under construction in Miyazaki, Japan will develop the necessary cryogenic technology and other components required.

With this serious effort underway, it is likely that the Japanese will be in a position to bring the maglev technology to maturity and commercialization, then mass produce it and market it in the United States, Western Europe, and throughout the developing sector.

As with the development of commercial fusion, the United States could play a critical role in cooperative efforts to bring maglev technology on line.

Marsha Freeman heads the industrial research division of the Fusion Energy Foundation.

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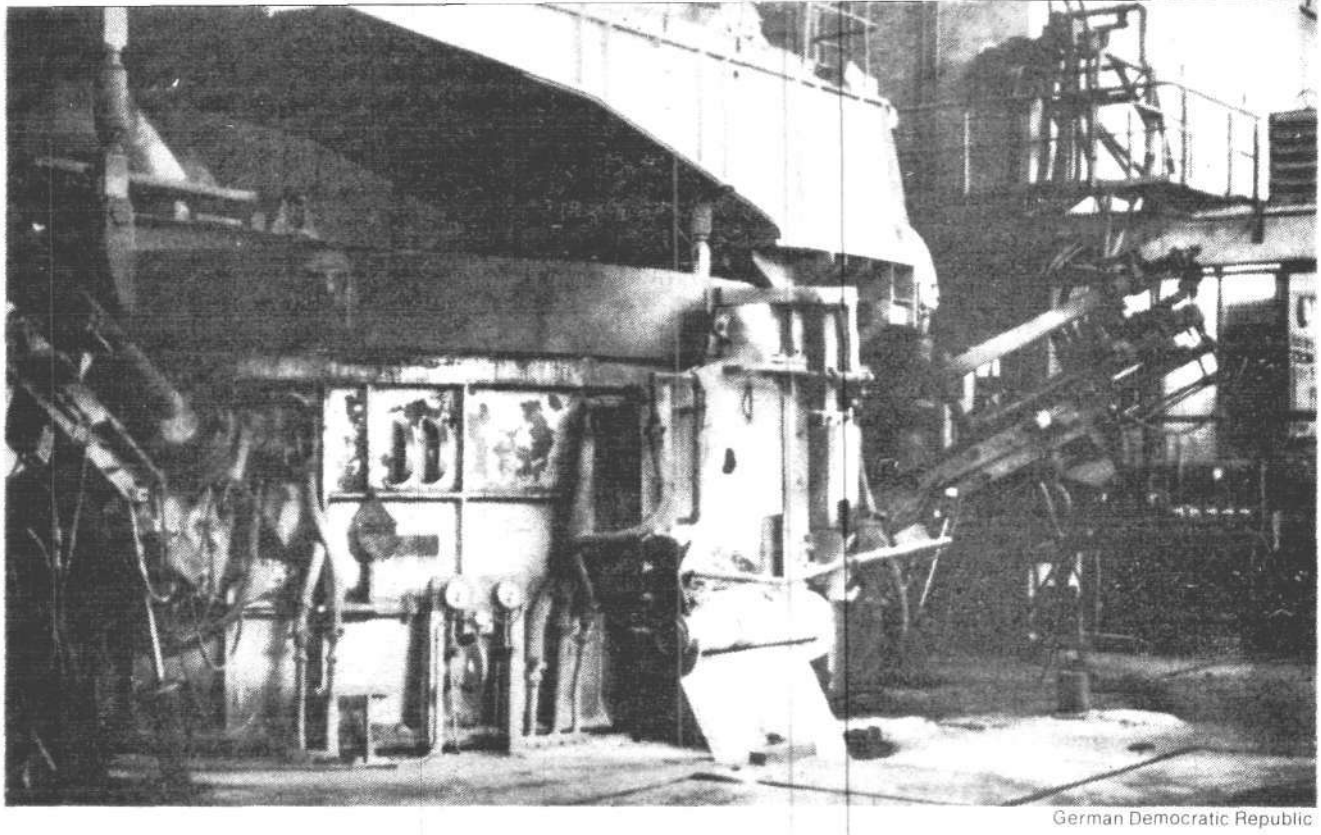


German Democratic Republic

The 10-ton plasma steel furnace. The argon plasma torches are inserted at an angle at each side of the furnace and produce temperatures up to 15,000° C.

Research

E. Germans Develop Plasma Steel Process

A new plasma steel-melting process developed by the East Germans and the Soviets will be offered to U.S. firms later this year, according to Dr. Franz Mueller, department chief of the East German Ministry of Ore Mining, Metallurgy, and Potash. Dr. Mueller made the announcement at the first Economic-Technical Congress of the German Democratic Republic, held in New York City May 9-10, where the system was displayed.

The new steel process uses a plasma torch and was developed out of work in both countries on high-temperature plasma physics. The process is highly efficient and reduces the cost of steel production by $400 per ton compared to conventional high-temperature electric arc furnace designs. In addition, the plasma torch process operates at only 40 decibels compared to the 140 decibels of conventional furnaces, and thus it does not require expensive noise control equipment.

The plasma process provides heat to produce high-alloy steel from scrap through a set of relatively low-temperature argon plasma torches, which are inserted into the vessel at an angle (see picture). This direct current arc plasma torch can produce temperatures up to 15,000° C compared to the maximum temperatures of 3,600° C for conventional furnaces that use electricity for energy. The higher-process temperature allows the recovery of almost 100 percent of the alloying materials in the scrap. It also decreases the iron losses, and has a higher melting efficiency and a lower heat and dust exposure for the operators.

The high-current plasma torches have power ratings of several megawatts, and are the major new development for the steel process. The consumed power of each torch is between 12 and 15 MW, with the secondary current of the torch reaching up to 10,000 A. The secondary voltage from the plasma is rated at 660, bringing the total power to about 6.6 MW.

The basic research to come up with a clearer statement about the gas/slag/bath sequence reaction under this plasma heating has just begun. Especially interesting, Dr. Mueller reported, is the behavior of hydrogen, nitrogen, and oxygen, particularly when plasma-forming gases other than argon are considered. For example, because of the dissociation and ionization processes that occur in the plasma state, the furnace permits the alloying of nitrogen directly in the gas phase, which is more economical than the conventional process.

100-Ton Furnace Planned

The first experimental plasma furnace was developed in East Germany in 1969 and had a 3-ton capacity. A 5-ton plasma furnace, equipped with a vertical torch, was put into operation in the Soviet Union in 1972, and a year later the East

Germans built a 10-ton furnace, which has produced more than 120,000 tons of steel ingots. East Germany's currently operating 30-ton plasma furnace was planned and designed by specialists from the GDR and the Soviet Academy of Sciences at Novosibirsk, Siberia and put into operation in 1977. Now both nations are planning a joint 100-ton plasma furnace.

The plasma furnace has produced more than 100 grades of high-quality steel alloys, including heat-resistant, corrosion-resistant, high-speed, and special alloy tool steels.

Quarks on Way Out?

New Argonne Evidence Vs. Quarks

New results obtained at the Argonne National Laboratory's Zero Gradient Synchrotron in Illinois on the collision of spin-aligned protons add to the growing body of evidence that disproves the quark theory of elementary particles. The quark theory attempts to explain the phenomenon of elementary particles by positing the existence of pointlike quarks as the ultimate particles of matter.

Previous results at Argonne have shown that protons with their spins parallel interact much more violently than those with opposed spins. This behavior implies a geometric structure that characterizes high-energy interactions, but conflicts with a notion of point particles, which by definition are symmetric.

The quark theorists had predicted that the asymmetric effect would decrease at higher angles of deflection; that is, when the particles were sent into head-on collisions. However, the latest Argonne results demonstrate that parallel-spin scattering dominates even more strongly at the highest scattering angles, thus showing conclusively that the small-scale structure of the proton is highly asymmetric.

Dr. Alan Khrish, who heads the Argonne Synchrotron Group, commented that the quark theorists to whom he relayed the new data were "astounded" and could not offer any explanation that would reconcile the results with the quark theory.

Physicist Questions Quark Existence

In a lecture at Columbia University in May, leading particle physicist Dr. Sidney Drell raised serious theoretical questions about the reality of quarks, the postulated ultimate constituents of matter. Drell, who is from the Stanford University Linear Accelerator Center, compared the scientific development of the evidence for the existence of the neutrino, the massless neutral particle, with the evidence claimed to show the existence of quarks. Unlike the work around the neutrino, the current data showing the apparent structure of protons and other particles are extremely ambiguous, Drell said. Since apparently quarks cannot be isolated, he asked, in what sense can they be said to exist?

"Our present plight with quarks may not be very different from that of an inquisitive mariner," he said, trying to break a magnet apart to isolate its north pole. The problem, Drell emphasized, is that quarks may be merely symptoms of certain geometric properties of particle structure, not point entities in themselves.

Drell's speech was a significant contribution to a growing tendency within high energy physics to move away from the problematic quark hypothesis.

Soviets Report

Four Soviet researchers at the Moscow State University and the Institute of Steel and Alloys have reported results with the compound copper chloride, CuCl, [sic], that point to the possibility of producing a high-pressure, high-temperature super-conductor. If such a superconducting material can be developed, it would revolutionize the technologies like fusion, magnetohydrodynamics, and electrical transmission than now require expensive and cumbersome cryogenic systems to maintain superconducting materials at supercool temperatures.

The Soviet experimental results, reported in the *Soviet Journal of Experimental and Theoretic Physics* in January, have created a stir in the U.S. physics community. Dr. Bernd Matthias, a pioneer in the development of numerous superconducting materials, said in a *New York Times* interview May 9 that he strongly doubted the accuracy of the Soviet reports. Matthias, who is a respected U.S. physicist, said that he believed the phenomenon of superconductivity is necessarily dependent on supercold temperatures.

The Soviet scientists found that under conditions of high pressure (about 50,000 atmospheres) and relatively high temperature (between 100 and 170° K) the CuCl compound exhibits dramatic increases in diamagnetic and electric conductivity properties. Both of these properties can be indicative of superconductivity.

The highest temperature reached so far for any superconducting materials is 23° K, and the achievement of high-temperature superconductivity, known as HTS, is one of the most difficult problems in physics today.

The Soviet researchers reported that when the CuCl, under the high pressure indicated, was quickly heated and cooled in the 100-170° K range, there was a phase transition to the state of increased diamagnetic susceptibility that approached the Meissner effect of perfect diamagnetism in superconductivity. In

High Temperature Superconductor

addition, increases of electrical conductivity by several orders of magnitude were observed. The research team is pursuing the hypothesis that there may be local superconducting effects taking place in the crystal that are not continuous or homogeneous but that point to the possibility of producing a high-pressure, high-temperature superconductor.

In an interview this month, Nobel Laureate Dr. John Bardeen, the co-developer of the BCS theory of superconductivity, suggested that there could be other explanations of strong diamagnetism besides superconductivity. However, he insisted that the Soviet results are interesting and that continued experimentation is vitally necessary. Researchers at Bell Labs had predicted the possibility of materials like CuCl becoming superconducting at high temperatures, Bardeen said. He stressed that the observed effect was under high pressure, and he said that he hoped the researchers would be "able to produce the material and the effect without the need for constant high pressure."

Agriculture

Labor-Intensive Agriculture Wastes Energy

The high productivity of U.S. agriculture is based mainly on the intensive use of commercial energy, report Dr. Marvin Duncan and Kerry Webb in the April *Economic Review* of the Federal Reserve Bank of Kansas City.

In an article titled "Energy and American Agriculture," Duncan and Webb debunk the environmentalist proposal that U.S. farmers should return to a more labor-intensive agriculture in order to conserve energy and augment the supplies of developing nations. U.S. agriculture is the most energy-efficient farming system in the world and subsistence farming uses on average more than three times the energy to produce an equal amount of grain, the authors show.

Machine Power Productive

Comparing rice yields in capital-intensive agricultural systems like the U.S. and Japan with those in labor-intensive systems like India and China, the authors demonstrate that even though per hectare the developed countries use substantially more installed horsepower (tractors, combines, and so forth), fertilizer, and irrigation energy than the developing countries, the difference in the *total* energy input per hectare is minimal. "Japan and the U.S. have substituted machine power with vastly superior productivity for labor and animal power," Duncan and Webb state.

The energy use per unit of product yield is much lower for U.S. and Japanese farmers than for their counterparts in underdeveloped countries, the article shows. For example, the *total* energy input for the U.S. is 32 million Btu's, while the energy input in India—wood, crop residues, human and animal labor—is 26.5 million Btu's. However, the U.S. rice yield in kilogram per hectare is 5,100 compared to India's 1,400. In other words, the energy intensity in million Btu's is about three times greater in India than in the U.S.: 19 to 6.3.

Conservation measures in farming would have no significant effect in alleviating a national energy crisis, Duncan and Webb assert. Energy-efficient U.S. agriculture uses only 3 percent of the total energy consumed in this country—an efficiency that has improved as capital intensity has increased. A less energy-intensive farm system would mean higher food prices, fewer exports, and hardly any increase in available fuel supplies.

Capital-Intensive Savings

To underscore the superiority of capital-intensive agriculture, the authors show that a farm laborer employed in the U.S. for 10 hours in 1976 would cost $26.50 in wages, while the same physical work could be purchased as electricity for only 3 cents.

The one weakness in this otherwise excellent report is that the authors' solution—to "stimulate new technology with greater energy efficiency" in farm equipment, plant breeding, and so on—omits mention of the need to simultaneously expand energy resources through nuclear power.

Colombia Peasant Leader Calls for Advanced Technology

Fausto Charris, director of the Colombian National Agrarian Federation, FANAL, called for the development of the nation's uranium resources as an essential part of the national program to develop Colombia's labor power and industrialize. "Colombia is one of the largest producers of uranium in the world (and) here we are still using solar mirrors, something which is counterproductive because we should be advancing toward nuclear energy," Charris said.

FANAL is a mass-based peasant federation with ties to the conservative labor federation, UTC.

In an interview with the Colombian daily *El Siglo* May 28, Charris criticized the lack of program among Colombia's trade unions and said "...workers and peasants should propose full employment but with advanced technology; that is to say, taking full advantage of full industrialization."

Books

The Antiscience Movement The Last Time Around

by Dr. Morris Levitt

Hutchins

The Physicists:
The History of a Scientific Community in Modern America
by Daniel J. Kevles,
New York: Alfred Knopf,
January 1978, $15.95

Science always comes under severe attack during periods of economic crisis. This is not a natural sociological phenomenon, however. Depressions are simply the times when nests of antiscientific cockroaches in the universities, foundations, and the media feel safe to come out into the light and do their job.

The February 1978 issue of the official magazine of the American Physical Society, *Physics Today*, contains an important study of what the last major antiscience rampage looked like at the outset of the Great Depression of the 1930s. Its author, science historian Daniel J. Kevles of the California Institute of Technology, provides material sufficient to demonstrate that there is a direct line connecting that period back to the first antiindustrial movements sponsored by the Fabian Society on American campuses at the turn of the century, forward to the postwar "Ban the Bomb" movement, and then to the environmentalist campaigns of the 1960s and 1970s.

Right in the middle of these subversive operations against the American Republic is a man long overdue to be hauled down from his pedestal and named as the arch opponent of science and republicanism—Robert M. Hutchins.

The End of Science Ideology

Kevles's article, an excerpt from his just published book, *The Physicists: The History of a Scientific Community in Modern America*, documents (although that is not his political aim) that the Fabian rampage against science in the early 1930s was based on a highly coordinated and fine-tuned ideological campaign whose immediate objectives were to shatter the morale of U.S. physical scientists and technologists and shut down their research and training facilities. The campaign came very close to succeeding.

Just as today's antiscience mobsters hope to dupe labor and industry into swallowing the lie that advanced technologies reduce the total number of productive jobs and result in "overproduction," the so-called humanist movement of the 1930s aimed to sucker the credulous into blaming science for the economic havoc that actually was due to the British-designed Anglo-American monetarist madness of Versailles and the 1920s. Moreover, with science out of the way, there is no form of social practice or epistemological standard to compete with untrammeled fascist madness.

The opening shot of the attack was a moratorium on scientific research proposed by the English Bishop of Ripon in 1927. He was supported by British author G. K. Chesterton, who argued, "There is nothing wrong with electricity: nothing is wrong except that modern man is not a god who holds the thunderbolts but a savage who is struck by lightning."

On the U.S. side, the upfront man for savagery was the Fabian *wunderkind* selected as president of the University of Chicago at age 30, Robert M. Hutchins. The subsequent founder of the postwar "collective nuclear guilt" movement and the corporatist Center for the Study of Democratic Institutions, Hutchins told the university convocation in 1933 that "science and the free intelligence of Man....have failed us." With Hutchins providing overall academic legitimacy for a "revolt against science" (including elimination of traditional courses and grades), the other pieces fell into place for an assault against the scientific and technological base of industry.

The major Fabian mouthpieces, the *New Republic* and the *Nation*, along with the Second International's League for Industrial Democracy (this British-controlled group in the 1960s gave you Students for a Democratic

Society and the weathermen) all went after the so-called exploitation of science by big business. The Ralph Nader of the day was one Frederick J. Schlink, a former engineer at the National Bureau of Standards who founded Consumers Research Inc. to expose all federal scientific agencies as "little more than handy consulting or guidance services to business enterprises." The telephone giant AT&T was singled out for congressional investigation for allegedly controlling technology for "excess" profits and monopolizing patents.

These reformers had no interest in actual progress by accelerating technological innovation in industry and agriculture. Their real concern was to replace value-free science with what the anti-Federalist revisionist historian Charles Beard called "the assertion of moral values." Beard, of course, didn't bother to mention that the concept of value-free science was precisely the sort of wretched British nominalism against which the Founding Fathers fought the American Revolution in "the pursuit of happiness" — perfection.

The Case of the Rockefeller Foundation

What better place to do the moral asserting and also extract penance for the sins of industrial enterprise than in the foundations (called in Fabian-speak "accumulations of vested wealth") which had been funded by the leading industrial families to support scientific research and education. When Frederick P. Keppel, the head of the liberal Carnegie Corporation, called for switching foundation funding from the physical sciences to the social sciences, the Fabians had more than ideological reasons for doing so. It is probably little known that the Rockefeller Foundation, before it became such a nest of zero-growth perversion, built physical science in this country in the post-World War I period. In the 1920s the foundation strongly supported National Research Council post-doctoral fellowships in the sciences and built up outstanding science departments at eight major universities that are scientific leaders to this day. The Rockefeller General Education Board donated $19 million to academic science, increasing by sixfold the pitiful total endowment from all sources to science in the U.S. at the turn of the century!

This great contribution was terminated and funneled instead into what were called socially relevant projects by two arch-Fabians in the Foundation, Warren Weaver and Raymond B. Fosdick.

Weaver, a former mathematics professor at the University of Wisconsin, became head of natural sciences at the foundation in the early 1930s. He immediately brough to bear the worldview acquired during his many years in Madison as an intimate of the LaFollette family (whose political offspring include Hubert Humphrey and Walter Mondale). His chief ally was foundation trustee Fosdick, a seasoned hand in redistributionist politics in New York and London, from the settlement houses to the League of Nations. In his 1929 book, not so subtly titled *The Old Savage in the New Civilization*, Fosdick penned the following piece of quintessential British intelligence bestiality, "Science has exposed the paleolithic savage, masquerading in modern dress, to a sudden shift of environment which threatens to unbalance his brain."

To make sure that humanity would in fact go off the deep end socially and psychologically, Weaver and Fosdick convinced the monetarist-infected Rockefeller Foundation Board of Trustees to cut *all* funding to physics unless it was directly connected to biological, chemical, and social research (the new funding recipients). The new goal of research was the "analysis and control of animate forces," and especially to gain understanding of the physiological basis of insanity — that is, for fascist social engineering and brainwashing.

The direct and indirect effect on physical science when combined with other funding cuts was devastating. Kevles summarizes the situation that resulted as the Weaver-Fosdick cothinkers in the Roosevelt administration and depression financial conditions took their toll:

"In Congress economizers slashed the budgets of all the federal scientific

agencies an average of 12.5 percent. The Bureau of Standards....emerged with an appropriation almost 26 percent below the 1931 level....State monies allocated for research fell sharply at such scientific centers as the Universities of California, Wisconsin, and Michigan....In the private sector, at Stanford and MIT, campaigns for new capital funds collapsed; a sizable part of the Cal Tech and all the Cornell endowments for research were wiped out....At Bell Laboratories, General Electric, and numerous other industrial research establishments, retrenchments were the order of the day....By the same year [1933], General Electric had fired some 50 percent and AT&T almost 40 percent of their laboratory personnel."

Topping off the slaughter, in 1934 the Rockefeller Foundation completely cut off its traditional $100,000 annual contribution to the National Research Council fellowship fund, throwing most new science PhD's out of work.

Once Again

The situation was not really reversed until the onset of World War II, followed by the Manhattan Project, postwar reindustrialization, and renewed emphasis on science during the space program that lasted until the mid-1960s.

If the antiscience mob had completely won in the 1930s, the U.S. might not now exist. But neither did we exterminate the disease. Instead, just as we stand at the threshold of the greatest triumph of applied and theoretical science, the development of controlled thermonuclear fusion, the enemies of humanity are again trying to shut down advanced scientific research — fusion, the breeder reactor, recombinant DNA— and destroy high-productivity industrial and agricultural technology.

This time, we can't afford to wait for another world war to decide the situation. If we want a future, we must fight for science as if our lives depend on it *now*.

Morris Levitt is the executive director of the Fusion Energy Foundation.

FEF News

PARIS CONFERENCE: ECONOMIC GROWTH VS. MALTHUSIANISM

"Nuclear power plants represent culture and technology in our time like temples did for the Greeks and cathedrals did for medieval times," nuclear architect Claude Parent told the June 13 FEF conference in Paris.

The meeting brought together scientists, engineers, and policymakers from the French nuclear industry, the national electricity concern (EDF), the Pasteur Institute, and several French universities, as well as diplomatic representatives from Asian and Soviet bloc embassies for a day-long discussion of the necessity of energy growth and high-technology development.

The main thrust of the conference sessions and the specific topic of the Parent presentation was disproving the widespread assumption that man must solve his current problems within the confines of a Malthusian dilemma—growth means exhaustion of finite resources. In France, as the speakers noted, this prevailing opinion takes an acute form in discussions of population growth. Dr. Alfred Sauvy, a well-known French demographer, and Dr. P. Dodin, an epidemiologist from the Pasteur Institute, both attacked the notion that population growth was bad and would lead to starvation, epidemics, and worse. Both speakers proved that a stable population would not be desirable, using statistics and documentation on the necessity of population growth to sustain economic growth.

Presentations by the FEF staff covered the specific technologies for the development of fusion, the need for a broad industrial development as well as energy-dense agriculture, and the financing of this development.

CLARKE WATSON JOINS BOARD

Clarke Watson, a leader of the American Association of Blacks in Energy group, joined the board of the Fusion Energy Foundation this month. Watson, an energy consultant, participated in the formulation of the progrowth energy program of the National Association for the Advancement of Colored People.

Clarke Watson

FEF ANNOUNCES CONFERENCE ON EAST-WEST COLLABORATION

The FEF will sponsor a conference on "East-West Scientific and Economic Collaboration for World Development" in New York City Oct. 5. Planned as a major international event, the conference will culminate a series of 1978 FEF international meetings focusing on development.

The conference will be particularly timely following the recent 25-year cooperation and trade package negotiated between West Germany and the Soviet Union, FEF director Dr. Morris Levitt said in his conference announcement.

"On May 6, 1978, West German Chancellor Schmidt and Soviet President Brezhnev signed a 25-year treaty that promises to be one of the most important diplomatic events of this century. For the first time, both leaders stressed that there is no acceptable alternative to peace. The only possible basis for war-avoidance is extended scientific and economic cooperation, not only bilaterally but through a joint development commitment for the underdeveloped world," Levitt said.

The East-West conference will cap the Soviet-West German process of energy and development policy deliberation with the presentation of specific, detailed proposals for major U.S.-Soviet joint efforts in energy development, space exploration, and the industrialization of the underdeveloped sector.

One of the chief purposes of the October conference will be to bring together the governments, business interests, labor leaders, and scientists who recognize the strategic international and domestic importance of such a global

Uwe Parpart

development perspective, and who recognize that U.S.-Soviet relations are the key to that policy.

The first conference panel will include a full status report on U.S. and Soviet efforts in developing thermonuclear fusion power and will discuss how collaboration with other countries, such as Japan, has the potential to transform the entire global energy and resources picture.

The second panel will evaluate specific three-way trade and development proposals put forward by the foundation, focusing on the market potential and tremendous need for U.S. capital and high-technology exports to the Soviet Union.

In the evening keynote presentation, Uwe Parpart, FEF director of research, will address the question of U.S.-Russian relations from the time of the U.S. Civil War to the present. The most important focal points are the World War II Stimson-Bush policies, the Eisenhower "Atoms for Peace" initiative, and the subsequent detente proposals. The FEF is inviting experts on U.S.-Soviet relations to comment on the Parpart presentation.

FEF COMPLETES FIRST STAGE OF INTERNSHIP PROGRAM

The FEF has just concluded the first stage of an ongoing internship program of science education from an advanced standpoint. The program is modeled after a similar project of Felix Klein, the late 19th century mathematician, who undertook the education of students in elementary science from the highest conceptual standpoint possible.

The six university students invited to the FEF internship program participated in a series of six seminars on the frontiers of plasma physics and the status of fusion research. The seminars were led by plasma physicists and members of the FEF staff and the subjects ranged form the latest techniques in the fluid theory of plasmas to the relationship between particle physics to field theory.

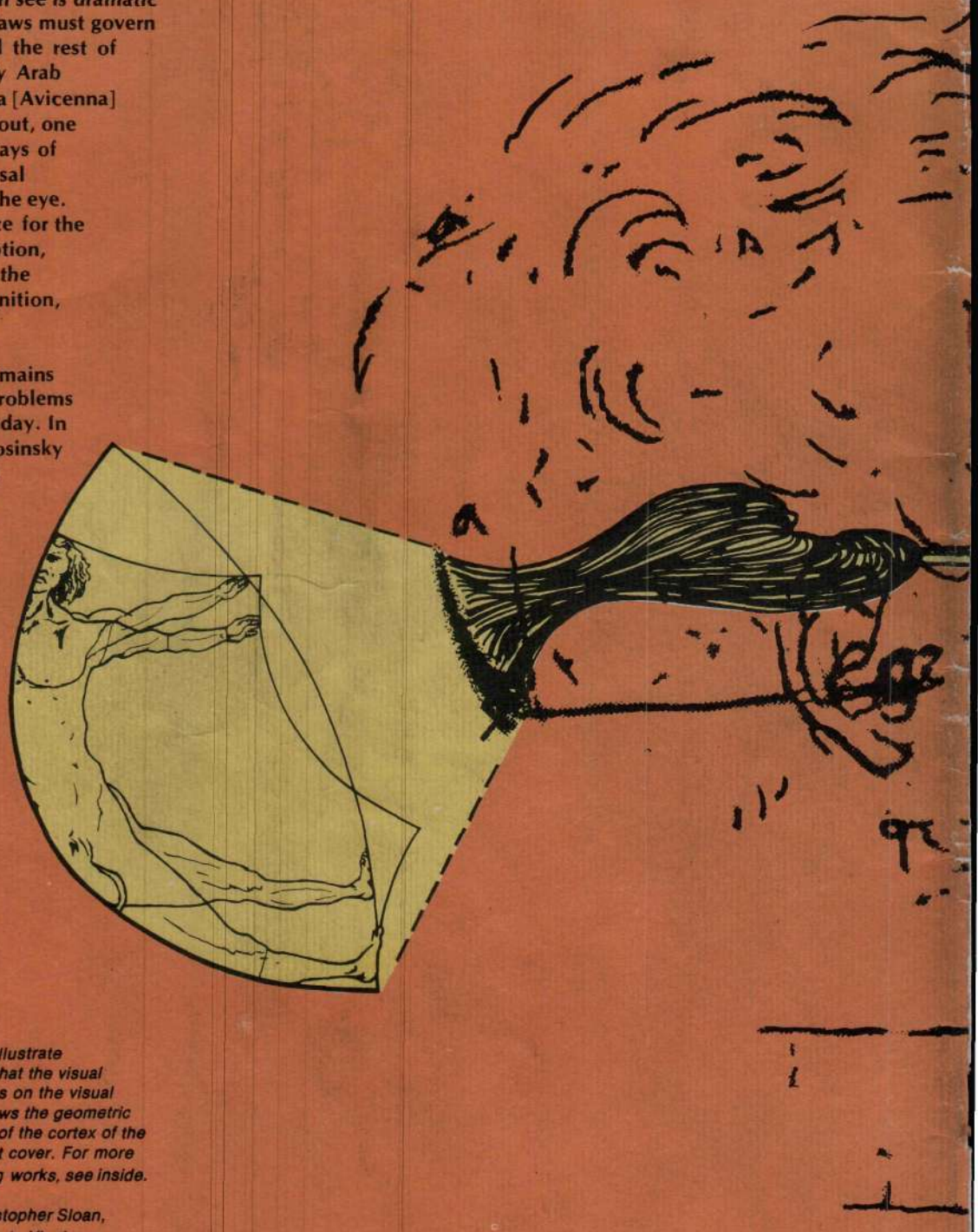
The second phase of the summer program is planned for July 5-14.

New Discoveries About an Old Problem

Throughout history, scientists and philosophers in the tradition of Plato have called the eye the window of the soul. They chose this characterization not only because vision is a critical sense, but also because an understanding of vision demands the resolution of the most difficult problem of science and philosophy: How can there be a coherent set of laws for processes as apparently different as human mentation and the physical world?

The fact that man can see is dramatic proof that one set of laws must govern both man's mind and the rest of the universe. As early Arab scientists like Ibn Sina [Avicenna] were fond of pointing out, one of the most efficient ways of discovering this universal coherence is to study the eye. The eye is the interface for the transition from perception, which is governed by the laws of optics, to cognition, which is governed by the laws of thought.

Visual perception remains one of the foremost problems in neurophysiology today. In this issue, Dr. Ned Rosinsky discusses some recent breakthroughs in the study of vision by Dr. Eric Schwartz that significantly advance the knowledge of how we see.



The cover:
The front and back covers illustrate the orderly transformation that the visual system in the brain imposes on the visual scene. The back cover shows the geometric transformation in one side of the cortex of the scene depicted on the front cover. For more details on how this mapping works, see inside.

The cover design is by Christopher Sloan, after sketches by Leonardo da Vinci.