21st CENTURY SCIENCE & TECHNOLOGY

November-December 1988

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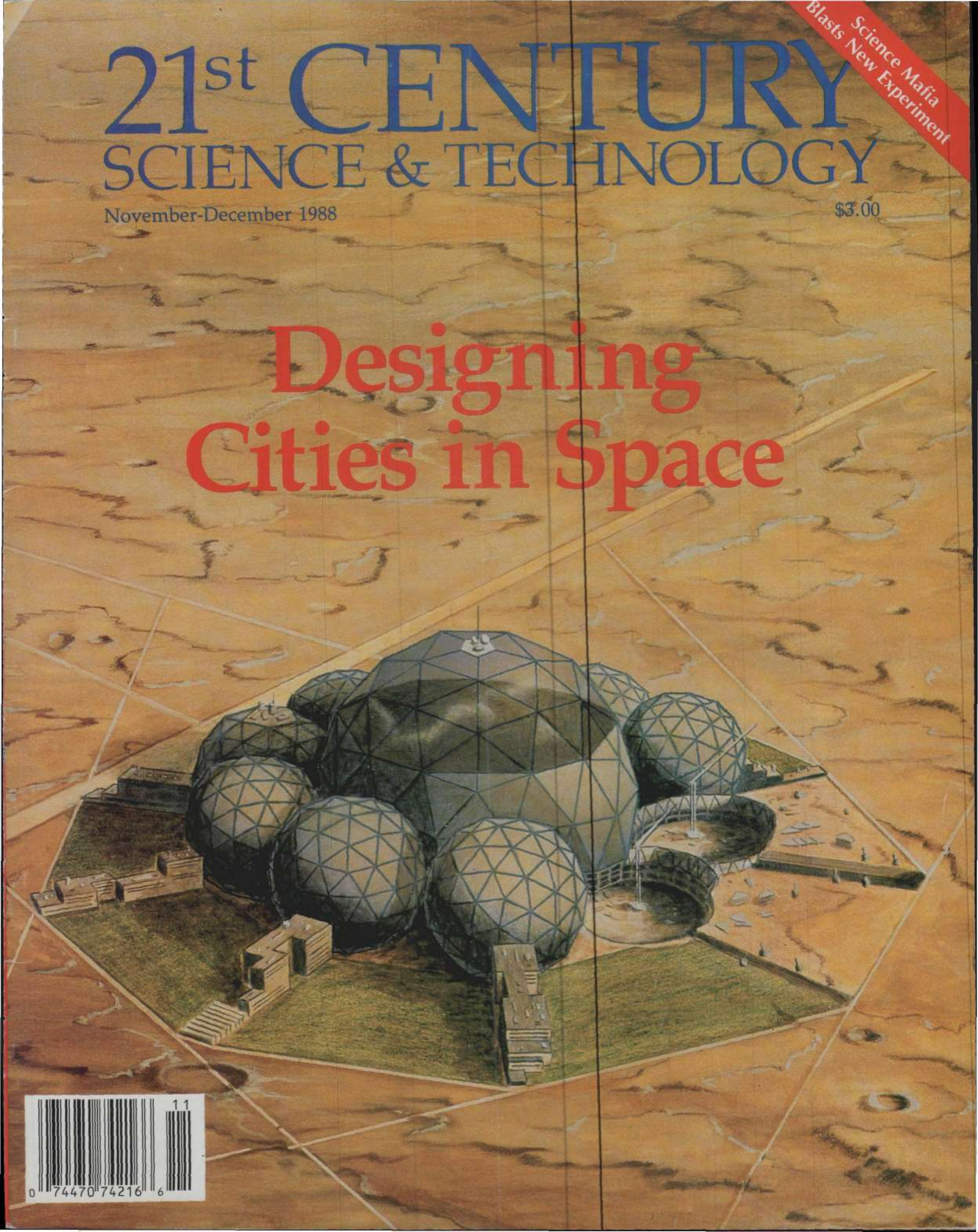
Science Mafia Blasts New Experiment

Designing Cities in Space



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On the cover: Illustration of Kepleropolis, proposed design for a city on Mars, by Christopher Sloan; cover design by Virginia Baier.

Go Nuclear!

If the United States is to survive as an industrial nation, we must go nuclear—and we must do it aggressively and fast. The only way to accomplish this is to mass produce standardized, medium and small-size modular nuclear units, using advanced reactor designs.

The reason for going nuclear is not the yet-to-be-proven greenhouse effect—although many of the people who buried nuclear power are now calling for its exhumation to save them from the warming of the atmosphere. The fact is that unless we begin now to mass produce nuclear power plants, it will not be possible to sustain any real economic recovery in the United States. Without nuclear energy, it will not be possible to have anything remotely resembling our current living standards here, nor will it be possible to prevent much of the world's population from succumbing to starvation and death.

Electricity use is increasing at 4 percent per year nationwide, and more in some regions. The conservation and austerity-motivated projections of the Carter years for 2 percent electricity use growth rates up through the year 2000 are far short of the mark. Unless we add to the power grid in the early 1990s—that's in the next five years—Americans will be thrown into the abysmal conditions of the East bloc or of the developing sector, where there is little industry and where domestic electricity is so irregular that one is never sure if there will be enough power to boil water.

As this issue's special report spells out, the only reason this nation has not been subject to more widespread brownouts in 1988 is that depression conditions and the shutdown of heavy industry have cut down the real demands for power in an industrial nation.

Mass Production

Mass production of nuclear plants means designing and equipping factories to turn out on an assembly line numbers of standardized, modular, medium-sized nuclear reactors that would be transported by rail, truck, or barge to prepared plant sites. It also means licensing a *standardized* design, so that each nuclear plant does not have to go through a lengthy licensing process.

There is no problem in readying the science and engineering to produce such modular nuclear reactors. The problems are strictly political: We have to overthrow the tyranny that killed this efficient source of energy in the 1970s and 1980s by turning routine seven-year plant constructions into costly fifteen-year nightmares.

Once the world leader in developing civilian nuclear technology—from reprocessing, to reactor design, to fuel breeding—this nation has now taken a back seat. We are the only nuclear nation, in fact, that does not reprocess spent fuel, but stockpiles it instead (as a target for environmentalist propaganda).

The United States has 35 years of experience with commercial nuclear power here and abroad. Although we have the largest number of nuclear plants in any one country (106), this represents by no means the largest ratio of nuclear-generated power to total power. Here nuclear in 1986 was about 16 percent of total power produced. Western Europe, in contrast, is 30 percent nuclear, with France leading the world at 65 percent.

A Nuclear Renaissance

Although the U.S. nuclear industry is now half-dead, the situation can be reversed. What's required is an unequivocal presidential policy statement on the necessity of going nuclear and the setting up of a presidential panel to plan a crash program for a nuclear renaissance. This includes a public education program that stresses the facts about nuclear power and an adequate research budget for all the advanced nuclear technologies, for university research, and for training nuclear industry workers.

Immediately, we can bring on line the more than 14 gigawatts of nuclear power now stalled in construction or licensing. Simultaneously, factories must be geared up to turn out quantities of standardized plants. In order to reap the benefits of shop fabrication, these nuclear plants have to be smaller in capacity than the typical 1,000-megawatt plant of today. The loss of the traditional economy of scale achieved by constructing larger plants is compensated for by the cost savings from assembly-line production, standardization, sharing of facilities as two or more modular units are grouped together, shorter lead times for completion, and reduced financial risk. Further, experience from Navy reactors and other small mobile reactors suggest that there will be additional savings from the greater reliability of smaller reactors.

In addition, there will be cost savings from the use of new nuclear technologies under development, like General Atomic's high temperature gas reactor or General Electric's PRISM, a new modular breeder reactor, and, of course, fusion energy.

If we start now, the factories can be ready in three years, and the first nuclear plants can roll off the assembly line in five years, ready to be installed at prepared construction sites. The alternative—not going nuclear—constitutes an immeasurable risk to the future of humanity.

NEWS BRIEFS

SPACE SCIENCE TECHNOLOGIES CAN FEED THE WORLD

21st Century Editor-in-chief Carol White led a panel on using new technologies to increase food production at the founding conference of the international Food for Peace organization in Chicago, Sept. 4-5. "A serious national commitment to colonizing the Moon and Mars would involve assembly-line production of modular nuclear power plants and the rapid development of fusion power," White said. With these energy technologies we could increase world production for feeding 50 billion on Earth, she said. Joining White on the panel were Dr. Frank Salisbury, a plant physiologist working on growing food on the Moon, and Dr. Martin Welt, a pioneer in food irradiation.

INERTIAL FUSION PROVEN FEASIBLE, LLNL PHYSICIST TELLS CONFERENCE

Dr. Erik Storm from Lawrence Livermore National Laboratory's inertial confinement program told an international conference in August that a bomb-ignited experiment with the X-ray laser was used to demonstrate that a certain X-ray pulse could ignite the fusion process. Storm was participating in the annual Erice conference in Sicily on nuclear technologies.

FORMER VENEZUELAN PRESIDENT PROMOTES FUSION AS SOLUTION

Gen. Marcos Perez Jimenez, who served as Venezuela's president in the 1950s, promoted fusion power as the solution to the energy crisis in an interview Aug. 30 with *Elite* magazine. "My government had reached the conclusion—as did the Shah in Iran before he was overthrown by Khomeini—that oil is more valuable as a basic resource for petrochemicals than as a fuel," the general said. "Man has succeeded in testing hydrogen explosions and . . . is working actively to achieve a controlled explosion that . . . will permit us to have a [source of] controlled, inexhaustible, clean, noncontaminating energy."

INDIA TO OPEN NEW ASTRONOMY AND ASTROPHYSICS CENTER

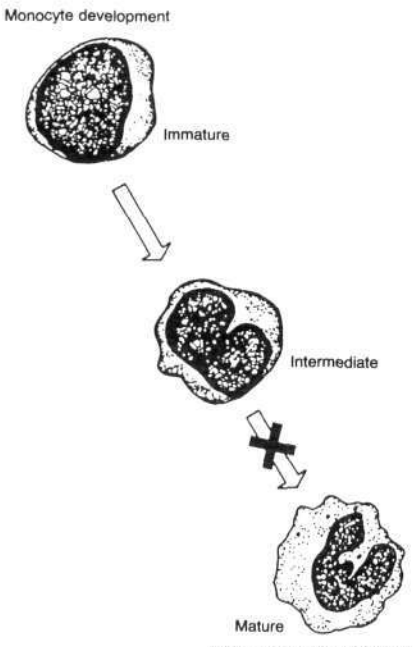
An Inter-University Center for Astronomy and Astrophysics will open in July 1989 in Poona, India, part of the government's decision to make astronomy and astrophysics a priority. The center, to be headed by Dr. Jayant V. Narlikar, will conduct basic research and have an extensive visitor program. Narlikar is widely known for the Hoyle-Narlikar steady-state cosmology and the theory of conformal gravity that he and Sir Fred Hoyle developed. "I think the cosmological issue is quite open and one should try different approaches to see their limitations and capabilities," Narlikar told *21st Century*.

ARGONNE LAB STUDY SHOWS MARIJUANA DAMAGE TO IMMUNE SYSTEM

Smoking marijuana may damage the body's immune system by preventing the development of certain white blood cells, according to an in vitro study by researchers at Argonne National Laboratory. The weakened immune system may then make the marijuana user more susceptible to disease, said Dr. Eliezar Huberman, who coordinated the study. Although the depression of the immune system was known to be an effect of smoking marijuana, scientists did not know why this happened. In the Argonne research, cell cultures were inoculated with the main psychologically active substance in marijuana, tetrahydrocannabinol or THC. The cells did not develop to maturity, and the higher the concentration of THC, the more severe the effect. The next step will be to test humans.

Philip Ulanowsky

Carol White at the podium of the Food for Peace conference. Seated are (from left) Jonathan Tennenbaum, director of the European Fusion Energy Foundation, Martin Welt, and Frank Salisbury.



Argonne National Laboratory

Marijuana derivatives such as THC stimulate early development of monocyte blood cells but prevent them from completing the maturation process, thus damaging the immune system.

The Lightning Rod

My dear friends,

Recently, the Soviet cultural journal *Literaturnaya Gazeta* expressed the wish that "the fate of the world will be taken up by the two Michaels." That reminded me of a little fable.

Once upon a time there was a boy named Michael—or maybe there were two boys. At any rate, there was a Bad Michael and a Good Michael. They were very different, but sometimes people said it was hard to tell them apart. (Maybe they were Siamese twins.)

Good Michael was very concerned that people have clean, safe energy, use it wisely, and not have to pay too much for it. At least, that's what he said.

Bad Michael wanted all the energy he could get, any way he could get it. He only cared about power.

Good Michael was fervently opposed to power—especially nuclear power.

"We tried that once," he explained. "We built our nuclear power plants with all these expensive safety systems, in case anything went wrong. Then, one day, it did. And we had to use the safety systems! What if they hadn't worked? I was terrified."

From then on, as far as Good Michael was concerned, all nuclear plants had to have catastrophe plans for when the safety systems didn't work. However he refused to participate in drawing up the plans.

"What's the point of planning for a catastrophe?" he demanded. "That's just throwing money away. Besides, anything that's used to build bombs has to be bad."

Bad Michael hated nuclear bombs and missiles even more than Good Michael—he said. (However, when it was proposed that a new technology be used to "render nuclear weapons impotent and obsolete," Bad Michael objected violently. And Good Michael agreed with him. You can see why people were sometimes confused.)

Meanwhile, Bad Michael built nuclear power plants like mad. One of them turned out to be a real bomb—it blew up. (Just like Good Michael, Bad Michael didn't believe in safety systems—so he hadn't built any.)

"That does it!" Good Michael exclaimed. "I'm not going to let any more of these dangerous things be built in my backyard."

"I completely agree with your decision," said Bad Michael, who went right on building nuclear power plants in his own backyard and everybody else's, the same way he always had.

Whereas Good Michael went back to the tried and true, traditional methods of energy production—water wheels, sun-baked rocks, campfires, and other backyard generators.

"I've still got the first windmill I ever owned," he bragged.

Unfortunately for Good Michael, things don't always work out the way they're supposed to when you're a good boy in your own backyard. Sometimes being a good boy isn't good enough.

There came a day when there was a severe power shortage in Good Michael's backyard. To make matters worse, there was a heat wave that went on so long people were talking about a permanent change in climate—the

"greenhouse effect."

"Too many campfires," some of Good Michael's best friends muttered. "Not enough energy, too much hot air."

They began asking some embarrassing questions. Questions like "Whatever happened to nuclear power?" and "Why did we stop building those nuclear plants—they seemed to work pretty well for awhile there."

This upset Good Michael no end. "No! NO!" he shrieked. "You can't fit a nuclear plant into a greenhouse." Some people suggested he didn't sound wholly rational.

But just when things were looking their blackest for Good Michael (and this was not entirely a metaphor), Bad Michael came to the rescue.

"I've got more power now than anybody," he declared. "That makes me the world's leading expert on the subject. And my expert opinion is, that no one has the right to ask Good Michael embarrassing questions that get him upset. And if anyone does, I'll see that he (or she) is short-circuited—permanently."

Bad Michael put his arm around Good Michael's shoulder and smiled beatifically. An eerie silence fell over everybody's backyard.

Letters

Damnation . . .

To the Editor:

. . . I have decided after thoroughly reading both the March-April and May-June issues that I am not in agreement with the content and right-leaning stance of the articles presented. I personally don't think that science has the ability to solve mankind's problems, and certainly don't think that more development is the answer.

Making a "livable" colony on Mars isn't where we should put our resources; stopping the wholesale destruction of the Earth's natural environment is where I think the emphasis should lie.

Would you choose to live over a nuclear waste dump? I for one would prefer to make do with less electricity.

Paul Kastner,
President
Consolidated Dutchwest Japan Co.
Japan

. . . And Praise

To the Editor:

21st Century is an excellent reporting magazine covering the cutting-edge technologies that will lead us into the future. The July-August issue raised the excitement of spaceflight, the promise of medical breakthroughs, our environmental control abilities, and more. . . .

Every high school should get your magazine.

Charles Schlemm
Burns, Tenn.

The Church and the Copernican Revolution

To the Editor:

Carol White's article in the March-April issue of *21st Century* ("Johannes Kepler: Voyager in Space," page 42) provided interesting historical documentation on the *Somnium* of Johannes Kepler. However, on reading it I considered it useful to clarify some areas touched on in the article. In particular, contrary to the impression given in the article, Christian "theological considerations" provided the origin of the heliocentric hypothesis (the hypothesis that the Earth and other planets travel around the Sun) of the Copernican Revolution forward.

The heliocentric hypothesis had been opposed for centuries by some of the chieftains among pagan ideologues. Thus, I believe that the assertion in White's article, that Christians were "unable to accept that God did not create man at the center of the universe" is in error. . . .

In the 15th century, Cardinal Nicholas of Cusa (1401-1464) put forward the heliocentric hypothesis based on "theological considerations" he developed in his *On Learned Ignorance*—as he wrote to Cardinal Julian, "a few deductions on the universe which many will find unusual."

The Cardinal argued that the Earth could not be stationary, since it is a creature of God, and only the Creator is absolute, unchanging, and immobile. Only God can be motionless, he explained. His creations are all characterized by motion. Therefore, any astronomical theory based on interpreting observations recorded on the assumption that the Earth is a fixed, immobile platform, is fallacious. In Book II of *On Learned Ignorance*, he writes:

"It is now evident that this Earth really moves, though to us it seems stationary. In fact, it is only by reference to something fixed, that we detect the movement of anything. How would a person know that a ship was in movement, if from the ship in the middle of the river, the banks were invisible to him, and he was ignorant of the fact that water flows? Therein we have the reason why every man, whether he be on Earth, in the Sun, or on another planet, always has the impression that all other things are in movement whilst he himself is in a sort of immovable center. . . .

"[But] only in God are we able to find a center which is with perfect precision equidistant from all points, for he

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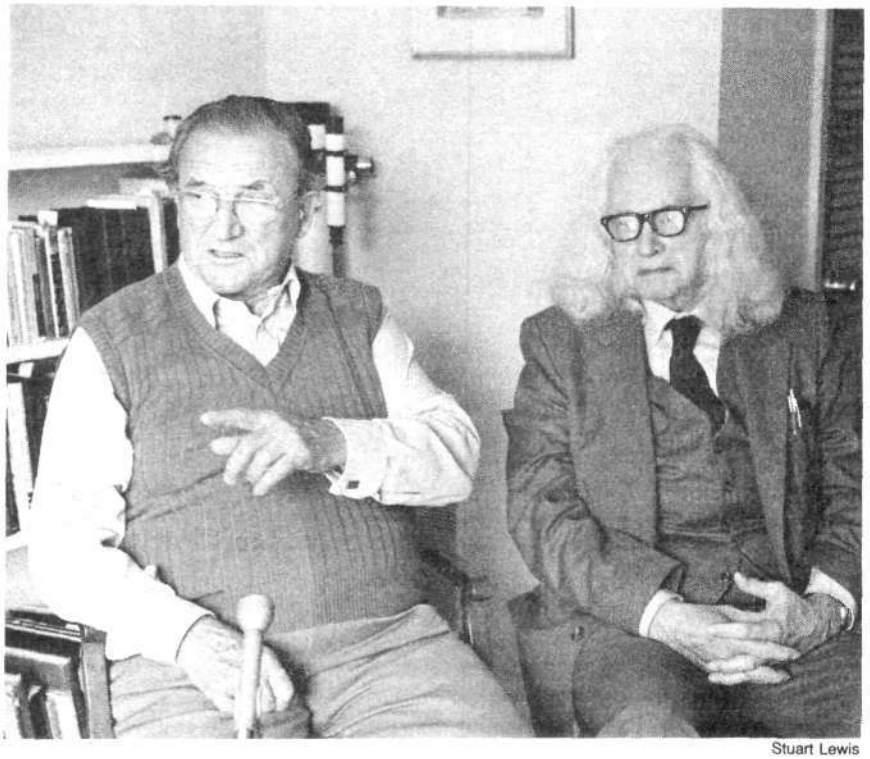

Stuart Lewis

Dr. Erich Bagge (left) and Dr. Robert J. Moon at a 1985 seminar discussing the early years in fission research, in which they were both involved in the 1940s.

A Nuclear Pioneer Discusses The Geometric Nucleus

EDITOR'S NOTE

This new section is intended to report hypotheses and notes on research in progress. The note below was submitted by Ralf Schauerhammer, managing editor of the German-language Fusion *magazine. Professor Erich Bagge, whose ideas Schauerhammer discusses, developed one of the first nuclear research centers in Germany after World War II and is the father of the first commercial nuclear-powered ship, the "Otto Hahn." He was a student of Arnold Sommerfeld and Werner Heisenberg.*

Some weeks ago I explained the key features of Dr. Robert Moon's geometric model of the nucleus (see "The Geometric Basis for the Periodicity of the Elements" by Laurence Hecht, *21st Century*, May-June 1988, p. 18) to Professor Erich Bagge of the University of Kiel. Although he had doubts about some of the specifics of the geometric construction, he agreed with the basic conception. He is convinced, he said, that the atomic nucleus can only be understood geometrically and that the formal description prevailing today does not explain much.

Bagge told me the story of how he arrived at a geometric conception of the nucleus 40 years ago.

When he read Maria Goeppert Mayer's 1948 paper on the empirically discovered "magic numbers" [numbers of neutrons or protons that correspond to the most stable nuclei, and that are used to account for changes in the nuclear properties of the elements], he concluded that there must be a geometrical explanation for these magic numbers.

Goeppert Mayer's basic concept was published in *Naturwissenschaften* 38:473 ff., 1948.* There are two rows of magic numbers: 2, 6, 14, 28, 50, 82, 126 and 2, 8, 20, 40, 70, 112. They result from the formulae:

$$N(n) = (n^3 + 5n)/3, n = 1, \ldots, 7$$

$$G(n) = (n^3 - n)/3, n = 2, \ldots, 7.$$

The series of magic numbers usually used is a combination of both, namely, $G(2) = 2$, $G(3) = 8$, $G(4) = 20$, $N(4) = 28$, $N(5) = 50$, $N(6) = 82$, $N(7) = 126$.

The "break," which is responsible for the shift from one series to the other, is traditionally explained as a result of the spin-orbital-force between nucleons. Bagge, however, considers these forces unnecessary and conceptually contradictory.

The crucial idea came to him one morning in January 1949 while shaving: What is important about the magic number formulae is that they reflect a three-dimensional geometrical structure, which Bagge explains as "minimal close packing of regular geometric solids."

One of Bagge's students, Juergen Heinrich Vossler, experimented with packing geometrically regular solids in a rubber skin, and he exactly reproduced the series of the magic numbers when he used ellipsoids. He approximated the ellipsoid by making a plane cut of less than a great circle on a table tennis ball, and gluing a second such ball into this opening. Vossler reported these experiments in his thesis, "Neuere Modellvorstellungen über die Schalenstruktur der Atome" (Recent Shell Models of Atoms).

Two-Dimensional Packing

A two-dimensional example of this packing can be demonstrated with coins. The number 1 is the first "two-dimensional magic number" and 7 is the second one, since 6 coins fit around the one in the middle. The third "two-dimensional magic number" is the minimum number of coins that "pack" around the 7.

I believe that Bagge thereby discovered an application to ellipsoids of a three-dimensional "isoperimetric

principle." The empirical reason Bagge gave for the success of the ellipsoids in reproducing the magic number series is the predominant occurrence of even numbers of nucleons. A deeper reason, however, might be found by viewing the process of nucleus-formation from the standpoint of conical functions and their elliptical integrals.

The history of Bagge's discovery is itself noteworthy. In 1949, immediately after getting the idea, he explained it to Hans Eduard Suess, the Austrian-American physical chemist, and J. Hans D. Jensen, the German physicist, who were passing through on a trip from Copenhagen. (Jensen made trips to Copenhagen to visit Niels Bohr.) They had not previously worked on the structure of the nucleus, but they took Bagge's idea and reformulated it in an algebraic version.* This they sent to the journal *Naturwissenschaften* without any mention of Bagge!

The referee for *Naturwissenschaften*, Otto Haxel [a collaborator of Jensen on this question, either then or later—ed.], delayed publication of a prior note by Bagge, so that it did not appear until the same issue that carried the article of Jensen and Suess, thus veiling Bagge's priority.

This is all the more interesting because Goeppert Mayer and Jensen later received the Nobel Prize for discovering the so-called shell structure of the nucleus.

In another journal, *Physical Review*, Samuel A. Goudsmit published Bagge's idea in an article on electron spin that again did not mention that the idea originated with Bagge. It was only after Bagge's intervention that a note was printed stating that Bagge had published "the same idea two years earlier."

It would be worthwhile to take Vossler's experimentation further using nothing more advanced than a microcomputer. If the major and minor axes of the ellipsoids are in the golden ratio, would this not produce the magic numbers most exactly?

Note

* Versions of Goeppert Mayer's papers appeared in English in the *Physical Review* in 1948 and 1949, and a version of Jensen and Suess's paper appeared in the same journal in 1949.

VIEWPOINT

The Benveniste Affair: Good News For Science

J.M. Dutuit

At the end of June 1988, a scientific matter burst into the world media that ordinarily would be seen as an encouraging event, were the brains of our age not congealed and atrophied by dogma. In fact, the affair in question is tending to become a scandal. It is like a burning odor emanating from the back kitchens of biological research.

If there is a flame smouldering, it is because of theoretical considerations that are implicit in this work. The universally accepted rules of intellectual investigation and the contemporary view of "matter" are themselves in question. Anyone in the university establishment who is not afraid of ideas—knowing that they are the very foundation of science—has no doubt of this. Some are sounding the alarm to announce the fire. Many fear that rationality will be shipwrecked in the ocean of false science and the tempests of kookery.

The most radical have declared their rights and convened commissions of inquiry that Torquemada would not have disowned—with sorcerer and fraud specialist at the ready with their anathemas! What a peculiar time we live in.

What I am referring to is, of course, the Benveniste affair.* Could this be the iceberg that transforms an "unsinkable" ship—our body of physical, chemical, and biological sciences—into a scuttled wreck?

On the hypothesis that Jacques Benveniste may be *neither* a fraud nor an incompetent, do the developments yet to come justify a panic? For if Benveniste were merely a fraud or an incompetent, surely there would be no need for so much commotion.

The principle of the Benveniste iceberg is simple. Its submerged mass—that is, the probable explanation for the phenomenon of degranulation in the absence of solute after sufficient dilution—is the entirety of the phenomena studied by optical biophysics, as I will explain below.

Molecular Materialism

Current biomolecular science holds that in order for information to be transmitted to a metabolic chain, it is indispensable for there to be some "physical" transfer from one molecule to the other, or an exchange of a group of atoms, of radicals, of electrons, with the enzymes being the transport workers.

Benveniste dissolved in water a substance that we will call *S*. This solution set off an allergic reaction of degranulation in vitro upon the basophils of the blood, a reaction used frequently to test a great number of molecules. It is classically accepted that the mode of action of the allergen *S* can only be molecular. It must be introduced into the solvent to set off the reaction of recognition, *R*.

Let us not forget that we are working in the context of a Cartesian, Newtonian physics, where the universe is made of "solid" individuated particles. These particles act upon one another according to linear chains of causality. In this system, every electromagnetic phenomenon is closely bound to a material, individuated substrate. The presence of the *substance* is the condition for action, the latter being none other than

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J.M. Dutuit, PhD and MD, is a paleontologist working with the Centre National de la Recherche Scientifique in the Paris Museum of Natural History. His viewpoint was translated from the French by Claudia Annis.

Note

* A news analysis of the Benveniste affair appears on page 16.

Will Glasnost Sink India's Soviet Nuclear Deal?

by Ramtanu Maitra

More than 10 years after Alexei Kosygin, then Soviet prime minister, made the offer to build nuclear power stations in India, a deal was finally signed in April 1988. However, one month later, a 30-page report by the late Soviet academician V. Legasov, published by *Pravda* May 20 and now making the rounds of India's nuclear establishment in English translation, may reopen the issue. The Legasov testimonial, which exposes the weaknesses of Soviet nuclear power plant design, has given fuel to opponents here of a nuclear deal.

For more than a decade now the pressure on India to accept Soviet reactors has been unrelenting. First, prime minister Morarji Desai and later, in 1980, Indira Gandhi had flatly turned down the offer. Moscow renewed the offer with Prime Minister Rajiv Gandhi in 1985 soon after India announced a target of 10,000 megawatts-electric (MWe) of nuclear power by the end of the century.

The Soviet offer, accepted after three years of negotiations that were delayed in part by the Chernobyl incident, includes installation of two 1,000-MWe plants using pressurized water reactors on a turnkey basis. The reactors' enriched uranium fuel is to be supplied by the Soviet Union. According to one report, under the terms of the contract India will have at least five years' ready supply of enriched uranium fuel stocked up prior to commissioning of the plants. The Soviet Union will also take back the spent fuel rods.

Unofficial reports indicate that the first Soviet reactor will be installed in Koodankulam, a sleepy little town in southeast Tamil Nadu.

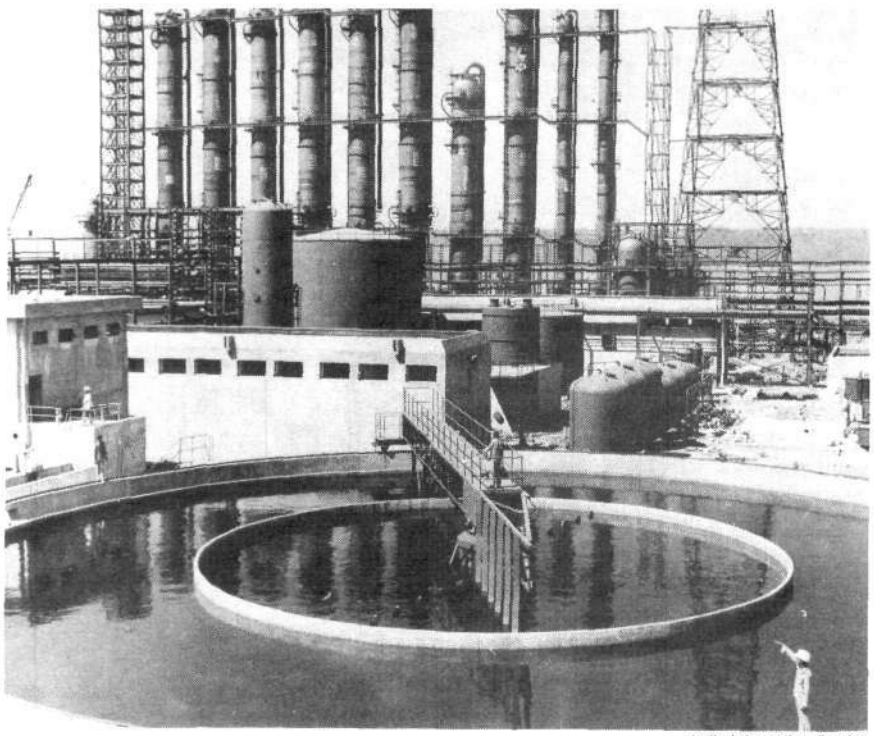
Under the circumstances, Legasov's report is bound to cause a flutter. Although it does not discuss the Soviet VVER-type reactors to be supplied to India, the report does document the weakness of the Soviet design and operating system for nuclear power plants. For example, referring to the hazard probability analysis developed by Prof. Rasmussen at the Massachusetts Institute of Technology and used routinely in the United States, Legasov admits: "I have not seen in the Soviet Union any scientific group, which even with the slightest competence could examine these problems."

Curiously, the exposé is a kind of suicide note. Legasov, who was in charge of the nuclear power plant program in the Soviet Union, took his own life after issuing the report.

The quality question adds an entirely new dimension to the arguments raised so far against the import deal. Indian opposition to the nuclear import option—from the Soviet Union or anywhere else for that matter—is based on past experience and the claim that India's own nuclear program will be disrupted.

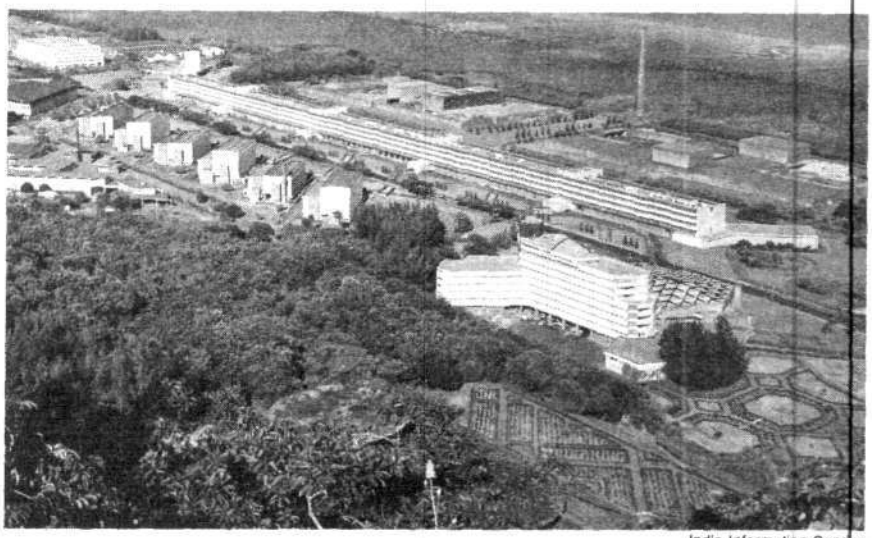
A Bad Precedent

India acquired two light water reactors (LWRs)—boiling water type—from the United States in 1963 under an agreement that specified, among other things, that these reactors would be operated on no other fuel except that supplied by the United States. Then, in 1978, during the antinuclear heyday of the Carter administration when the infamous Nuclear Nonproliferation Act



India Information Service

Exchange towers at the heavy water plant at Kota, shown under construction.



India Information Service

The Bhabha Atomic Research Center in Trombay. In the background are the radiological, food irradiation, and processing laboratories.

spearheaded by Senators Percy and Glenn was signed, fuel shipments were abruptly halted to India's Tarapur nuclear power station.

India—a nonsignatory to the Nonproliferation Treaty on grounds that it discriminates against non-nuclear-weapons nations—flatly refused to bow to the treaty's mandate to place the two American-made reactors under the "full-scope" safeguards inspection system of the UN International Atomic Energy Agency. Moreover, New Delhi rightly insisted that a bilateral agreement between two nations cannot be simply brushed aside by passing new domestic legislation. After much haggling, the Carter administration authorized fuel shipments to India.

But the matter did not end there. In 1981, the United States once again threatened to cut off fuel to the Tarapur plant after India announced it would reprocess the spent fuel. India pointed out that the 1963 agreement mandated that safeguards be applied to reprocessing but did not refer to the issue of whether reprocessing should be undertaken or when.

This controversy further fouled India-U.S. relations until, finally, in July 1982, the late prime minister Indira Gandhi and President Ronald Reagan worked out a compromise formula whereby India would continue to receive supplies of enriched uranium fuel from France.

This bitter experience convinced many that a nuclear tie-up with the Soviet Union—the other prominent member of the London Club of nuclear weapons powers and a similarly crusading power against "nuclear proliferation"—is asking for trouble.

Other Worries Legitimate

India's own nuclear program is about three decades old and is from all accounts a sound one. But it is a program in which LWRs and enrichment plants do not play any role. Since India has a small amount of uranium reserves—assured reserves are around 30,000 tons—the Indian program is based on using natural uranium as fuel in the first stage, and then moving quickly to breeder reactors.

More important, the program planned to utilize the country's large thorium reserves, with U-233 (produced by irradiating thorium-232) as the future fuel. India has so far pursued this program to the letter, and has already succeeded in converting Th-232 to U-233, although commercial fuel rod-making and the rest of it is yet to be achieved.

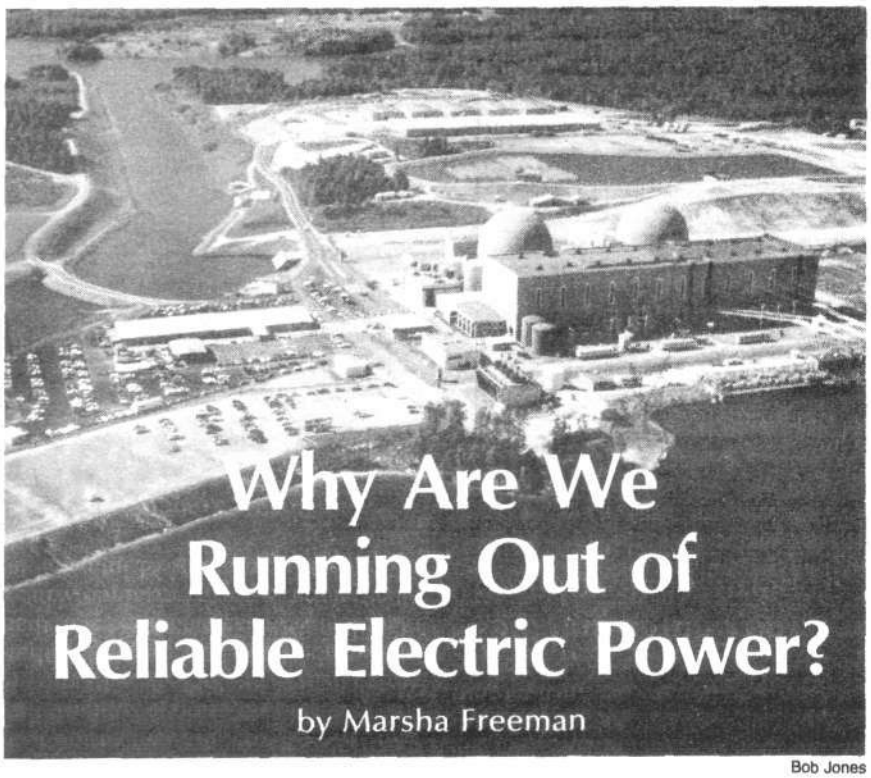
Influential Indian nuclear scientists, including the past two heads of the Atomic Energy Commission, have held the line against importing LWRs on the grounds that too many varieties of reactors will mix up the power program and effectively derail it. They are also uneasy that further inclusion of LWRs will foster a lobby within the country insisting on building LWRs indigenously. These scientists believe such a situation will set back the program further, since master LWR technology will take away a significant amount of manpower and time.

By all accounts it was the yawning power gap in the country that prompted the present administration, with its explicit heavy investment in rapid economic growth, to overrule these admittedly weighty considerations. There is no question that the target of 10,000 MWe of nuclear power by 2000 will be impossible to meet indigenously, and little doubt that buying tested power plants that are to be operational by 1997 will give an important boost to the economy.

Quality Questioned

Whether or not they were aware of the problems, Indian nuclear scientists never questioned the quality of Soviet reactors publicly. The blow-up of the graphite-moderated RMBK-type reactors at Chernobyl caused some apprehension, but the gross negligence by the operation crew, as de-

Continued on page 21



Why Are We Running Out of Reliable Electric Power?

by Marsha Freeman

Bob Jones

Today and tomorrow's shortage of one of the things all Americans take for granted, electricity, is the product of a decade of demonstrations, legal challenges, and regulatory obstructionism by the antinuclear Malthusians. Here, the North Anna nuclear plant in Virginia.

Local communities across the nation experienced voltage reductions, temporary brownouts, and interrupted electrical service this summer. Yet, unfortunately, the worst is to come—a guaranteed shortfall of available electricity for the next few years. The cause is straightforward: For the past 10 years, nuclear power development has been sabotaged and U.S. utilities did not place into service more than 100,000 megawatts (MW) of new generating capacity that had originally been scheduled.

The picture looks even worse for the coming decade. The North American Electric Reliability Council (NERC), which monitors the U.S. electrical grid, forecasts that between 1987 and 1996, only 79,300 MW of new capacity are supposed to come on line, according to a survey of the electric utilities. This is an average annual growth rate of about 1 percent, while the projected average annual growth rate in demand is *double* that.

Both of these projections, however, are quite unrealistic.

The only reason we have not yet experienced widespread blackouts is that economic depression conditions have masked the real shortfall in generating capacity. A healthy economy that is increasing the physical output of manufactured goods, agricultural products, and infrastructure would drive an electricity growth rate that is double that of today. For example, a 7 percent annual rate of growth was the norm during the 1960s industrial buildup to send man to the Moon.

Predicting Growth

The takeover of economic policy by the "postindustrial society" crowd in Washington in the 1970s substituted "service" industries and fast food joints for steel and power plant production. Under the Carter administration, consumers were told that conservation (austerity) was the latest "source" of energy, and that burning wood and garbage would replace nuclear energy. Austerity, combined with skyrocketing prices after the Mideast oil embargo, sent electricity growth below 4 percent per year.

Even with the collapse in energy-intensive real production, the growth in population in the United States and the summer heat wave and drought have been enough to keep the growth in electricity peak demand between 3 and 4 percent in most parts of the nation.

Yet, even this underestimated 4 percent per year growth rate is a far cry from the 2 percent that is being predicted for the next decade. How did the utilities decide on this extremely low rate of growth?

The utility companies have been stymied at every turn in their attempt to put new capacity into service. For the first time since the Depression, a utility company, Public Service Company in New Hampshire, has been driven into Chapter 11 bankruptcy. Given exorbitant interest rates, it could not raise the amount of money required to complete a nuclear plant project.

Construction and licensing times for both coal-fired and nuclear plants have increased to the point of absurdity, because of the complicity of federal and state regulators in allowing "intervenors" to sabotage the completion of projects, and the antinuclear grandstanding of political figures, like New York governor Mario Cuomo and Massachusetts governor Michael Dukakis.

For these reasons, it has taken twice as long to build and license New York's Shoreham nuclear power plant as it took to build the Panama Canal!

As they look down the road to the next decade, utilities are trying everything possible to avoid building large, baseload power plants. They are hoping that a minimal growth rate, combined with pleadings to consumers to cut consumption, will allow them to continue to provide reliable service with little new capacity.

Because of the gap between new capacity and demand, according to the utilities' own projections, the capacity margin in every regional reliability system will be *lower* at the end of the next

decade than it is now. This margin is not "extra" capacity, but the flexibility the companies have to continue uninterrupted power deliveries through weather extremes, emergencies, and unscheduled plant outages.

However, there is hardly any chance that even the paltry 79,300 MW of planned new generating capacity projected to be put into service in the next decade will materialize. And remember, even this 79,300 MW is only *half* what is needed according to the utilities' own low-growth projections.

New Capacity Uncertainties

Let's take a closer look at these 79,300 new megawatts.

Of this total, approximately 14 percent, or 11,717 MW, are supposed to be added not by reputable utility companies, but by "independent power producers." Since the economic rage under the Reagan administration has been deregulation and "private enterprise," in March 1988, the Federal Energy Regulatory Commission (known as FERC) promulgated new rules to allow virtually anyone to build "power plants."

A large number of these unregulated nonutility facilities are small, "alternative energy" projects, which will burn wood or biomass (garbage) or use solar energy. Half of the megawatts these mom-and-pop-style producers are supposed to bring on line are currently classified as "unknown" in origin.

The proprietors of such plants are under no obligation to provide power beyond the short-term contract they sign with consumers. If a small natural gas plant (to take one example) becomes "uneconomical" when prices increase, the supplier will disappear. Thus, in the future, your electricity could depend upon speculators who are literally here today and gone tomorrow.

According to FERC, electric utilities should be *required* to purchase whatever power these "independents" produce, even if it might be more expensive than the power the utilities generate themselves, and although it has the potential to throw the delicate regional transmission systems into chaos.

To deregulate electric power production and transmission would do to this industry what has been done already to the trucking, telephone, and airline industries—make it unreliable, unsafe, and uneconomical.

What about the other 67,800 MW of planned new capacity? NERC reports that 25 of the new coal-fired units that are supposed to come into service in the next 10 years—35.8 percent of the total—are not yet under construction.

NERC states that 9,800 MW of the coal additions now under construction are plants of 100 MW or more with projected in-service dates that allow only 5 to 9 years for construction. Since it typically takes 8 to 10 years to build and license large coal plants, NERC states, "It seems likely that much of this new coal-fired capacity will either be completed late, or replaced with shorter lead time [and more expensive] generator types."

In addition, Congress has been threatening to pass more stringent pollution control legislation, which would make it uneconomical to continue to operate older coal-burning plants in the industrial heartland. Approximately 11 percent of the Midwest coal capacity available in 1986 would go out of service. Pollution control gadgets that would have to be added to newer operating plants would lower their reliability and their output.

NERC estimates that if these new regulations were enacted, the industrial heartland of the country would have to add another *currently unplanned* 25,000 MW of new capacity.

Nuclear Sabotage

The concerned citizen might now ask, can't nuclear energy come to the rescue?

The facts are that since 1974, half the nuclear plants that had been ordered (104 nuclear power plants) have been canceled. This missing megawattage would have been the margin for real growth in the economy, as well as a defense-in-depth against heat and drought over the past decade and today.

The sabotage of nuclear energy, however, not only left us short of capacity, but also slashed the potential overall growth rate of the electrical industry, because nuclear was the fastest-growing component of the industry as a whole: During the 1970s, the amount of electricity produced by nuclear plants doubled approximately every two years, while electricity produced by burning coal—the second-fastest growing source—grew by only 35 percent during the same time period. Since 1977, the rate of nuclear-produced electricity has not even doubled once.

One might think that the death of nuclear power came because of public outcry in response to the March 1979 incident at the Three Mile Island nuclear plant in Pennsylvania. Actually, it was the Mideast war and oil embargo in 1973 that threw the utility industry for a loop the following year when, for the first time ever, electricity growth dropped to less than 1 percent.

Although demand growth rebounded after 1974, the antinuclear extremists were on the offensive, and in 1976, they placed on the ballot in seven states the first propositions to stop nuclear plant construction. No state or local

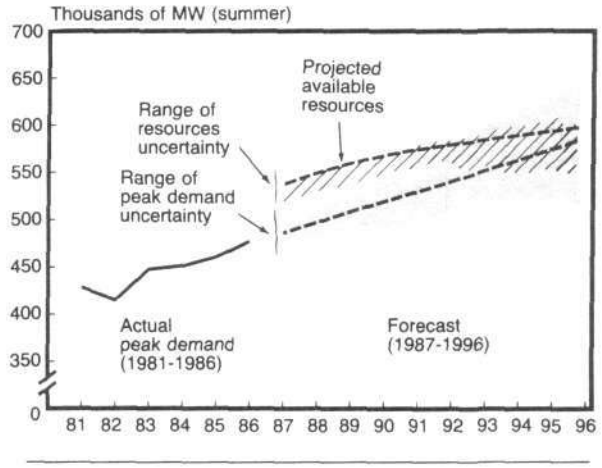
PROJECTED PLANTS NOT YET UNDER CONSTRUCTION

Type	Total MW planned	% of total not yet under construction	Number of units	Thousands of MW
Nuclear	25.3	0	0	0
Coal	22.7	35.8	25	8.1
Hydro	2.5	79.8	85	2.0
Other utility	17.3	90.0	145	15.7
Non-utility	11.5	84.0	NA	9.6
Total	79.3	44.6	—	35.4

Source: North American Electric Reliability Council

Of the projected new capacity between 1987–1996, 44.6 percent is not yet underway.

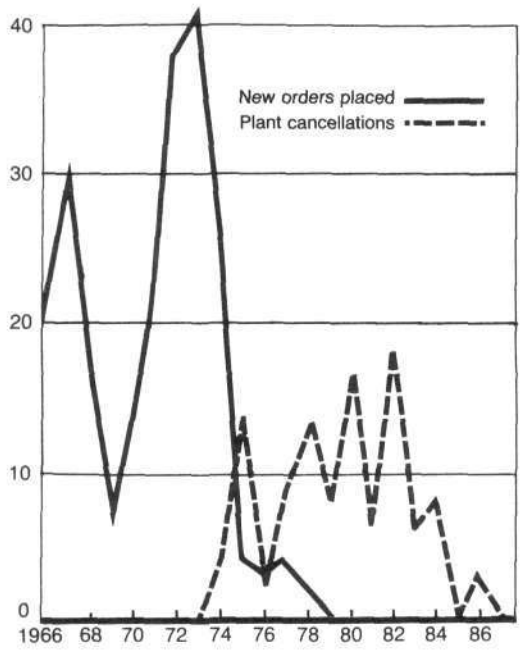
Figure 1
PEAK DEMAND AND PROJECTED RESOURCES: RANGES OF UNCERTAINTY



Source: North American Electric Reliability Council

Americans may be shivering (or sweltering) in the dark if peak electricity demand continues to grow at double the projected 2 percent and if the planned new capacity is delayed in coming on line. If the new electric generating resources that have been projected by the utilities do not come on line on time (hatched lines) and the peak demand grows faster than the projected average 2 percent per year (lower gray area), there could be a shortage of capacity by the early 1990s.

Figure 2
NUCLEAR PLANT ORDERS AND CANCELLATIONS



More than half the 104 nuclear plants ordered by U.S. utilities since 1966 have been canceled.

electorate has ever passed such a proposal (even in Sacramento, California, where the antinukes have tried 14 times to shut down an operating plant), but the result was to put the nuclear utilities and the nuclear industry on the defensive in a battle they are still losing.

During the years of the Carter administration, and through the office of Energy Secretary James Schlesinger, every possible tactic was tried to stop advanced energy technology development. Nuclear waste was made into a political issue by the shutdown of the Barnwell nuclear reprocessing plant. The White House unsuccessfully tried to get the entire world to stop the development of fast breeder technology under the guise of stopping weapons proliferation, and the United States then killed its own breeder program at Clinch River. Fusion energy development was to be superseded by solar collectors.

By the end of the 1970s, the die was cast. Intervenors had been successful in delaying projects at or near completion. Wall Street had succeeded in making building nuclear power plants the kind of financial risk that no utility executive wanted to take. The last nuclear power plant ordered by a utility in the United States was in 1978.

Seabrook: Financial Waterloo

In 1976, ground was broken to build two nuclear units at Seabrook, New Hampshire, near the Massachusetts border. The estimated cost of the two 1,150-MW units was less than $1 billion at the time. What happened after that is worth telling in detail, because it typifies the process by which an industrial nation is turned into a Third World country.

In 1979, the New Hampshire state legislature passed a law prohibiting the utility from including the cost of building the plants in its rate base. As a result, the rates for consumers have been set as if Public Service Company of New Hampshire had invested only $600 million in the plant, although its share of the investment has equaled more than $2.9 billion. What drove up the cost of the power plant?

Because the company could not raise the construction funds from the ratepayers, it was forced to resort to the Wall Street bond market. As interest rates soared, the projected cost of one unit (the second was canceled) was swollen by financing costs to $5.4 billion.

Almost four years ago, Public Service began to face financial difficulties. It staved off bankruptcy by suspending dividends on stocks and selling junk bonds. In May 1987, Public Service had to go back to the financial markets to borrow another $150 million to keep the plant ready to open, while Governor Michael Dukakis was campaigning to keep the finished plant closed.

Only $100 million of the needed money was raised, and that at a staggering interest rate of *9 percent over the prime rate*, plus .25 percent for each month the loan was outstanding. This

brought the financing charge to a whopping *13 percent above the prime rate*, which is classified as usury in most states!

By fall 1987, the *Wall Street Journal* referred to Public Service as the "Brazil of utilities," because the utility failed to make an Oct. 15 interest payment of $37 million. In December, the New York Stock Exchange suspended trading of the utility's stocks and bonds for a brief period. Finally, in January 1988, with nowhere else to go, Public Service became the fourth largest company to file for Chapter 11 bankruptcy protection in U.S. history—and the first public utility to do so since the Depression.

How did Governor Dukakis prevent the opening of the nuclear plant that would have started to produce the revenue Public Service needed to stay alive? Part of the fallout from Three Mile Island was a requirement from the federal Nuclear Regulatory Commission (NRC) that there be a plan to evacuate local communities within a 10-mile radius of a nuclear power plant.

After the Soviet Chernobyl accident in April 1986, Dukakis ordered his staff to halt all work on evacuation plans for the six Massachusetts communities within the 10-mile radius of Seabrook, and this brought to a standstill the ability of Public Service to obtain its NRC operating license.

The story of Seabrook is not over, however, because in fall 1987, the NRC ruled that evacuation plans could be taken out of the hands of noncooperative local politicos, and that utility evacuation plans that met NRC criteria would be acceptable. Since then the Seabrook management has submitted its own plan.

Shoreham: 23 Years and No Power

Like Michael Dukakis, New York Governor Mario Cuomo has made a political career out of sabotaging nuclear power. The Shoreham plant, owned by the Long Island Lighting Company (Lilco), remains fully completed but shut down, while the utility tries to buy enough power and run auxiliary equipment to keep the lights on.

The ostensible reason the plant is not operating, as with Seabrook, is that local and state authorities refused to participate in an evacuation plan. And Dukakis made the campaign promise to New Yorkers in April, just before the June presidential primary there, that even if Lilco had an evacuation plan to meet NRC guidelines, he would block the Federal Emergency Management Agency from cooperating with such a plan.

Not to be outdone, Governor Cuomo came up with the ingenious plan of having a government agency buy the completed nuclear plant for $1, so that it could be torn down! It has been estimated that the cost of decommissioning the plant would be more than $444 million. And who will pay for this? Supposedly the cost will be met by enormous rate increases for consumers, and tax breaks for the utility from the Internal Revenue Service.

Because of constantly changing regulatory requirements and years of intervenor challenges to the plant, Shoreham's cost has escalated 80-fold. Ready to operate since 1984, the plant is sitting there at only 5 percent of rated power while Long Island residents suffer brownouts and shortages.

As with Seabrook, the Shoreham story is not over and the plant may yet produce power for the people of New York.

Constitutional Issues

Shoreham and Seabrook have become a national policy question because of the constitutional issues involved. In 1954, Congress passed the original Atomic Energy Act, which committed this nation to the development of civilian nuclear energy. On June 28, Governor Dukakis wrote a letter to President Reagan objecting to an executive order Reagan has been considering, which would put the responsibility for bringing nuclear plants on line back into the hands of the federal government, where it belongs.

The authority for protecting the "health and safety" of citizens rests within states' rights, Dukakis said, and therefore he had the right to stop multistate nuclear projects. In response, Scientists and Engineers for Secure Energy wrote a letter to the president in July, correctly stating that the Atomic Energy Act gives *exclusive* authority to make safety judgments to the *federal* agencies, as "the U.S. Supreme Court has repeatedly reaffirmed."

For the past eight years, the United States has drifted aimlessly without any plan to provide its citizens with reliable electric power. Luckily for President Reagan, there have not been oil embargos or major crises in energy during his term in office. However, luck is not going to get us through hot summers, cold winters, and drought, and luck won't ensure a resurgence of real economic growth. For the near term, there will likely be localized shortages as the utilities scramble to try to maintain the integrity of the delicate national electric grid without enough baseload capacity.

Short-term solutions may be needed while the industry tries to gear up renewed construction on baseload power plants. These facilities, including gas turbines, would be more expensive than large plants. The alarming facts are, however, that present U.S. manufacturing capabilities could not even keep up with any surge in demand for such systems. Already, high-voltage circuit breakers and interrupters are being imported.

In developing countries, people live either with just a few hours of power each day or without any electricity at all. Imagine what this would do to daily life in the United States. Unreliable power would throw the United States back to the conditions of many Third World nations—a sorry place to be after two hundred years of industrial development.

Letters

Continued from page 5

alone is infinite equality."

Copernicus by the way, was also a man of the Church. Calling the universe the "work of the Best and Greatest Artist," he became a doctor of canon law in 1503 and canon of the cathedral of Frauenburg on the Baltic in 1512. In 1530, he provided a preliminary outline of his heliocentric system in the *Commentariolus*.

This emendation I consider a useful one to the article on Kepler's *Somnium*, and on a broader level, one which helps guard against the notion that Christian theology was somehow hostile to the Copernican Revolution. Rather, it was sum and substance of it.

Robert Gallagher
Washington, D.C.

Nature Blasts New Experiment On High-Dilution Effects

by John Grauerholz, MD

A singular illustration that we are living in a dark age occurred over the four-week period from June 30 to July 28, 1988. For those who missed the first performance of the Holy Inquisition, the editors of *Nature* magazine staged a rerun for the the benefit of those scientists who might be guilty of thinking and uttering forbidden ideas, or looking into forbidden areas.

The initial event in this auto-da-fé was the publication of an article in the June 30 *Nature* describing biological effects of highly diluted solutions of antibodies on human white blood cells. The article was accompanied by an editorial titled "When to believe the unbelievable."

The article itself, "Human basophil degranulation triggered by dilute antiserum against IgE," reported on research conducted at the INSERM 200 laboratory at the University of Paris (South) by Dr. Jacques Benveniste and his colleagues and subsequently confirmed at three other laboratories in Milan, Toronto, and Rehovot, Israel. The data indicated that highly diluted solutions of antibodies retained their ability to stimulate a reaction by certain white blood cells *even at dilutions at which antibody molecules were no longer present.*

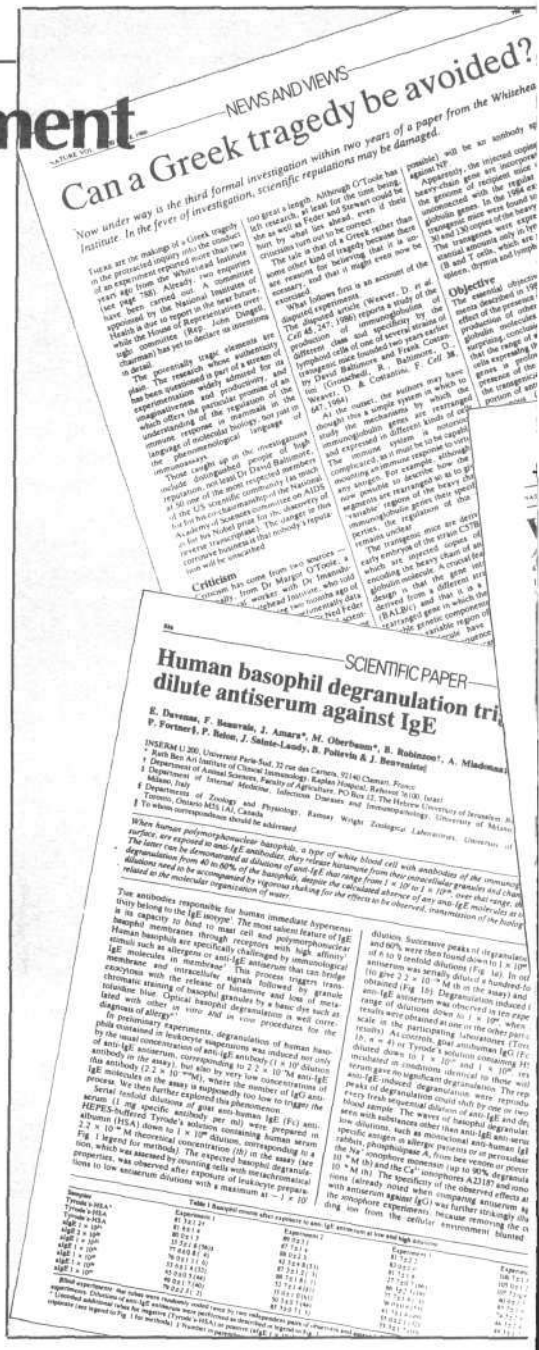
These results are truly remarkable, since they would overturn the hegemonic theory in the field of molecular biology today. Traditional theory holds that the immune system works according to a lock-and-key model, with the alerted antibody identifying, pursuing, and then binding foreign molecules, while simultaneously transmitting the message to the body to mass produce more of itself. If no foreign molecules exist and an immune reaction still occurs, then clearly something other than direct physical interaction between molecules is involved.

The white blood cells used in the experiment are known as polymorphonuclear basophils. The term polymorphonuclear refers to the many-shaped, irregular nuclei of these cells, while basophil refers to the fact that the cells contain granules that stain with basic dyes (from baso = basic and philia = attraction to). These granules contain histamine, a chemical with which hayfever and other allergy sufferers are all too familiar.

Basophils carry antibodies, known as Immunoglobulin type E, or IgE, on their surface membranes. When these surface antibodies are exposed to antibodies against themselves, known as anti-IgE antibodies, they cause the cells to release histamine from their granules into the bloodstream, resulting in the watery eyes, runny noses, itching, and sneezing characteristic of allergic reactions. This release of histamine also results in a change in the staining of the granules, which lose some or all of their affinity for basic dyes.

The Experiment

Benveniste and his colleagues investigated the ability of progressively more dilute solutions of anti-IgE antibodies to cause the degranulation of the basophils. The solutions were prepared by a process known as serial dilution in which a 10th part of one solution is diluted with 9 parts of water or other solvent and mixed thoroughly. A 10th part of this new solution is then mixed with 9 parts of solvent and so on. This results in dilutions of 1/10, 1/100, 1/1,000, and so forth. Based on the molecular weight of the antibody molecule and the initial concentration, once a dilution of 1 part in 10^{74} had been reached, less than 1 molecule of antibody was present in the system. Yet activity was still present at dilutions of 1 part in 10^{120}!


NEWS AND VIEWS

Can a Greek tragedy be avoided?

Now under way is the third formal investigation within two years of a paper from the Whitehead Institute. In the fever of investigation, scientific reputations may be damaged.

SCIENTIFIC PAPER

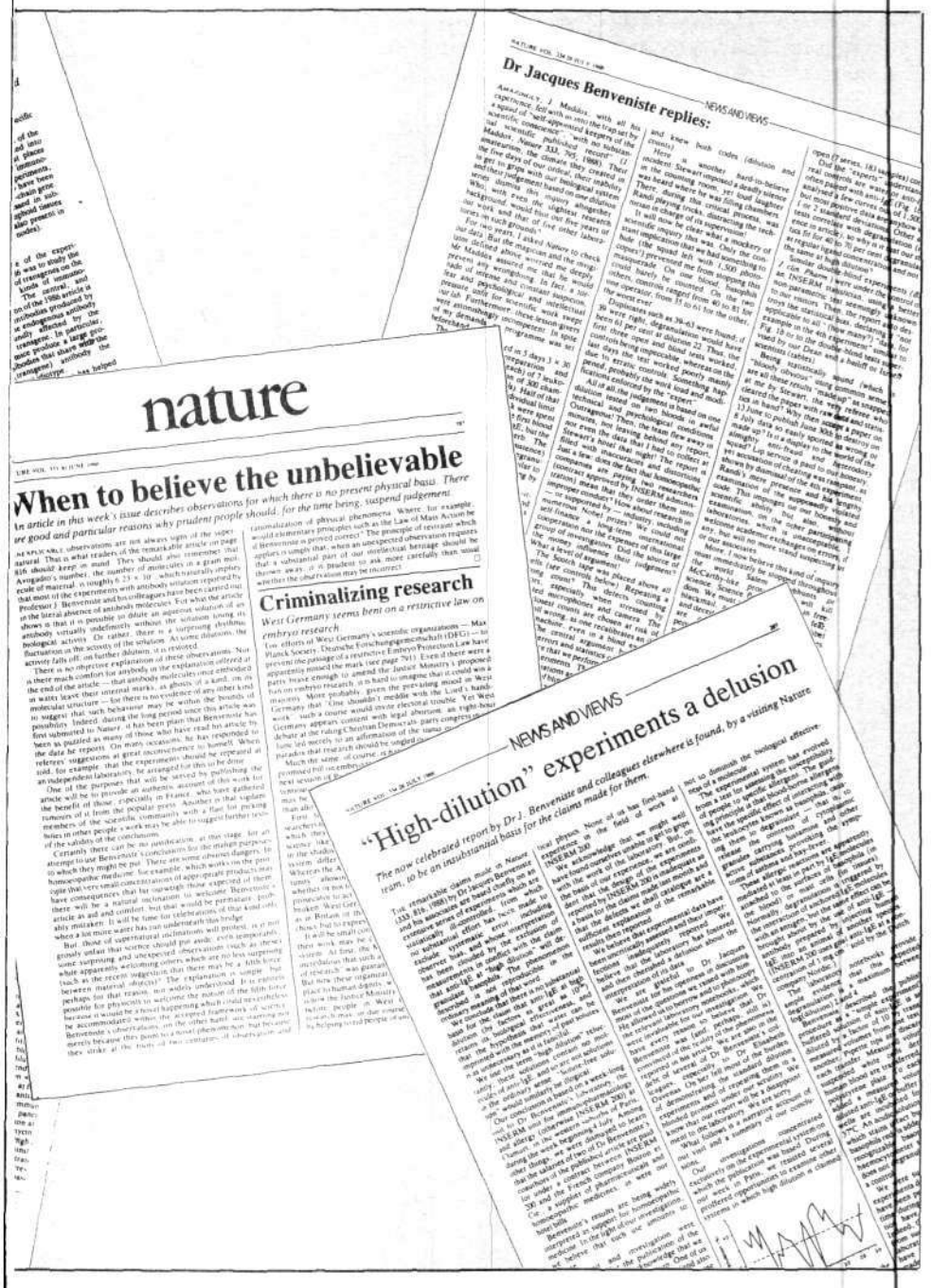
Human basophil degranulation tri
dilute antiserum against IgE

E. Davenas, F. Beauvais, J. Amara*, M. Oberbaum†, B. Robinzon†, A. Miadowna
P. Fortner‡, P. Belon, J. Sainte-Laudy, B. Poitevin & J. Benveniste‡

Table 1 Basophil erosion after exposure to anti-IgE antiserum at low and high

The activity was measured by microscopic examination of the basophils for loss of staining of the histamine granules. Not only were low dilutions (below the point at which antibody molecules could be present) capable of producing the effect, but the effect appeared, then disappeared, then reappeared in a periodic fashion as the dilution process continued.

Similar periodic waves of degranulation of basophils were seen with other substances such as monoclonal



Benveniste's reply to Nature's *inquisition, published July 28, concludes: "Salem witch-hunts or McCarthy-like prosecutions will kill science. . . . Never let these people get in your lab. The only way definitively to establish conflicting results is to reproduce them. It may be that all of us are wrong in good faith. This is no crime but science as usual and only the future knows."*

antibodies against IgE, antibodies against specific antigen from allergic patients, certain toxins, and other chemicals. However, solvents in which such molecules had not been present at one time did not produce the effect. In other words, even though the molecule might not be present at the high dilution, it had to have been present at a lower dilution in order for the high-dilution effect to occur. In addition vigorous agitation of the solution was necessary for the effect to appear at high dilution.

Benveniste hypothesizes that his results may be attributable to some form of organization being imposed upon the solution—an imprint or template if you will, of the original molecule—which is then transferred through successive dilutions, whether or not a particular degree of dilute solution evokes an active immune response.

Upsetting *Nature*

That these results were highly upsetting to *Nature* is evident from the accompanying editorial it printed in the issue in which Benveniste's article appeared:

"Inexplicable observations are not always signs of the supernatural," the editorial begins.

"There is no objective explanation of these observations. . . . [F]or there is no evidence of any other kind to suggest that such behavior may be within the bounds of possibility. Indeed, during the long period since this article was first submitted to *Nature*, it has been plain that Benveniste has been as puzzled—as many of those who have read his article—by the data he reports. On many occasions, he has responded to referees' suggestions at great inconvenience to himself. When told, for example, that the experiments should be repeated at an independent laboratory, he arranged for this to be done. . . .

"Certainly there can be no justification, at this stage, for an attempt to use Benveniste's conclusions to the malign purposes to which they might be put [homeopathic medicine, for example]. . . .

"But, those of supernatural inclinations will protest, is it not grossly unfair that science should put aside, even temporarily, some surprising and unexpected observations (such as these) while apparently welcoming others which are no less surprising (such as the recent suggestion that there may be a 'fifth force' between material objects)? The explanation is simple, but, perhaps for that reason, not widely understood. It is entirely possible for physicists to welcome the notion of the fifth force because it would be a novel happening which could nevertheless be accommodated within the accepted framework of science. Benveniste's observations, on the other hand, are startling not merely because they point to a novel phenomenon, but because

they strike at the roots of two centuries of observation and rationalization of physical phenomena. Where, for example, would elementary principles such as the Law of Mass Action be if Benveniste is proved correct?"

Unorthodox

Obviously, the implications of these results are perceived as threatening to a view of science that has become hegemonic over the past 200 years. They are, in other words, unorthodox, which is to say they contradict "right opinion," (from ortho = right and -doxy = doctrine or opinion). These particular results were so unorthodox, in fact, that although *Nature* received the paper on Aug. 24, 1987, it did not accept it for publication until June 13, 1988. During this time, the experiments were rerun at a number of other laboratories by request of the referees reviewing the paper. In addition, during this period, Benveniste repeatedly requested *Nature* to come to the laboratory to observe the experiments and redo them.

"Where would elementary principles such as the Law of Mass Action be if Benveniste is proved correct?"

Nature finally agreed to publish the paper in its July 14 issue, *after* a visit by an investigation committee was to have been made to evaluate Benveniste's laboratory. Then, suddenly, *Nature* decided to publish the article earlier, on June 30. Publication would then occur *before* the investigation committee was to come to the laboratory.

Now it might seem a bit odd that after taking nearly a year to accept a paper for publication, *Nature* could not have waited two more weeks until its investigating committee had finished its work, especially since there were such serious reservations about the results. As *Nature* itself noted in its June 30th editorial, Benveniste himself was puzzled by the results and had sought assistance in finding an explanation for them.

The Hidden Agenda

That there was a different agenda than the search for truth became evident when the composition of the committee became known. It was to consist of John Maddox, editor of *Nature*; James ("The Amazing") Randi, a professional magician; and Mr. Walter Stewart, who has made his reputation hunting down scientific "fraud."

Randi, a highly talented professional magician, has carved out a niche for himself as a debunker of so-called paranormal, or as the editors of *Nature* put it, "supernatural" phenomena. One of Randi's favorite targets is Uri Geller, the Israeli mystic, about whose alleged psychic powers *Nature* had once published an article that drew some criticism. Randi's forté is detecting the sorts of sleight-of-hand that might escape the scientifically trained observer.

Stewart is a scientist at the National Institutes of Health in Bethesda, Md., and is one of a group of crusaders for integrity in experimental science whose qualifications were best described by editor Maddox: "They have no substantial scientific published record of their own . . . they are self-appointed keepers of the scientific conscience." Even more interesting, Stewart was one of the referees of Benveniste's paper, who, with the raw data and statistics in his hands, had cleared the paper for publication.

Conspicuously absent from the group was any scientist with actual laboratory experience in the area in question. When Benveniste became aware of the composition of the committee, he experienced a well-justified apprehension that was borne out in spades by subsequent events.

The Inquisition

This intrepid group of "ghostbusters" descended upon Benveniste's laboratory to exorcise the malign spirits of high aqueous dilution, once and for all. Unfortunately, during the first three days of the inquisition, the high-dilution degranulation effect occurred in three out of the four trials. And in the fourth trial, degranulation did not occur even at *high* concentrations of the antibody, indicating a problem with that particular specimen as opposed to a statistical variation in the method. The samples were examined "blind," that is, the identity of the particular sample was unknown to the person analyzing the sample.

Investigator Stewart then declared these results "valueless" and proceeded to alter the experimental procedure so as to obtain a trial in which the effect did not occur. In order to facilitate this, magician Randi employed his professional talents to distract the laboratory technician assigned to observe Stewart while Stewart prepared the samples for analysis. Having obtained one such "unsuccessful" trial, Stewart and his fellow truth seekers then packed their bags and issued a report reeking with innuendoes of incompetence and willful misconduct on the part of Benveniste and his laboratory staff.

In true inquisitorial fashion, editor Maddox then offered not to print the report if Benveniste would recant his heresy. Benveniste declined this kind offer and wrote a response, which was published along with the report in *Nature* July 28.

The report concluded that Benveniste's results were not to be believed because they were not reproducible and were "based chiefly on a series of experiments which are statistically ill controlled, from which no substantial effort has been made to exclude systematic error, including observer bias, and whose interpretation has been clouded by the exclusion of measurements in conflict with the claim that anti-IgE at 'high dilution' will degranulate basophils."

This might all sound very damning until one considers that magician Randi apparently detected no sleight of hand on the part of the laboratory personnel and in fact used his own abilities on that score to help investigator Stewart produce one trial that did not work after three that did.

As for the statistics, Stewart had them in hand when he refereed the paper. If they were so bad, why was the paper cleared for publication without beforehand informing Benveniste of the problem?

Then what about the other laboratories where the effect was reproduced? It is hard to escape the conviction that a precommitment to get a certain result was greater on the part of the investigating team than on the part of Benveniste's group.

Now, Benveniste's results may represent an artifact, an uncontrolled condition or practice in a given laboratory—or they may not. If they do,

such practice is common to at least four laboratories in different parts of the world and may be affecting other studies in these and other laboratories. If so, an effort to identify it is vital to ensure the accuracy of other such assays in these laboratories. Such an effort would require one or more experienced laboratory scientists with expertise in the particular techniques and equipment being used.

From the composition of the investigating team, however, it is obvious that the gameplan was to document fraud, and when that failed, the fallback was a series of scattershot accusations and innuendoes. In retrospect, it would appear that a decision was taken to rush the article into print and then print a devastating attack on it as the most effective method of destroying not only this experiment, but also Benveniste and his collaborators and the general line of research into high-dilution effects.

Homeopathy Not the Target

The target of this witch-hunt may appear to be homeopathy, a branch of medical practice based on the efficacy of highly diluted solutions of various drugs. However, although Benveniste is interested in phenomena occurring at high dilution, he holds no particular brief for homeopathy. In fact he published an article in the March 5, 1988 issue of the medical journal *Lancet* reporting a study that proved that two well-known homeopathic drugs, Opium 15CH and Raphanus 5CH, had no effects on the clinical conditions for which they were prescribed.

The real threat represented by Benveniste's data is that they relate to the immune system, an area that so far has proved refractory to adequate explanation by molecular biology, the accepted method of rationalization of physical phenomena in the area of living processes. Molecular biology is based on the premise that life arose on the basis of a statistical fluke in the random interaction of molecules, and it rules out any higher-order causal processes. Obviously, these ideas are based upon broader philosophical conceptions of the meaning of life.

For example, the high priest of molecular biology, Jacques Monod, who won the Nobel prize for studies designed to squeeze the phenomena of

Reuters/Bettmann News Photos

Jacques Benveniste in his laboratory: "Science flourishes only in freedom."

biology into the straitjacket of information theory, characterized life in these terms:

"Life appeared on earth; what before the event, were the chances that this would occur? The present structure of the biosphere far from excludes the possibility that the decisive event occurred only once. Which would mean that its a priori probability was virtually zero. . . . The universe was not pregnant with life nor the biosphere with man. Our number came up in the Monte Carlo game. Is it any wonder if, like the person who has just made a million at the casino, we feel strange and a little unreal?"

Selective Persecution

Another clue to explain the behavior of *Nature* comes from a story that appeared in the same June 30 *Nature* in which Benveniste's experiment was first reported. This story by editor Maddox appears in a News and Views column titled, "Can a Greek Tragedy Be Avoided?" It reports accusations against the work of a leading molecular biologist, Dr. David Baltimore, by the same Walter Stewart who was brought in to Benveniste's laboratory.

It is instructive to compare the way the two cases were handled by *Nature*. Baltimore's work involved the use of transgenic mice, produced by inserting genes from one strain of mice into the embryos of another mouse strain, to study diversity in antibody formation. These particular mice were created in 1984 and used in experiments at the Whitehead Institute in Massachussetts in 1986.

Problems arose when a postdoctoral student at the Whitehead Institute, Dr. Margaret O'Toole, testified before a congressional committee that the data published in 1986 could not be experimentally reproduced. Subsequently, Stewart and his partner at NIH, Dr. Ned Feder, joined in the attack on the assays and statistical analyses used by Baltimore's group.

To understand the relevance of this story to Benveniste's work, it is necessary to explore the "Greek tragedy" that *Nature* editor Maddox was so concerned to avoid. This "tragedy" was that Stewart et al. was ripping to shreds work by David Baltimore, which, as Maddox wrote, "offers the particular promise of an understanding of the regulation of the immune response in mammals in the language of molecular biology, not just in the phenomenological language of immunoassays."

That this attack on one of the high priests of molecular biology was displeasing to the gods and might have unwholesome consequences was stated quite plainly by Maddox: "Although O'Toole has left research, at least for the time being, she as well as Feder and Stewart could be hurt by what lies ahead, *even if their criticisms turn out to be correct* [emphasis added]."

Maddox also explained how selective rigor must be applied to orthodox research: "The chances are that the 1986 article in the dispute is flawed in some of its analyses, but that it has also demonstrated that transgenic mice are an interesting way of learning how the immune system is regulated. That process will continue, uninhibited by the errors (alleged or otherwise) in the 1986 paper. Who, in ordinary circumstances, would complain of that, error (unproven) notwithstanding?"

Is it not relevant to inquire whether Maddox might have persuaded Stewart to reduce his chances of getting "hurt" (to quote Maddox) by turning his "nit-picking persistence" (again quoting Maddox) onto a more acceptable target? Certainly his sweetly rea-

sonable tolerance for Baltimore's questionable results is in sharp contrast to Maddox's personally supervised hatchet job on Benveniste.

Benveniste's heresy is not the more obvious case of "forbidden ideas" but the more profound one of having witnessed, and reported, "forbidden events." It is these forbidden events that mock politically powerful, but epistemologically flawed, scientific paradigms, since there is no way to compass the events within the paradigm. In this particular case, if the findings do not represent an artifact or experimental quirk—and they well may not—then the explanation must be sought elsewhere than on the molecular level.

Structured Water

The closest point of comparison would be to the spin coherence of nuclei in the "structured water" found in living tissue. By comparing the varying time of relaxation of tissue in different conditions, through the use of nuclear magnetic resonance (NMR) technology, diagnosis of tumors and other pathogenic conditions is made possible. Such "structuring" of water, which involves a collective molecular effect, does not, however, involve shaking as a precondition. Benveniste's results would involve the transmission of subatomic rather than molecular magnetic resonances in an ordered manner throughout the solution, and the persistence of this resonance in the absence of the original molecule that induced it.

Such transmission of organization in the absence of molecules has been documented in studies of mitogenic radiation by the Russian scientist Alexander Gurwitsch and his student V.P. Kaznocheev. In the Kaznocheev experiment, uninfected cell cultures separated from virus-infected cell cultures showed degenerative changes when the glass barrier between the cultures permitted the passage of ultraviolet light, despite the fact that no virus was present and no molecular exchange could take place.

Benveniste's results present the possibility that new and fruitful openings may be found out of the present dead end of molecular biology. These openings will be explored and developed by optical biophysics, which is uniquely capable of examining the living process as a process, as opposed to the molecular-biological approach, which is analogous to smashing a watch into pieces and then trying to figure out how it works by looking at the individual pieces.

The real Achilles heel of current biological science is that the statistical information theory model, based on the Second Law of Thermodynamics, by its nature is incapable of dealing with singular events, such as life, which, as Jacques Monod states, it necessarily regards as highly improbable.

It is useful to remember that when the 19th century physicist Bernhard Riemann predicted the existence of acoustical shock waves, many years before their empirical demonstration, a number of eminent physicists of the politically dominant Newtonian-Maxwellian school proved, according to their mathematics, that such shock waves were "impossible." That they were later proved wrong did not alter their view; it simply motivated them to suppress and distort Riemann's work.

More recently, these same arbiters of "acceptable" science have attempted to cover the inability of their flawed mathematics to explain certain subatomic phenomena with a shower of quarks.

The great physiologist Claude Bernard, a colleague of Louis Pasteur, once described a scientist as a man asking questions of nature. There are no unsuccessful experiments, he said, because whatever the answer, knowledge is obtained that forms the basis for further questions. *Nature* editor Maddox apparently believes that nature gave a wrong answer and that it is the job of *Nature* to correct nature, or at least punish the asker of the bad question.

The gods of orthodoxy can always eliminate ideas by assassinating, physically or otherwise, those who espouse them. But natural phenomena are a consequence of that underlying lawfulness of the universe that proceeds with—to use an appropriately French term—"la belle indifference" to the wishes of the self-styled gods of Olympus who think they run "the system," or to the wishes of their functionaries, like Mssrs. Maddox, Stewart, and Randi.

Viewpoint

Continued from page 7

an effect upon other *substances*.

This materialism—with its capability of endowing each part of the universe with individual existence as an object—protects the objectivity of the latter, and that of our consciousness as well. But the price we pay for such materialism is the uncertain character of the universe; in this scheme, scientific prediction can do nothing but announce the global future of molecular units in accordance with Boltzmann's laws of probability applied to thermodynamics. In practice, this means the increasing entropy of the physical universe with life giving way to entropy, for it is then nothing but a graft, living at the expense of the physical universe. (This is the view of Ilya Prigogine, for example.)

Benveniste and the scientists who verified his experiments repeatedly increased by a factor of 10 the proportion of water to solute. They continued to test the allergenic power of *S* by the same biological technique. Even when very high dilutions were reached, where the chance that the solution contained even a single molecule of the substance *S* became infinitesimal, the "solution" still set off the reaction *R*. This therefore proved that the action is not dependent on the appreciable presence of *S*, but rather on the "imprint" that *S* left on the solvent.

Benveniste therefore posed the hypothesis that certain electromagnetic events took place while *S* was in the solution, *modifying the behavior of this water in a lasting way that was specific to S*. Thus, certain information was being transmitted throughout the procedure of dilution in a manner that was purely active and not material. One can imagine the door—or rather the immense gates—that open suddenly, and, as most will think, onto the unknown.

Those who know even the general findings of optical biophysics, however, will be less astonished and less scandalized.

Benefits of the Benveniste Affair

My purpose here is to review succinctly the general findings and the useful consequences that can be expected from this Benveniste affair, as

much for the benefit of fundamental science as for technological applications. The enormous value of Benveniste's work is that it demonstrates meticulously that the entire body of the biochemical disciplines is indissolubly linked to that of optical biophysics. *His work therefore cannot be to the detriment of science but to its enrichment.* Please, do not panic!

It may seem disagreeably outmoded to some to refer to Louis Pasteur. Yet we must do him the justice of recognizing that he founded optical biophysics when he demonstrated the specific dissymmetry characteristic of organic molecules, by showing their differential action upon light. Through these experiments, one could already conceive of the inseparability of *biochemical properties from properties of* action upon light, in this case its polarization. Pasteur had no "spectrometer" at his disposal other than tartrate crystals.

Today the only bounds we can impose on optical biophysics are arbitrary ones for merely technical purposes. This is so because the sum of verified and reproducible experimental work demonstrates that every metabolic activity is accompanied by the emission and reception of ultraweak electromagnetic waves of variable wavelengths, or else by the generation of electrical or magnetic fields. These waves and fields have at least one fundamental property: *specificity*. A given molecule, a complex of molecules, or a tissue, has an *electromagnetic signature*. The molecular representation of life is therefore very incomplete, and has fallen behind with respect to what is known in optical biophysics.

What is missing in molecular biology is the vast domain of electromagnetic phenomena. Although simplistic, one can say that the same step has now been taken in biology as in physics since the discovery of superconductivity.

For anyone who is a bit acquainted with the various avenues of research in optical biophysics, at least one thing is already proven: An intense, coherent, active and passive electromagnetic activity accompanies metabolisms that heretofore have been able to be conceptualized only in terms of their biochemical characteristics.

To be ignorant of these developments was still conceivable 20 years ago. Today, now that hundreds of studies have been published, the general lack of attention to these facts can be explained only by conformism. Another factor that undoubtedly acts as a brake is that any biophysics laboratory that aspires to explore these domains of optical biophysics must have at least $3 million for equipment. How can anyone build such a laboratory without massive governmental aid? And how can a government be convinced of the need for this research if its scientists have a less than profound knowledge of this research and its economic implications?

What man of science has the high authority and total freedom that he might have sufficient influence to convince a government of the imperative necessity for the creation of an Institute of Optical Biophysics?

The stakes are high. The entirety of biological science requires renovation. At issue directly are current ecological and physiological laws. In addition, pharmacological and medical science are concerned, as well as agriculture and food science, epidemiology, and the study of infectious disease.

To take one example, it has been demonstrated in the United States that one can tune electromagnetic pulses to exactly the right frequency to quickly, effectively, and cheaply kill locusts. From this experiment, one can conceive that explanations for heretofore inexplicable ecological phenomena will begin to multiply.

The Choice

The choice for science therefore cannot be clearer: Either one considers that everything essential has already been discovered and that one must therefore put curses on any scientific work that might disturb this world view. (In this case, this means tainting the discoverers with some alleged crime.) Or, one could welcome in what is probably a scientific revolution.

Let me restate this clearly: What is upon us is not the wrecking of biology, but very much the contrary; nor is it the death sentence of molecular biology. What we face involves the *opening up* of the field of biology. The only death involved is the death of a dogma—the dogma of the intangibility of DNA. To be sure, this revolution in scientific approach involves tremendous technological upheaval: man becoming capable of acting upon the biosphere with extraordinary precision.

And so, instead of panic there should be rejoicing. If all goes well, in history the Benveniste affair will come to be remembered as the signal of a great revolution in science and technology.

New Delhi Report

Continued from page 11

scribed by the Soviets themselves, has been accepted as the main reason for the Chernobyl catastrophe. Legasov's critical appraisal, however, points to deeper problems.

Referring to the poor quality of some of the equipment developed for Soviet nuclear plants, Legasov said that it happens because "either there were no materials or no organization which would have taken up the work of developing a non-trivial compressor, a non-trivial heat exchanger. . . ."

Soviet Safety

Legasov was also sharply critical of Soviet safety systems. He pointed out that the fuel safety rods, which are lowered to absorb neutrons and thus cut off the possibility of a runaway atomic reaction within the reactor, are manually operated in Soviet reactors and that no system is available in which the safety rods go down automatically to kill the neutrons. This and many other improvements, Legasov said, "were not rejected but they were being considered very slowly. . . ." Legasov also pointed to the deteriorating quality of engineers recruited to do the oeprational and maintenance jobs.

No doubt the picture of the Soviet nuclear establishment presented by Legasov is disturbing and unworthy of a nation that built the world's first commercial nuclear power reactor. Indian nuclear scientists will do well to insist on making sure exactly what they are getting. At least academician Legasov has given them fair warning.

Ramtanu Maitra, a nuclear engineer, is editor-in-chief of the magazine Fusion Asia.

Microscopes Beyond the Limit

by Charles B. Stevens

Currently we are celebrating the third century of what, according to Sir Isaac Newton, should have been a dark age. Three centuries ago Newton calculated that telescopes had reached their ultimate size and none could be constructed with greater resolution, because of the limits imposed by aberration, which he had theoretically determined.

In a similar mode, contemporary naysayers have found that microscopes are also theoretically limited. But just as scientists over the centuries have found the means to push back the apparent limits for telescopes, scientists today have begun to break through the supposed limits more recently proposed for microscopes.

In recent years major advances have been made in visible light microscopes and in the development of microscopes that utilize other forms of radiation and even particle beams.

Among the latest developments is the scanning tunneling microscope, called the STM. The STM works like a blind man's cane, feeling out the surface of a microscopic sample on which the bumps and corners are made by atoms and molecules.

Scanning Tunneling Microscope

A tiny metal tip is passed along the surface of the sample. The tip is kept at a constant distance of a few angstroms (1 angstrom is a hundred-millionth of a centimeter). This constant distance is maintained by keeping a constant voltage between the tip and the sample and observing the quantum tunneling current. This current depends on the distance between the tip and the surface. Therefore, keeping the current constant ensures that the distance is always the same. The result is that movements required to keep the distance constant reveal the atomic-scale hills and valleys of the surface of the microscopic sample (Figures 1-2).

Recent applications of the STM have included the imaging of biological molecules submerged in water. Eventually it is hoped to be able to actively image these molecules in water while they are reacting. This could reveal the fine details of reactions and give crucial insights into how the reaction of two compounds is catalyzed by a third. Another potential application currently being pursued is to find the actual sequences or codes for DNA.

The STM is not limited to recording just the physical shape of a surface. Other microscopic properties can be detected. H. Kumar Wickramasinghe of IBM has developed a technique for recording the magnetic and thermal properties of surfaces.

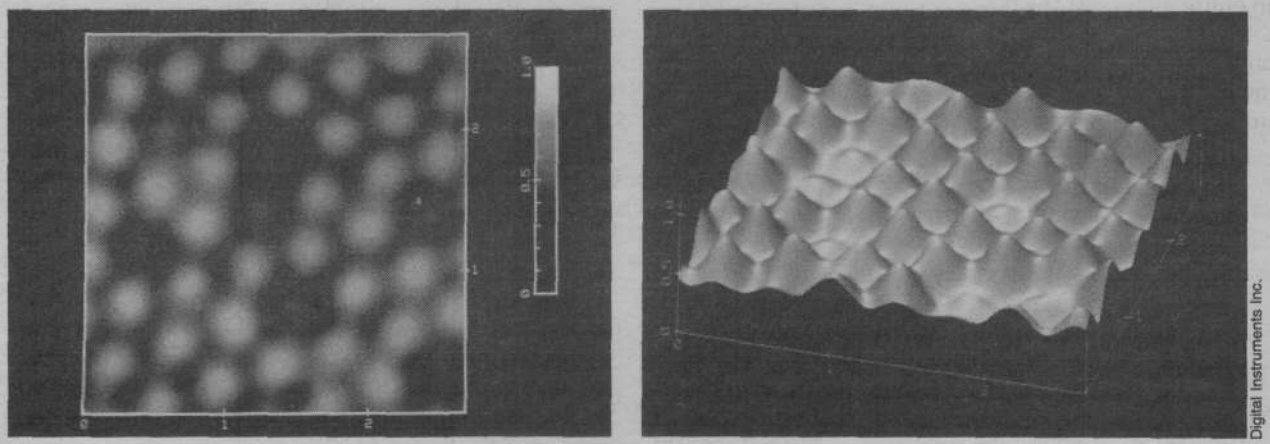


Figure 1
THE SCANNING TUNNELING MICROSCOPE

The scanning tunneling microscope (STM) works like a blind man's cane, feeling out a surface on which the bumps are made by individual atoms or molecules. A tiny metal tip carrying a voltage scans the surface and electrons "tunnel" to it in spite of strong repulsion—a phenomenon understood only in terms of quantum mechanics.

Shown at left is an STM image of atoms of $Bi_{14}Te_{11}S_{10}$, a semi-metal. The atoms are 3 angstroms apart. The units on the image are nanometers, and the scale shows depth in nanometers in terms of light and dark.

At right is the same image in a surface perspective, after computer processing. These images and that in Figure 2 were made on a Digital Instruments (Calif.) NanoScope II scanning tunneling microscope.

Resolution Below the Wavelength

In general, the resolution of a microscope is determined by the wavelength of radiation it utilizes. Because of this, scientists are developing microscopes that utilize the shortest wavelengths practicable.

For example, X-rays have wavelengths 50 times shorter than visible light, so that X-ray microscopes give up to 50 times better resolution. Electron microscopes are 25 times better than the X-ray microscope. Yet in both cases these systems are very limited, because the sample must be specially prepared and is damaged during the exposure. To follow important processes in living tissues, scientists would like to have a microscope with the resolution of the X-ray microscope but using visible light.

Scientists at Cornell University are developing a system that promises to do just that—the near-field scanning optical microscope. It can already make out details smaller than 0.1 the wavelength of visible light. The fundamental concept of this new system is to do away with the lens altogether. A tiny cylindrical probe, which has a diameter of less than one visible-light wavelength, could be brought very close to the sample. Then, by scanning the probe across the surface of the sample, an entire picture would be generated.

In practice the Cornell team does not utilize a tube quite that small. Instead the researchers arrange for their electronic detector—the system that sees the light—to be limited to seeing only a subwavelength spot. The microscope consists of a hollow, needle-shaped tube made from glass with an opening 150 billionths of a meter across. The inner diameter of the tube is 50 billionths of a meter. The outside of the glass tube is coated with aluminum and the tube is connected to sensitive photodiodes.

The near-field scanning microscope should find major applications in imaging biological processes and systems such as viruses, chromosomes, and molecules in vivo. The microscope can also be used to examine the surfaces of integrated circuits without damaging them as scanning electron microscopes do.

Philosophers and psychologists have long noted the selectivity of human perception. Now, researchers are making electronic eyes do the same thing, with major technological and scientific implications. Electronic transient detectors are everywhere nowadays, from the supermarket to the airport. Air traffic controllers have computer systems that automatically remove images they do not want to show up on their radar screens, such as stationary buildings and trees. This is done by having a computer remove a stored image from the active signals being picked up by the radar.

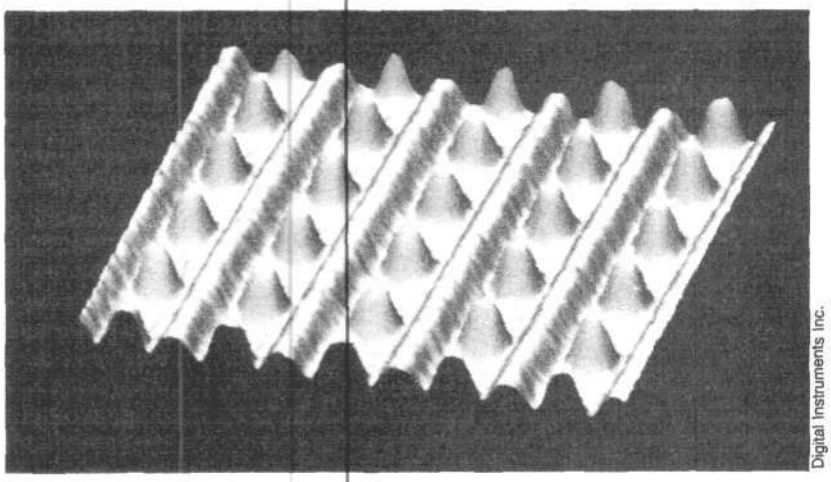


Figure 2
AN STM IMAGE OF A SECTOR HEADER MARKER ON A COMPUTER DISK STAMPER
The sector header is a position marker on a magneto-optical disk, a computer storage device for high information density. The stamper shown here is manufactured by an etching process like that used in making semiconductors. The image is 9 micrometers across.

Transient Detection Microscope

Scientists at the University of Southern California in Los Angeles have incorporated this technique in a new kind of microscope—the transient detection microscope. The system images only those elements of the field that are in motion, and is intended for observing moving biological systems such as microscopic protozoa.

The advance by these researchers is that they have developed a technique utilizing nonlinear optics in place of electronic computers for distinguishing between moving and nonmoving elements of the field.

The image consists of a hologram (three-dimensional picture) of the sample. For the transient detection microscope, the hologram is recorded and maintained in a crystal of barium titanate. The hologram is continuously being re-recorded and updated in real time. Simultaneously, the old image is being subtracted from the new image. If the two do not differ, nothing will be visible.

The technique involves nonlinear optical processes: In simple terms, two laser beams are used to create the hologram in the barium titanate crystal. The crystal has optical properties such that the image, once generated, is stored. A second image of the sample is generated within the crystal, and the crystal then subtracts the first image from the new image in terms of the throughput of laser light. That is, the laser light that emerges from the crystal has had the first image subtracted from the second. This altered laser beam creates the display for the user.

Unlike analogous systems that use spatial light modulators or computer processed images, the transient detection microscope does not break up the image into discrete elements or pixels. Therefore, the resolution of the image is not degraded by the subtraction process. The system can also be used to enhance the imaging of stationary specimens, particularly in cases where the sample must be observed in subdued light.

Plasma Focus Achieves 5-fold Increase In Fusion Output

by Charles B. Stevens

A new method that has increased the fusion output of the plasma focus technology by a "factor greater than 5," has been reported by the plasma focus research team at the Stevens Institute of Technology (SIT) in Hoboken, New Jersey.

Most exciting is the report from Professor Vittorio Nardi, who heads the plasma focus team, on the possibility of near-term technological applications of this advance.

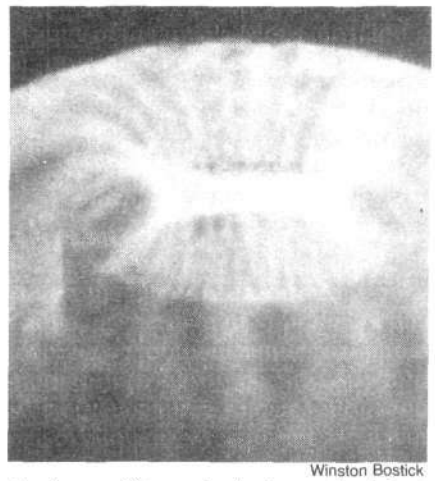
Nardi says that fusion and high-energy particle beam outputs of the plasma focus could be utilized in a wide range of systems, including the production of medical radioisotopes, materials testing facilities, and various types of diagnostics both for applied engineering and basic science.

According to the Stevens research team, this increase in output results from a more efficient acceleration of high-energy particle beams within the machine's plasma, and from increased trapping of these beams in neighboring regions that maintain extremely intense magnetic fields—greater than a hundred million gauss. (The Earth's magnetic field is just a fraction of a gauss.)

The New Method

The new method consists of introducing a field-distortion element in the gap between the electrodes of the plasma focus device.

The plasma focus fusion device is of a simple design that looks like a large



Winston Bostick

A plasma filament photographed in a 1970s version of the plasma focus device at the Stevens Institute of Technology. Recent experiments have demonstrated that such filaments are probably the way high energy particle beams are generated and trapped in the device's plasma.

Plasma Focus Provides Clues to Formation of Cosmic Dust

The experiments on the plasma focus machine may explain how cosmic dust forms. Interstellar dust is thought to be a prerequisite for the formation of stars and planets, but it is not known how interstellar dust is formed from gas.

The Stevens Institute plasma focus team reports that it has detected the formation of ion clusters in the plasma focus device. The device uses very high current and magnetic field densities compared to those involved in other techniques of ion cluster formation, and the resulting ion clusters are found to be much more stable.

The plasma focus has currents in excess of one million amperes. Alternative techniques utilized until now to form ion clusters have been (1) low-current discharges with immediate extraction of the ion cluster in a high-vacuum drift chamber, and (2) cooled hydrogen gas jets in a high-vacuum chamber, where neutral molecular clusters condense and are later ionized by an oscillating electron cloud. The supercluster component found in the plasma focus has a remarkably longer lifetime than those produced by these alternative techniques.

Intense Magnetic Fields

A possible explanation of this longer lifetime is the presence of the very intense, 100-megagauss magnetic fields, which could hold these superclusters together. Apparently some of the filamentary, force-free plasma structures seen in the plasma focus current sheath before the plasma pinch takes place somehow survive the explosive pinch breakup. These surviving plasmoids, which are seen to have a closed toroidal configuration, seem to eventually form into clusters. The apparent means for transformation is cyclotron radiation cooling.

Because of the high magnetic fields, these plasmoids generate large cyclotron radiation outputs. The higher coherence of cyclotron radiation over more ordinary bremsstrahlung X-radiation could account for the rapid and effective cooling of these clusters.

The Stevens group notes: "It is conceivable that this high-rate cooling and related ion/neutral-atom cluster condensation is a major factor also in the formation of interstellar dust out of gas that—from direct observational evidence—was originally free of solids." The experiments may also begin to uncover the fundamental processes responsible for crystal formation.

radio tube, with two electrodes shaped like hollow cylinders, one inside the other. The cylinders are inside a vacuum chamber filled with hydrogen gas. A compressed current pulse generates a large electric field between the electrodes, ionizing the hydrogen, making it an electrically conductive plasma.

With the flow of electric current between the electrodes, plasma nodules form that can sustain enormous energy densities. Fusion reactions result, with an output of bursts of X-rays, relativistic electron and ion beams, and neutrons. (See "The Plasma Focus Fusion Device," *21st Century*, Sept.-Oct. 1988, p. 37.)*

The field-distortion element is a small piece of solid material placed in the gap between electrodes. It concentrates the interelectrode current into a thin plasma current sheath. This process is initiated at the beginning of the discharge and effectively eliminates diffuse distributions of current behind the high-density plasma current sheath, greatly increasing its power density.

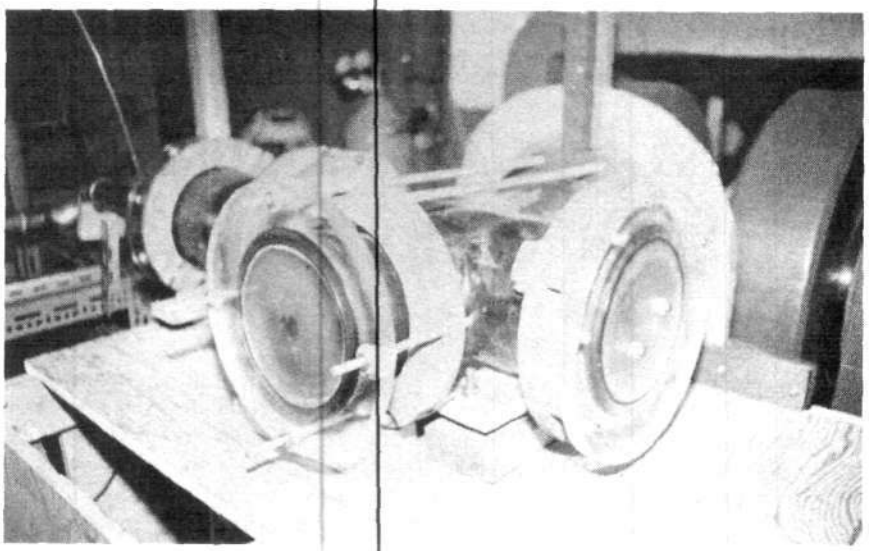
Another advantage of the field-distortion element is that it virtually eliminates bad shots—misfires of the device. There are relatively small fluctuations of the fusion energy yield from shot to shot with the field-distortion element. However, this reflects more the randomness of the processes involved in the pinch disintegration and fine-structure decay than the dispersion of a sizable fraction of the current in a diffuse low-density flow behind the pinching plasma current sheath.

Fine Structure Detected

The pinch is formed by a multiplicity of filaments with diameters of about .5 millimeter, which have been observed in the Stevens laboratory. The existence of a fine structure in these plasma current filaments on an even smaller scale, less than .1 millimeter, has been detected with new high-resolution techniques.

Experiments have demonstrated that the plasma filaments are probably responsible for the generation of high-energy particle beams through inductive-field acceleration in the plasma focus. These filaments have also been found to be responsible for trapping high energy particle beams within the plasma.

Nuclear activation of carbon and nitrogen that have been mixed with the plasma focus filling gas, and of carbon and boron-nitrogen solid targets has been measured. The activation is due to the bombardment of these elements by the high energy particle beams.



Philip Ulanowsky

The vacuum chamber from an early plasma focus device at Stevens Institute. The particle beams produced by the plasma focus are measured in the magnetic field created by the Helmholtz coils at left. Two ports to the plasma focus are visible.

Note

*A full report on these results can be found in *IEEE Transactions on Plasma Science*, June 3, 1988 pp. 368-378.

An economist examines the task of building cities that are beautiful and will last through a thousand years of technological progress.

Designing Cities In the Age of Mars Colonization

by Lyndon H. LaRouche, Jr.

Planning the colonization of Mars gives deeper meaning to the ages-old task of rendering man's habitation of unfriendly natural environments fruitful, healthy, and as agreeable as possible. We must consider features of the artificial Mars environment other than merely the molecular-biological requirements of the human being. We must take into account the importance of immunizing the psychological well-being of the colonists against the eerily new kinds of stresses associated with prolonged exposure to the alien environments of space.

We must take into account, in a new way, both the physiological and psychological importance of the architectural design of the local environment in which the explorers and colonists work and perform their normal personal functions away from the workplace. Admittedly, the permanent colonization of Mars is probably 40 years ahead; yet, even

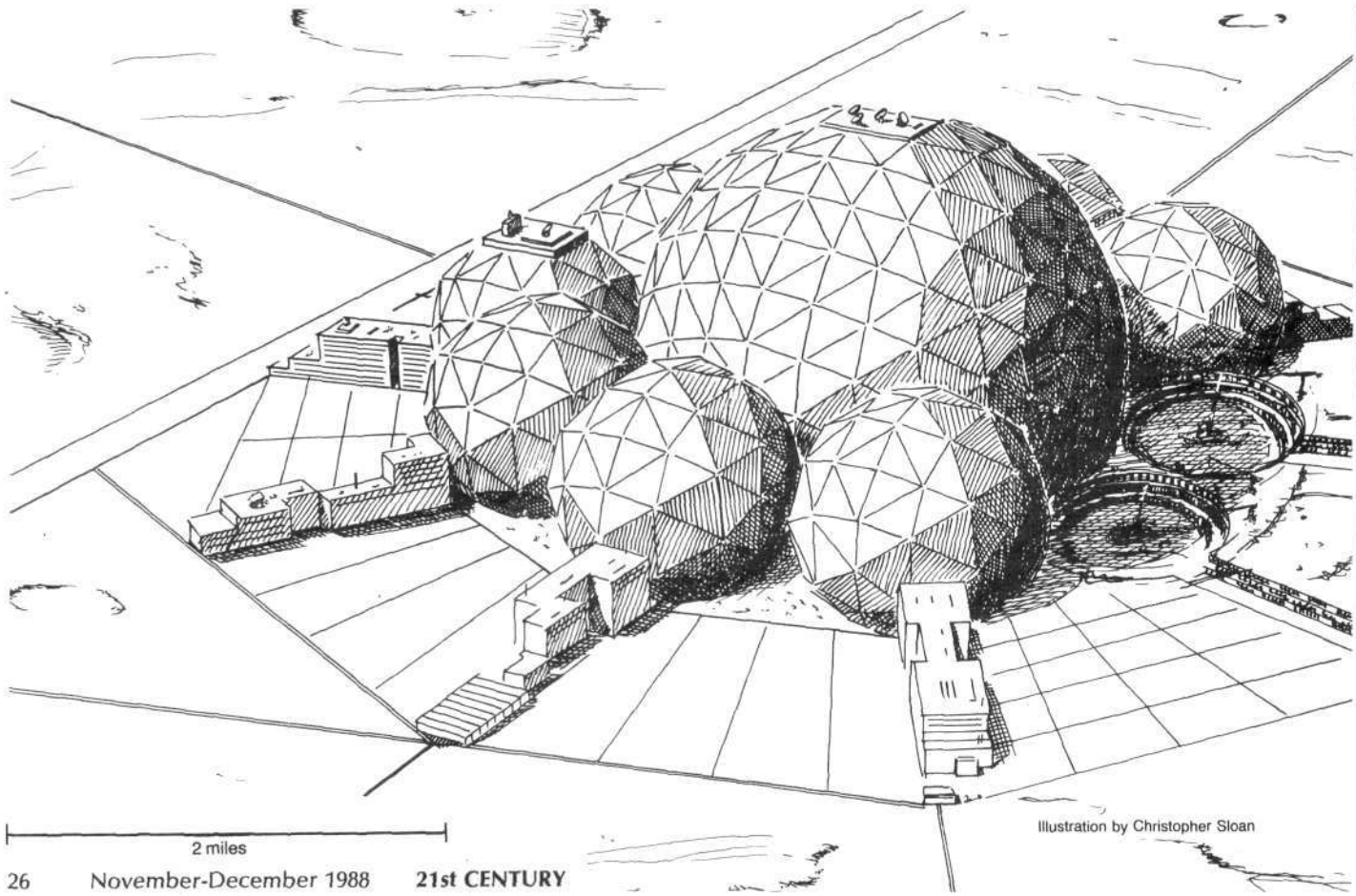


Illustration by Christopher Sloan

now, in the early stages of planning that colonization, and during the coming months and years, we must set some of the architectural guidelines for planning the future geometry of the new cities, the working space and the ordinary living space, in which space explorers and colonists will work and live.

Increasing fascination with space-exploration, especially among the young, ensures that whatever we announce as necessary features of the colonization of the Moon and Mars will have an increasing impact in reshaping the policies governing life here on Earth. Even in the stages when only a handful of Earthlings are actually venturing into space, increasing portions of the Earth-bound population will shift the popular sense of human identity toward the idea of mankind as a space-explorer and space-colonist. This will bring about an adjustment in popular values, a change in the way human beings think about human beings.

During the coming years, while flights deeper into solar space are still mainly in the planning and development phases, more and more people on Earth will look at life here on our home planet through eyes which are becoming, in the informed imagination, the eyes of the space-explorer. With ever-greater frequency, the suggestion will be made, that what we can accomplish in space might point toward the best solution for problems here on Earth.

This spillover of space planning into practice on Earth is a sometimes indispensable, as well as a likely result of the growing popularity of space colonization programs.

Thus, over the years immediately ahead, increasing attention to the design of future cities on the Moon and Mars will lead toward the easier recognition of the urgency of the establishment of many new cities on this planet, new cities designed and built—in the Sahara Desert and elsewhere—in ways influenced by our thinking about architecture in space. That connection is the subject area in which this report is situated.

To bring this matter within the reach of as many laymen-readers as possible, I begin with reference to some very ordinary features of my own adolescent introduction to "human engineering," to show how this led me to uncovering the scientific principles which should govern proper practice of architecture in space colonization.

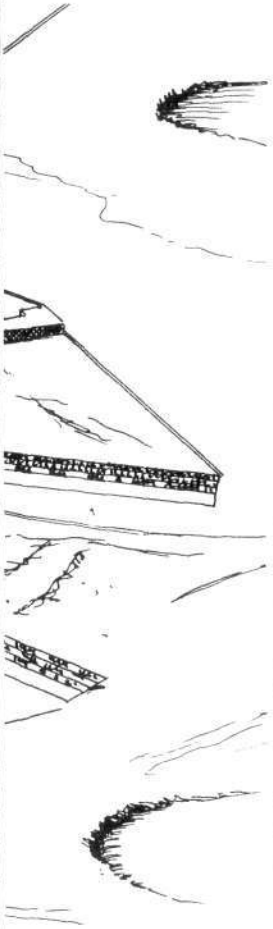


Figure 1
KEPLEROPOLIS:
A PROPOSED CITY DESIGN
FOR MARS

Kepleropolis, shown here in the construction stage, is designed to support 500,000 individuals. Its main dome, 1 mile in diameter, is built in a crater. The construction material for the dome is not yet invented; it would be transparent yet block cosmic rays. The ecliptic of the dome is at ground level. On the surface level is a large educational and recreational park. Immediately subsurface are administrative offices, and on levels below that are transportation and storage facilities and a central fusion power plant.

Atop the dome is a 1-mile high astronomical observatory and communications station. Surrounding the main dome are 10 smaller domes, each capable of supporting neighborhoods of 50,000 individuals. These domes are linked to industrial buildings along the outer part of the radii extending from the central dome, and the areas between the industrial buildings are devoted to terra-forming, agricultural and industrial activities.

'Human Engineering'

My first gainful employment began before my 16th birthday, in a summer job as what is called a "hand-dinker"—at 25¢ an hour—in a slipper-manufacturing firm. It represented about as low a level of skill as one might find in such a place. My assignment was to stand at a wooden block, with a die in the left hand and a shoe-cutter's mallet of several pounds weight in the right, and to punch out as many of the same object as I could, over and over again, each hour. At first, that work seemed to me about as boring as one might imagine. I quickly realized that it need not, and should not, be boring.

My thoughts at that work-bench were on the subject of what is called *motion-study*. The object of my inquiry was to discover how I could accomplish the maximum of the *desired result with the least effort; soon, I added, with the* least painful aftereffects experienced overnight and the following day. The mental image I adopted, was of the ordinary pendulum of a grandfather's clock: to achieve a rhythmical movement, in which my body fought itself the least in bringing about those motions, with the proper force, to achieve the optimal result.

My father had secured this lowly employment for me as part of his program for training me as a management consultant in the shoe-manufacturing industry. Indeed, this did help to impel me toward the consulting profession. The scientific principle I confronted in seeking to master that lowly, repetitive toil was an experience which guided my attention to the character and importance of "human engineering" of the operator's workplace, and of the traffic flow of materials and work-in-progress through the production center locally and the production facility as a whole.

No person, but one who has developed the habit of looking at every experience in this way, should be considered qualified for the profession of "economist." Do not tell me silly money theories of how objects are bought and sold; tell me exactly how they are produced and how they are physically distributed. Tell me how much labor, of how many people, working under what conditions, is required to provide an acceptable standard of market-basket of goods for one household. Tell me not the importance of a certain amount of money in a salary or wage; tell me not merely the money prices of things. Tell me what kind of a life a year of a man's labor will, on the average, buy for his family household; tell me how you propose to effect economies of labor which will help to improve that life.

Only one who understands the importance of these questions, and has acquired the skills for answering them, is qualified to become an economist. These attitudes and skills are not sufficient, by themselves, to qualify a person as an economist; but, no person who lacks these rudimentary skills will ever be better than useless as an economist.

In recent decades, industrial "time studies" by teams of so-called efficiency experts have become notorious, as the higher-priced, trained industrial engineering was replaced by the cheaper fellow hired off the street for his skill in wearing a white shirt while using a stop-watch and clipboard on the factory floor. Today, "time studies" are notorious, because the drift has been away from capital-intensive investment in economy of labor, toward increasing the labor-intensity of the workplace. As my own view of "hand-dinking" experience indicates, the purpose of industrial engineers' "human engineering" practice was directly the opposite to policies of labor-intensification; the purpose was to achieve greater productivity and quality with less effort by the operative.

The benefits of "humanistic engineering" (a better term than "human engineering") include such obvious economic gains to employer and employee as lower rates of industrial accidents, less cardiovascular and other illness, and so on.

The skilled industrial engineer did not need to refer to a stop-watch very often. The norms of movements of eyes and limbs, once established, gave the industrial engineer handy reference tables of a sort he understood, because he had learned to construct such tables as part of his professional education. He worked essentially as I had, when I thought through the best methods for hand-dinking. He thought about the physical geometry of the movements of man, machine, and work-in-progress; once he had mapped those qualitative features of the job, he could assign allowed times for each required motion with far greater accuracy than a platoon of time study boys studying the same workplace.

As a youth, I saw this problem expressed in a brutal way each time I stood in a shoe-manufacturing payroll line-up myself, or observed the operatives punching out and leaving the plant at the end of the day. I could identify accurately the nature of the occupation of the older operatives, merely from observing their bodily movements as they passed the time-clock. Their bodies were distorted by the combination of labor intensity with the peculiarities of the organization of the workplace; so, one could spot the lasters, the welters, and so forth, from the posture of their arms, torsos, and way they walked.

Sadly watching that parade, one recognized the human importance of making operatives more the masters of their machinery, less an increasingly crippled appendage of the machine.

For this reason, I learned to hate technological stagnation bitterly. In "humanistic engineering," we work to change the geometry of the workplace, to the effect of simplifying the motions and reducing the effort required of the operative, with special emphasis on eliminating the kinds of repetitive motions which are unhealthful. We recommend to the employer: "build this . . . change the lighting, so . . . make this change in the tooling of the workplace," and so on. In a climate of investment in technological progress, there is gain in profit and quality by the employer, and personal and income advantages to the operative, too.

Trading so many dollars' worth of unnecessary exertion by the operative, against an investment which costs actually less per unit of output than the amount saved in terms of unnecessary operative's exertion avoided, is the normal way in which productivity increases with gains to the operative as well as the employer. This is true up to the point that paid-out dividends become too large a portion of gross earnings, or borrowing costs for new investments in capital stocks become much too high.

The humanistic professional might measure his personal satisfaction from his work by reflecting on the image of twisted bodies of middle-aged operatives parading past the time-clock. The personal conscience of the true professional is: that saddening spectacle, and everything akin to it, must be eradicated systematically from our production.

The gains effected so are not merely physical ones; the mental ones are more or less as important. In the longer time, it is the mental gains which are of the utmost importance. The employer who says to his employee, "I don't pay you to think," is not the genius-laden tycoon he might think himself to be. The secret of the superior productivity of U.S. labor, in times dating from earlier than our recent 20 years of "postindustrial" drift into technological stagnation, was precisely that U.S. farmer's and industrial operative's superior ability to think while working.

Every good industrial manager agrees. He might inform you of the steady gains in quality of product and productivity which industrial firms obtained through the employees' suggestion box. He might also instruct you on the subject of increased accident-proneness among operatives for whom a lower premium is placed on thinking as integral to the operative's role at the workplace. A more profound, more valid general argument could be made: The biophysics specialist might suggest that we correlate brain alpha-wave activity in persons with their ability to sustain continuing technological progress efficiently—and to avoid accidents on the job or while driving a motor vehicle.

In general, as the level of skill and technology are increased, production depends increasingly upon a more active role by the operator's capacity for effective kinds of problem-solving innovations, as an integral part of the workplace.

Think of space colonization as what it is: essentially, very high levels of skill and technology by every person involved.

The chief flaw in the relatively better sort of industrial engineering practiced up to about 20 years ago was the lack of attention to what should have been recognized as the underlying principles of motion theory. Industrial engineering education should have included at least two years' span of study of the relevant work of Leonardo da Vinci, Albrecht Dürer, Raphael, and Johannes Kepler. Had such studies been promoted as they should have been, a good industrial engineering graduate would have understood the principles which govern economy of labor. He would have mastered also, the rudiments of applying classical princi-

ples of aesthetics to architecture and urban design, and understood these subjects properly from the standpoint of "humanistic engineering."

General Design of a City

At the end of World War II, significant numbers of the leading scientists in Germany were gathered into a pool at Aachen, awaiting reassignments. Some of these applied their skills to planning the reconstruction of the war-ruined Ruhr district. Part of their design was implemented. Other elements, if not implemented, nonetheless influenced thinking about reconstruction policy.

Since about 1977, I had been engaged in studies for the economic development of Africa, including the urgent need for building cities of a new type in black Africa, as an indispensable, central feature of any successful effort to develop black Africa in a general way. My own work in the latter connection gave my associates an advantageous standpoint for recent examination of the work of the Aachen circles; leading features of the Aachen designs coincided on key points with principles of design I had come to view as elementary through my own work.

Such is science. Different groups of investigators, in different times and places but working from the same general store of knowledge, converge on the same result. The right principles of design of cities are not matters of local tastes; they are as universal as is the nature of the individual human being who, as the inhabitant of the city, is the measure of its proper design. The unchangeable principle governing the proper design of a city is elementary; it is the same for a city on Earth as it is for a permanent colony on Mars.

The proper design for a city is a study of motion of people, the goods they use, and their activities. The general scheme for design is therefore the principle of least action—which I shall describe at a later point in this report. It is sufficient, for the moment, merely to state as an assertion that the definition of least action required for this purpose is harmonic orderings cohering with those determined by the golden section of the circle. For reasons to be made clearer, the significance of the golden section suffices to show that the general design of a city is implicitly a proposition in Gauss-Riemann topology.

I shall develop this theme by stages, after I have described the general arrangements.

The simplest form of result has three features: (1) The paradigmatic form for approximately level regions is spherical, with one hemisphere lying above the surface and the other below the surface. Let us term the circular cross-section of the sphere at the surface-level the *ecliptic*, as in the ecliptic of the solar planetary orbits. Then, (2) the harmonic organization of the ecliptic is analogous to Kepler's arrangement of the orbits of the Sun and its eight major solar planets, as divided by the domain of the shattered ninth planet, today's asteroid belt lying between the orbits of Mars and Jupiter (Figure 2).

The Sun, tuned to a Keplerian C, is the central educational park of the city. The orbits of Mercury, Venus, Earth, and Mars correspond to the administrative and residential areas of the city. F to F-sharp, the asteroid belt, is the boundary between the inner city and the outer, "industrial" planets.

Since the design of the city is based on least-action movement of human activity (per capita, per hectare), it is the transport system—for persons and freight—which appears as a delimiting feature of the internal design. In the modern form of the city, this movement is on distinct levels: walking, passenger rapid transit, subsurface transit of freight, subsurface transit of activities by utilities.

Thus, the subsurface hemisphere is defined in terms of subsurface movements of people and freight, and in terms of stores of essential goods; the density of the subsurface structure increases as a function of per capita motion per hectare as we proceed inward from the "asteroid belt" to the "Sun," the educational and classical cultural activities situated within a large, educational and recreational park. So, within the inner part of the "solar complex," the density of activity increases as we near the "Sun."

Beyond the asteroid belt, the per capita density of activity per hectare in industrial use again increases, initially relative to the average for the inner portion of the complex as a whole, and then diminishes again, as the eye travels toward the outermost orbit of these "outer planets."

Throughout the complex, the density of movements per capita per hectare is harmonically distributed as in planetary orbits; these are defined in terms of transport systems, especially the subsurface rapid transit, freight, and utilities. The spokes and rims of these transport orbits are cut by a plane, self-similar spiral of movement, radiating from the "Sun" and intersecting the spokes and wheels of the outward and lateral movements.

The spokes are 12 in number, and the inner orbits are four. So, the spokes are named North, Northeast by North, Northeast, Northeast by East, and so on. The orbits are named for musical tones, Kepler-style. The spiral-way is known as the Gaussway.

This signifies that such a city has a finite maximum population. If more population is to be accommodated, an additional city must be developed, linked to others by high-speed magnetic-levitation rapid transit links—at nominal speeds of about 300 miles per hour. (Indeed, magnetic levitation is used throughout the surface transit systems for movement of persons and freight.) How large is that finite maximum?

At first glance, three factors appear to decide this: (1) the unit-area and volume required by an average person's mean-free-path motion within the city: the congestion factor; (2) the ratio of lapsed time expended in normal travel by a person within the city, to time spent in other activity; (3) the size of the "Sun."

These three factors must take two other sets of factors into account. The first of those two other sets of factors is that each design of a city is delimited by my six primary constraints for a Riemannian representation of technological progress: (1) level and rate of improvement of per capita market-basket content, in quality and quantity; (2) density and rate of increase of usable energy available per per-capita unit of per hectare population density; (3) level and rate of improvement of effective energy-flux density of modes of applied technology; (4) ratio of rural to urban labor force employment in the region in which the city is functionally located; (5) ratios of employments of the urban

labor force, in terms of scientists and kindred professionals per hundred members of the labor force employed as operatives, and in terms of capital-goods producing to household-goods producing operatives; and (6) the general level and rate of advancement of technology in practice. These six factors define the true basis for measuring individual activity levels within the city as a whole.

This is also affected in obvious ways by the second additional set of factors, the demographic factors centered around the birth rate per female of child-bearing age-intervals and life expectancies.

All three sets of factors, taken together as part of a single function, are the primary determinants of the city's proper choice of maximum population levels.

In all these considerations, the irreducible quantum of action is the activity scale required for the average individual. The individual person's level of activity, per unit of population density, becomes the definition of scale, with respect to which all other measurements are defined.

A good design for a beautiful city is one which will be durable through a thousand years of technological progress. This presumes that the city is designed such that it easily adapts to the effects of technological progress.

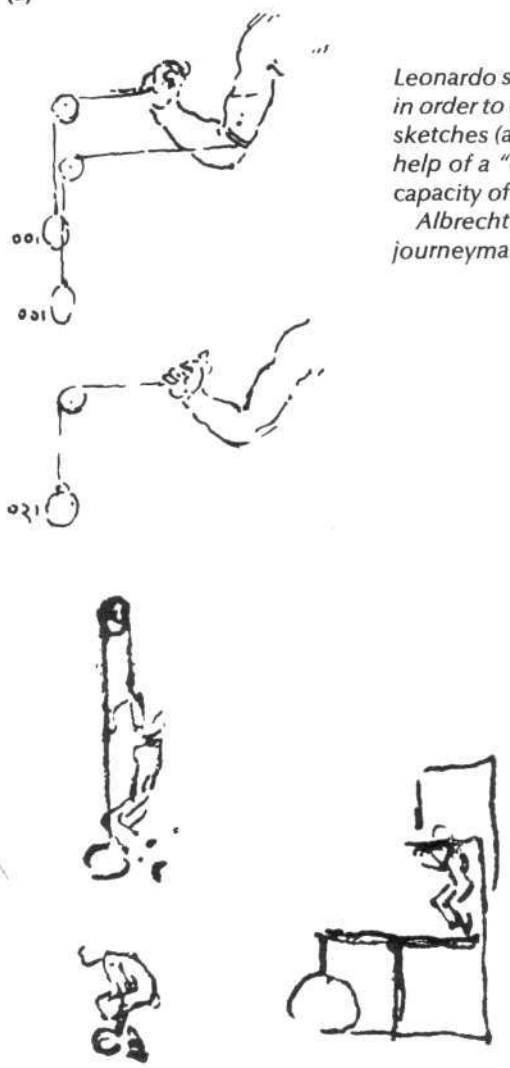
It adapts so, in terms of increasing of the energy-density per per-capita unit of population density. It adapts so, in terms of raising the level of effective energy-flux density per square centimeter cross section of target area of work. It adapts so, to related increases in mobility of persons. It

Figure 2
RENAISSANCE STUDIES OF THE PRINCIPLE OF LEAST ACTION

Leonardo studied the principle of least action in the human body and in animals in order to design machines that would have maximum work efficiency. In these sketches (a), he shows the estimated human muscular effort of the arm, with the help of a "dynamometer." This device measures force, representing the lifting capacity of the group of muscles under scrutiny.

Albrecht Dürer's 1518 pen and ink study of motion (b) shows a young man, a journeyman joiner, leaning forward as he works with a large drill.

(a)



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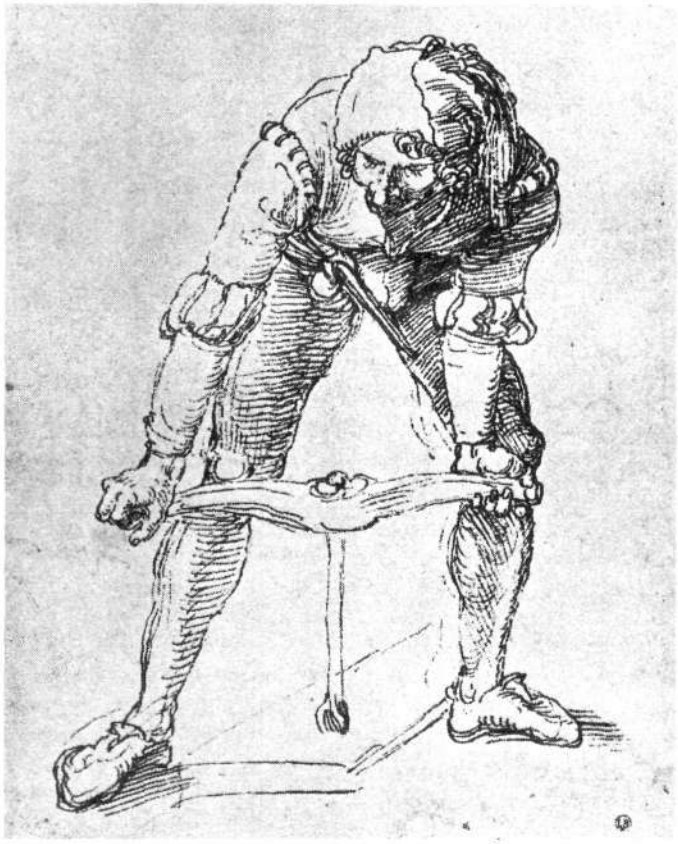


Source: Ladislao Reti and Bern Dibner, *Leonardo da Vinci—Technologist* (Norwalk, Conn.: Burndy Library, 1969), p. 69.

adapts so, to the increase of the ratio of time expended in creative leisure, to that required for labor.

What remains constant is man. The biology of the person requires daily about six to eight hours of sleep, two to three hours expended in eating. We know today, or should know, that—for what might be termed psychobiological reasons—no acceptable substitute for the "nuclear family" as a mode of development of new individuals will ever be discovered. We know that maturation will never be briefer than a span of between 20-odd and 25 years, of which at least between 16 and 18 years must be within the setting of the family household.

From this, the design of the dwelling unit follows. The size of sleeping and bathing quarters, the need for dining areas and their dimensions, and so forth, are defined in an elementary way. Improvements in privacy of thoughtful activities, and other advances in quality of dwelling places are desirable, and will become more demanded as society progresses. Yet, walking through some better maintained, older areas of cities in Europe and elsewhere, and from scholarship in the same matter, we see that the elements of design of a good space organization of the dwelling unit have not changed much over centuries, even thousands of years.

If we learn from those studies by applying principles of "humanistic engineering" to what we learn, we can do much better today than any preceding generation of mankind, in building a city today for whose design we will be thanked by its inhabitants a thousand years into the future.

Natural Human Movements

As I stated earlier, 20th-century industrial engineering wasted much of its efforts and contributed a few important mistakes, by neglecting the rigorous study of the natural movements of the human body associated with such pioneers as Leonardo da Vinci, Dürer, Raphael, and Kepler (Figure 3).

Since classical Athens of Plato's time and earlier, it has been the central principle of classical aesthetics, that beauty of form and movement is limited to those harmonic orderings of form which are coherent with a harmonic series based upon the construction of the golden section of the circle. Classical Western aesthetics defines this as a rigorously definable standard of beauty for the form of music, poetry, painting, sculpture, and architecture.

This standard was embedded in Western civilization by such writings of St. Augustine as his *De Musica*. In the wave of city building unleashed by Charlemagne, what were called "Augustinian principles" were the guide to the development of cathedral towns around such "Augustinian" works in light, acoustics, and form, as the famous cathedral at Chartres. Classical aesthetics was defended during the "New Dark Age" by such influentials as Dante Alighieri and Petrarch, and became the central theme of the Golden Renaissance at about the time of the 1439 Council of Florence. Brunelleschi's successful invention in architecture, completing the construction of the dome on the cathedral at Florence, was a signal point of reference throughout that century.

The single most influential scientific thinker of that entire period was Cardinal Nicholas of Cusa. Cusa's revolution in scientific method first appeared in published form in his 1440 theological text, *De Docta Ignorantia* (*On Learned Ignorance*). This text included a revolution in ideas about geometry and physics, solving several classical problems left over from the work of such as Parmenides, Plato, and, most immediately, the Archimedes whose work on the quadrature of the circle Cusa directly corrected in his own 1440 book.

What Cusa actually accomplished was the establishment of a true *non-Euclidean geometry*. Instead of a system of deductive theorems, based on a set of axioms and postulates, Cusa showed that the physical laws of the universe could be represented by means of nothing more than geometrical constructions, constructions all based on no more than a single principle of physical geometry. This principle of Cusa's is rightly described as a "Maximum Minimum Principle." In geometry, it is recognized as including the so-called isoperimetric theorem of topology, as that was elaborated by Bernoulli and Euler at St. Petersburg during Benjamin Franklin's lifetime. In physics, it is recognized as the Principle of (Physical) Least Action, as this was variously defined, geometrically, in various stages, by Fermat, Leibniz, and the work of Karl Gauss and his successors.

Following the publication of his *De Docta Ignorantia*, Cusa devoted a number of other published writings to matters of scientific method. Leonardo da Vinci was brought to systematic study of Cusa's scientific work through Leonardo's Milan collaborator, Fra Luca Pacioli, of *De Divina Proportione* fame. From the collaboration between Pacioli and Leonardo, nearly all of modern science was set into motion, together with several revolutions in painting and music.

Briefly, to assist the layman in following this, the part of Pacioli and Leonardo's collaboration which is of direct bearing upon understanding what we have identified as "the scale of individual human activity," is the following.

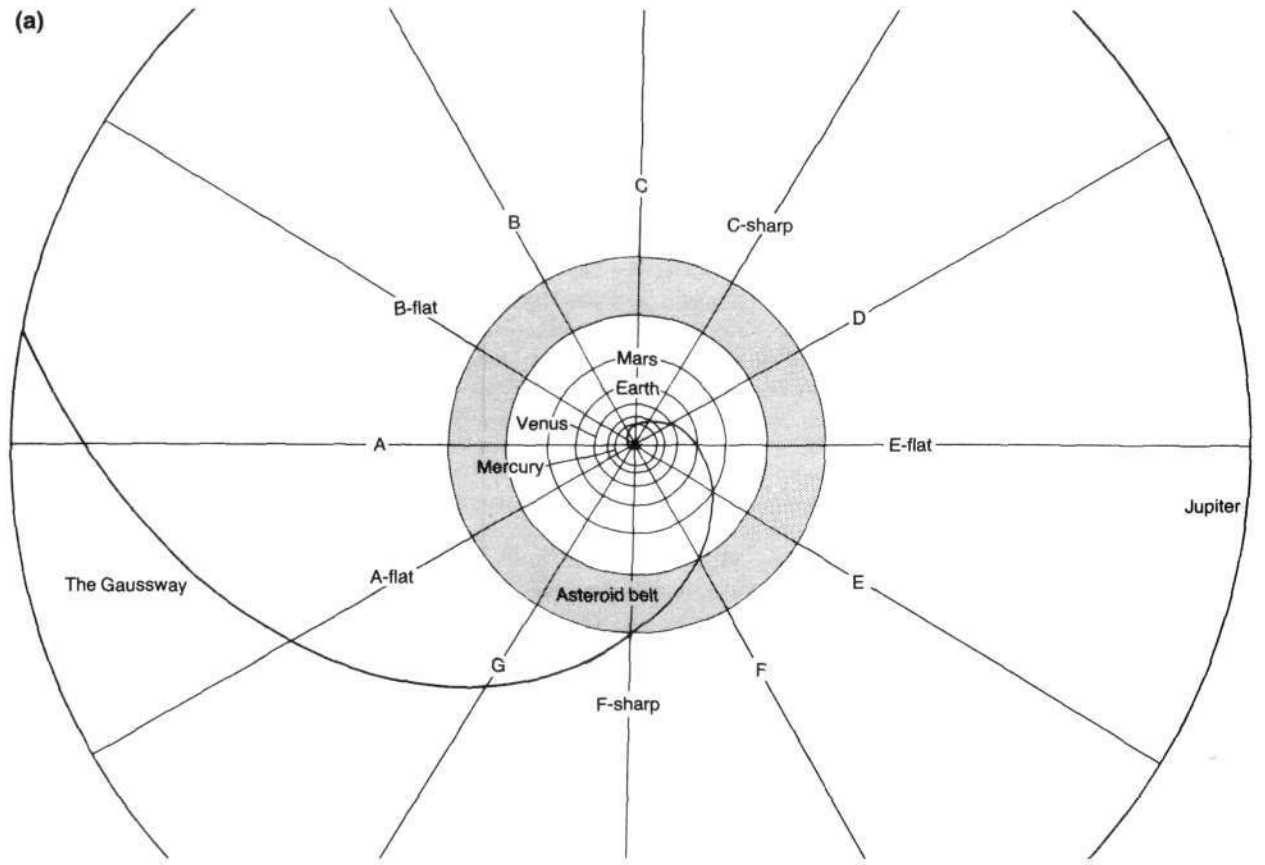
In one of his most influential dialogues, the *Timaeus*, Plato presents and discusses the fact that in visual space only five regular solids can be constructed. These—the tetrahedron, the cube, octahedron, the dodecahedron, and the icosahedron—have been known since as the five Platonic solids, or, simply, the Platonic solids (Figure 4). Plato ascribes the proof of this to a collaborator working at the Cyrenaic temple of Ammon.

The importance of the "five Platonic solids" is that they are a crucial proof that visual space—as our eye-brain define the image of space for us—is not empty space stretching infinitely, in straight lines of Albertian perspective, to beyond the furthest imaginable extremes of the very, very large and very, very small. What might appear, wrongly, to be empty space and time has an efficient geometrical shaping, and this in a way which contradicts all of our childish intuitions about the universality of extension in straight lines.

Thus, we say, physical space-time is self-bounded. This does not mean that our universe has some sort of fence around it. It means what is already clearly stated by the report that, in visual space, the only regular solids which can be constructed, excepting the sphere, are the five Platonic solids.

Plato already emphasized this notion of "self-boundedness" of visual space. For example, in his *Republic,* he supplies the usually misunderstood reference to what we call today "Plato's Cave." He warns that what we imagine ourselves to see, as images in visual space, are like shadows cast by firelight upon the wall of a darkened cave. Through our senses, we are able to know reality, but what our senses show us directly is merely the shadow of the reality.

Today, after the work of Gauss, Dirichlet, Weierstrass, Riemann, and so forth, we say, "Of course, that is true." Today, as especially in the case of *nonlinear* sorts of electromagnetic processes, we know that cause and effect occur



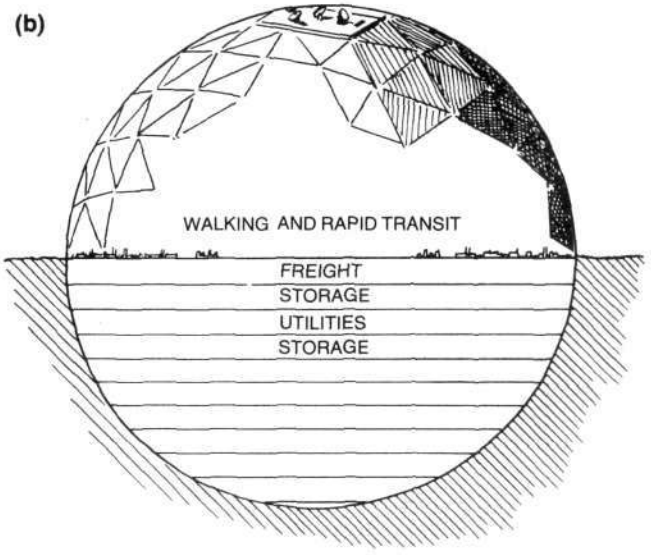


Figure 3
TWO SCHEMATIC VIEWS OF KEPLEROPOLIS

This proposed plan for a future city on Mars (or here on Earth) follows Kepler's harmonic view of the solar system. A cross-sectional view of the city, corresponding to the ecliptic in the solar planetary orbits, is shown in (a). The Sun is at the center, tuned to the note C, and is the location for the educational and recreational activities of the city. The orbits of Mercury, Venus, Earth, and Mars define the residential and administrative areas of the city. The asteroid belt at notes F-sharp to F is the boundary between the inner living areas and the agro-industrial orbits. The self-similar spiral from the Sun to the asteroid belt is called the Gaussway.

A vertical cross section of Kepleropolis is shown in (b), with the functions of various levels identified. The city will be built from the bottom up, with the surface level added when the deep substructure is complete.

outside the limits of our ideas of visual space. Cause and effect occur efficiently in what Gauss and Riemann enable us to define as a fully constructible geometry of the "complex domain." We can show also that the "shadows" recognized by our senses are a true, if distorted reflection, into "Euclidean space" of what actually is occurring within the physically real world of the complex domain.

Therefore, the study of the reasons for the uniqueness of the Platonic solids is the most fundamental line of inquiry in the physical sciences. What is the reason, that visual space should be "self-bounded" in the way this proof demonstrates? It should be obvious that no amount of interpretation of empirical evidence, stated in terms of the physical space-time of Descartes, Newton, Laplace, or Maxwell, is sound physics, unless we show that our observation of visual space has taken into account the reasons for the self-boundedness of the visual representation of physical space-time as a whole. Competent physical science begins, therefore, with rigorous proof that we have discovered the reason for this "self-boundedness" of visual space.

Pacioli recognized the importance of reconstructing the proof of the Platonic solids. He succeeded in producing a model of such proof which was improved upon by scientists such as Euler and Gauss during later centuries, but which that more advanced work shows to have been in the proper direction. Pacioli's and Leonardo's work shows that they properly grasped Cusa's contributions to the founding of modern scientific method. Leonardo, and Dürer, Raphael, and Kepler after him, established the basis for revolutionizing our approach to architecture and urban design, as well as establishing, in a related way, the principles of "humanistic engineering" which ought to inform the work of the qualified industrial engineer.

A scientist comes away from a study of Cusa's work as a whole with the sense that the proper descriptive name for "science" is "an intelligible representation of the lawfulness of the universe." This was what study of Cusa's work imparted to Pacioli and Leonardo, and Kepler later. Although our subject matter here is the principles of architectural form which must govern the design of new cities, it is also urgent—especially if it is our goal to design cities to endure for a thousand years—that we show that those principles are premised upon unassailable truth. Therefore, we should sum up the proper meaning of "intelligible representation."

Go to a blackboard. Draw upon that board all sorts of shapes of lines, including the most arbitrarily irregular ones you are able to produce. These are "representations."

Now turn to face the classroom. Can you meet any challenge members of the class might pose to you, on the subject of these representations? Can you show under what circumstances each of those representations might necessarily exist? In other words, can you start from a single, most elementary principle of a purely constructive geometry? Can you, without aid of any additional assumptions (axioms, postulates), and without any resort to formal deductive reasoning, show how constructive geometry generates each and all of those representations you have drawn?

If you can succeed in meeting that challenge, in the fullest of its implications, you have met, in that degree, the challenge of "intelligible representations," as distinct from mere "representations." The most troublesome question you must face is the very first question: What is the correct choice of "most elementary principle"? If you grasp what that question implies, you are prepared to appreciate the genius of Cusa's work.

Two examples which I have frequently employed, over the years, bring the idea of "elementary intelligible representation" to bear with full force. I challenge you to supply me an intelligible representation of two terms, "creation" and "life." These are terms common in our vocabulary, especially the latter. In modern civilization, all serious thinkers have recognized that these two terms have a connected meaning. Yet, I challenge you: If you can put such a word into your mouth, can you also supply me with an intelligible representation of what you mean by that word, or even any representation at all?

If you use as system of reasoning such as that of Euclid's *Elements*, these two words correspond to ideas for which you have no possible representation, and certainly no intelligible representation. Yet, already, Cusa did have an intelligible representation of both, and, Pacioli, Leonardo, and Kepler, a more elaborated such representation. This representation is the fundamental idea underlying a modern form of the science of classical aesthetics, and underlying the principles of functional form for design of new cities.

In formal logic, "creation" does not occur; it is merely asserted to have occurred. "Creation" is implicitly situated between two successive moments of existence, such that something which does not exist in the first, exists in the second. There is no representation of that which occurs between the two moments.

Perhaps the most famous case of use of formal logic to deny the existence of "creation" is that expressed by Immanuel Kant, most emphatically in his *Critique of Judgment*. Kant asserted that no intelligible representation of creative mental action, such as that responsible for fundamental scientific or artistic discoveries, is possible. Kant did not assert that "creation" does not exist; he argued that since the human mind is, according to his view, incapable of providing an intelligible representation of an act of creation, mankind can not know "creation" as an idea.

Kant's argument is absurd, with one qualification. In deductive logic, it is axiomatically impossible to provide even a representation of the idea of "creation," and certainly not an intelligible representation.

The word "life" encounters exactly the same difficulties as the representation of the word "creation." In formal logic, or in molecular biology, it is impossible to provide even a representation of "life" per se, let alone an intelligible representation.

Today, intelligible representations of "creation" are available to us even in mathematical physics, as the case of the Riemann surface illustrates this most directly and simply. The same Gauss-Riemann physics, applied to a more advanced representation of the work of Pacioli, Leonardo, and Kepler, permits us to provide an intelligible representation of "life" per se, as molecular biology cannot. Moreover, in the same context, we can show that both notions,

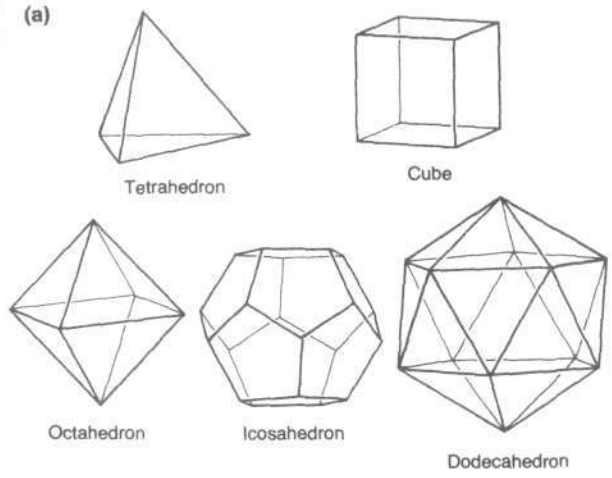
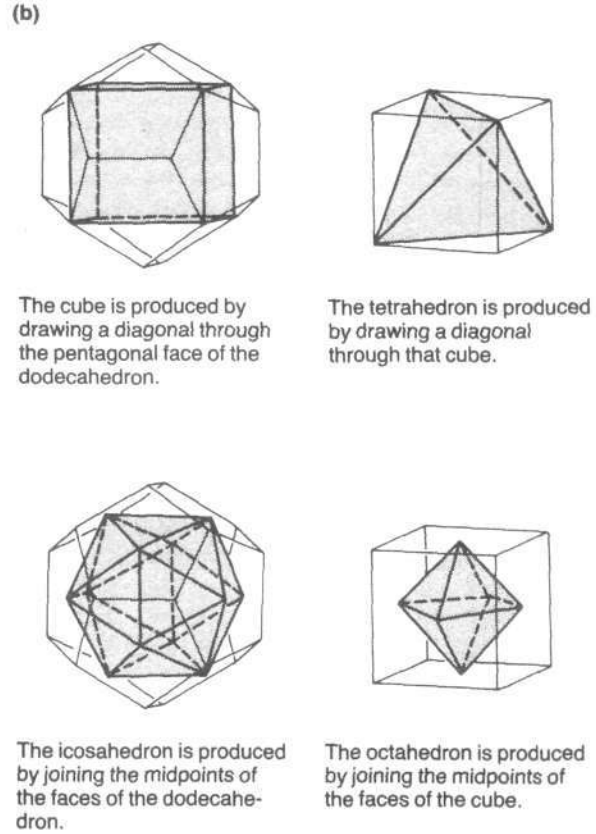


Figure 4
THE FIVE PLATONIC SOLIDS

As Plato discusses in the Timaeus, *there are only five constructible three-dimensional figures whose faces are all the same regular polygon (a). The tetrahedron, octahedron, and icosahedron have faces that are equilateral triangles; the cube has square faces; and the dodecahedron has pentagonal faces. Four of these Platonic solids can be derived from the fifth, the dodecahedron (b).*



"creation" and "life," are of the same characteristic.

This is no digression from the principal subject matter of the present article. A correct understanding of these two terms is essential for a rigorous definition of what architecture must measure as "human activity," for the work of designing cities which will be of durable worth for a thousand years yet to come. That connection will become clearer as we progress.

Functionally, there is only one Platonic solid, the dodecahedron, each of whose 12 equal facets is a regular pentagon; the other four, the tetrahedron, the cube, the octahedron, and icosahedron, are simply and directly derived from the dodecahedron, rather than the proof of their existence being derived separately from that for the dodecahedron [Figure 4(b)]. So, we must say that the dodecahedron expresses adequately the self-boundedness of visual space.

The construction of both the regular pentagon, and the dodecahedron, depends upon the prior construction of the golden section of the circle. So, the construction of the golden section represents the self-boundedness of visual space. In other words, the limit of constructibility of intelligible representations in visual space is constructions dependent upon the construction of the golden section.

This point is traced to its elementary root by aid of Cusa's solution to the problem of the intelligibility of the problem of attempting to square the circle, a solution whose result is reflected in a central way within his 1440 *De Docta Ignorantia*. Cusa implicitly eliminates the use of deductive method in geometry and in physics, and also eliminates all need to base geometry and physics on an initial set of axioms and postulates. From this point on, in the history of development of modern physical science along a pathway of progress, through the work of Leonardo, Kepler, Leibniz, Gauss, and Riemann, circular action is the only elementary conception upon which geometry and physics are premised.

Circular action is defined, topologically, as the least amount of perimetric action required to generate the relatively largest area or volume. Since volume exists, circular action must be understood as acting upon circular action in every interval, reciprocally. For purposes of identification, we call this "doubly connected circular action." The analysis of possible constructions in visible space requires us to employ the notion of "triply connected circular action."

That is the definition of the term least action, not only in constructive (or, "synthetic") geometry. It is also the basis for definition of "least action" in the physics of Kepler, Fermat, and Leibniz. It is the point of derivation for the work of Gauss, Riemann, et al., in defining the form of least action in the complex domain: multiply connected, (conical) self-similar spiral action. Understanding the way in which the two definitions of physical (multiply connected) least action are connected, is the mathematical-physics premise for those measurements of human activity central to proper architectural designs.

Pacioli and Leonardo already knew this universality of (circular) least action from the work of Cusa. For that reason, it was possible for Pacioli to elaborate a most respectable approximation of the stricter proof for the uniqueness

(a)

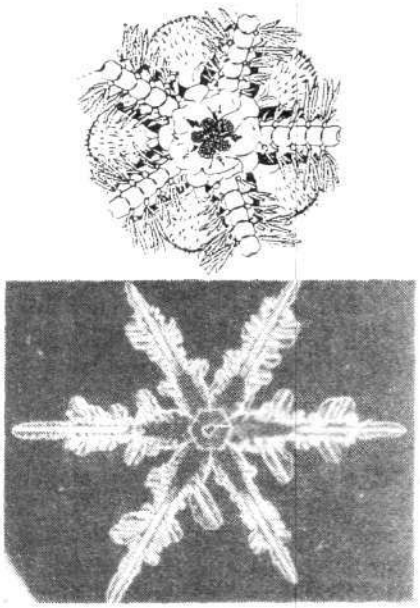
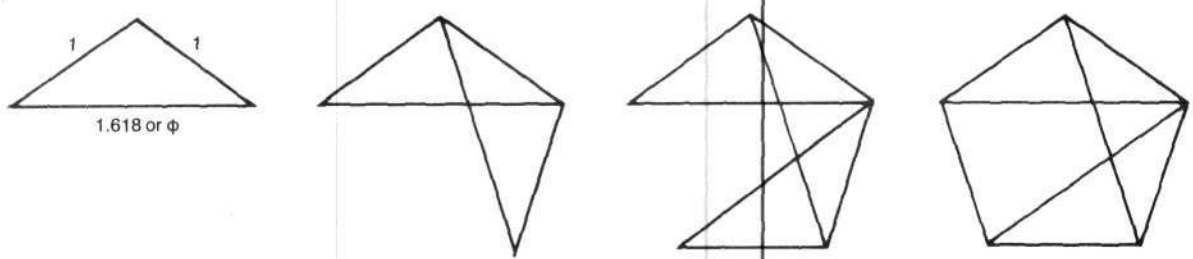


Figure 5
LIVING PROCESSES, PENTAGONAL SYMMETRY, AND THE GOLDEN SECTION

Living processes, plant and animal, are characterized by pentagonal symmetry, while inorganic matter (like the snowflake shown) is characterized by hexagonal symmetry (a). As Leonardo and Pacioli demonstrated, living processes grow according to the golden section ratio. That is, a line will have golden section proportions when it is divided into two parts such that the ratio of the first to the second part is equal to the ratio of the second part to sum of the two parts.

The pentagon is closely related to the golden section, and one example of this is shown in (b). Beginning with an isoceles triangle whose two equal sides are each 1, and whose two equal angles are 36°, the longer side will be the golden mean, approximately 1.618, a value designated by the Greek letter phi, ϕ. Identical triangles can be added to form a pentagon, as shown. Thus a pentagon with sides equal to 1 will have diagonals equal to the golden mean. The 36° angle is generated when a circle is divided into 10 sections by inscribing a decagon.

(b)



of the Platonic solids. If universal cause-effect action is representable as multiply connected circular action, all action in visual space is fundamentally underlaid by this form of physical least action. Hence, the self-boundedness of visual space, as shown by the Platonic solids, must be a constructible "property" of universal least action of this form. Hence, the golden section of least action, a construction itself derivable from nothing but this form of least action, is a sufficient demonstration of the necessary characteristic of the self-boundedness of visual space.

The most famous immediate application of this result, by both Pacioli and Leonardo as collaborators, was their definition of the form of life: All living processes are distinguished from ordinary nonliving ones, in respect to morphology of growth and function, in the respect that that form is ordered as an harmonic series consistent with the harmonic series defined by the golden section.

Today, we qualify that discovery. Between the limits of the very, very large (astrophysics), and of the very, very small (microphysics), any process which is harmonically ordered in congruence with the golden section is either a living process, or is a special class of work done by a living process. Kepler, who based his founding of a comprehensive mathematical physics chiefly upon the combined work of Cusa and Pacioli-Leonardo, was the first to prove that the universe as a whole is governed by the same harmonic ordering. Some leading scientists among the writer's collaborators are proving that a Gauss-Riemann correction for Keplerian laws of astrophysics also rules on the scale of organization of atoms and smaller scales of physics. With that qualification, Pacioli's, Leonardo's, and Kepler's geometrical (least-action) definition of living processes is conclusively demonstrated today to be fully as accurate as Pacioli represented this to be at the beginning of the 16th century.

Thus, all of the movements and related functions of the human physiology are harmonically ordered least-action-based movements of this sort.

This standpoint governed several aspects of the work of Leonardo. In anatomy, he explored the golden section harmonics of the physiology of persons, horses, birds, and so on. In pioneering the principles of design of machinery, and the design and use of weapons, the same principles predominated. He revolutionized the science of perspective by emphasis upon anomalies of visual space associated with the periphery of vision, rather than an Albertian, linear vanishing-point. This we note in viewing the originals of such master works of Raphael as the famous murals in the papal apartments and the "Transfiguration" in the Vatican.

It can also be shown that his general approach to application of hydrodynamics to not only water movements but also phenomena of electromagnetic radiation (including propagation of sound!) is based on the same principles of constructive geometry.

Thus, must "humanistic engineering" be reformulated in terms consistent with these principles of human physiology. Thus, must the design of new cities be adapted.

The Form of Mental Activity

This is also true of the most characteristic form of human mental life, the aspect of human mental life which absolutely separates mankind from the beasts. The form of design of the city must be agreeable to the form of this aspect of human mental behavior, as well as the functional requirements of form imposed by human physiology otherwise. It happens that the form of mental behavior is also congruent with the harmonics of the golden section. We must make clear the most relevant points involved.

Man is the only living creature who is capable of willfully changing the form of his species' behavior for the better, and does this through creative discoveries bearing upon laws of nature. Scientific and technological progress are but the paradigmatic expressions of human existence.

Today, we know how to construct an intelligible representation of the creative mental processes involved in either scientific discovery or valid works of classical forms of art. However, there is no principle in this (Riemannian) branch of mathematical physics to this effect which was not already stated in another way by the dialogues of Plato. Looking at the Socratic method retrospectively, in examples of such dialogues from the pens of Plato and Leibniz, the work on representation of nonlinear functions by Gauss, Dirichlet, Weierstrass, Riemann, and Cantor permits us to show that Socratic method is such a nonlinear method.

The reason that creativity is not an intelligible idea in formal logic—Kant's argument—is readily illustrated by reference to the case of any scientific discovery of a new principle.

If the previous state of scientific belief is represented in a deductive way, there is no way that the new discovery can be represented as a deductive action in those terms of reference. A new deductive schema, representing scientific belief consistent with the discovered new knowledge, can be constructed; however, there is no deductive method by which the transition from the first to second deductive schema can be represented.

This is Kant's problem.

If we compare the two deductive schemas directly with one another, a crucial difference is exposed. There is a difference among one or more of the postulates of the two arrays. The act of creative thought is reflected in the form of the changes in postulates which have occurred.

That is the characteristic of the Socratic method. In that method, every proposition considered is driven to deeper and deeper levels of critical examination, until the axiomatic basis underlying the proposition is exposed. An inappropriate, or otherwise false postulate is exposed to light and the appropriate change in postulate effected. The correct proposition is then constructed on this new basis.

The two cases, the case of the deductive mathematical representation of two successive schemas and the alteration of underlying postulates of propositions in Socratic method, are equivalent. The changes so encountered, in both cases, cannot be made intelligible, or even represented directly, in deductive method; they have the form of a mathematical discontinuity. By definition, formal logic does not permit the construction of a continuous function which includes such a kind of discontinuity. This is Kant's problem.

For such cases, we require continuous "nonlinear" functions of a sort which exist only in the mathematical physics of Gauss, Dirichlet, Weierstrass, Riemann, et al. Consider as much explanation of this as bears directly on the scope of this article.

Like the physics thinking of Cusa, Leonardo, Kepler, and Leibniz, the physics of Gauss and Riemann is not based on the methods of deductive geometry or algebra. It is based on the method of constructive geometry. We may say, that it differs from earlier forms of synthetic geometry because it is the constructive geometry of the complex domain, rather than of visible space. However, although that statement is an accurate one, we must restate it differently, for our purposes here.

The difference is that the mathematics of visible space's (shadow) images is based upon multiply connected circular action, while Gauss-Riemann physical space-time is represented by a constructive geometry based upon multiply connected (conic) self-similar-spiral action. A doubly connected form of least action, in the latter case, immediately defines continuous functions which generate discontinuities without losing their quality of being continuous. Such functions are the minimal precondition for representing intelligibly notions corresponding to "creation" and "life" per se.

This implies immediately the question, where does the golden section fit within Gauss-Riemann physical space-time? The answer is elementary. To illustrate this in the simplest way, project the image of a cone's self-similar-spiral onto a flat surface, enclosing that spiral within a circle corresponding to the perimeter of the cone's base (Figure 6). Divide the circle into 12 equal sectors by radii. Then, observe how these radii divide the lengths of the spiral's arm, and also how the spiral arm divides the length of the radii. The divisions are those corresponding to the golden section.

Since creative mental activity, as typified by the generation and assimilation of fundamental scientific discovery, is the characteristic form of human mental activity to be considered in the design of cities, what we have identified as the principle of measurement for human physiology is also the principle of measurement for human psychology.

Why Keplerian Harmonics?

I have reported earlier that the design of the city is based upon Keplerian harmonics, with the qualification that we must employ the correction of Kepler's calculations supplied by Gauss-Riemann physics. Since nearly all university textbook and classroom instruction on the subject of Kepler's work is rather savagely incompetent, that matter must

be cleared up immediately, before indicating how Keplerian harmonics apply to the design of cities.

Kepler informs us that his solar hypothesis was built entirely around two central sets of notions, those of Cusa and those of Pacioli and Leonardo. The hypothesis around which the entirety of his work was organized was Cusa's solar hypothesis as amplified by the work of Pacioli and Leonardo to which I made reference above.

Whether Kepler had access to the relevant sermons of Cusa, as well as the works of Cusa printed for publication during the 15th century, I cannot say at present. He certainly knew very well the work of Archimedes to which Cusa referenced his own discovery of what we term today the isoperimetric theorem. In crucial parts of his construction of the solar system, Kepler worked as if he knew how Cusa had treated the problem stated by Archimedes' theorems on the quadrature of the circle as a maximum-minimum problem.

Kepler applied to Cusa's solar hypothesis the work and associated theological, cosmogonical standpoints represented (chiefly) in Pacioli's *De Divina Proportione*. Hence, the golden section was central in his work, and the role of the Platonic solids subsumed by the golden section. Kepler's system gives us nine orbits for the principal planets: four inner planets, four outer planets, and a ninth planetary orbit lying between the two sets.

Gravitation occurs in Kepler's astrophysics as a characteristic of the self-bounded character of the visual form of physical space-time. So, Kepler's laws implicitly state the mathematical function for universal gravitation, which he links to electromagnetism as defined by Gilbert's *De Magnete*. If we examine this feature of his physics from the standpoint of the later work of Gauss, Riemann, et al., Kepler's gravitation is not a force acting between physical bodies, but the physical effect of the geometry of least action in self-bounded physical space-time.

In other words, Kepler's space is not empty space, not mere distance between interacting bodies; it is not the space of Descartes, Newton, or Laplace. Kepler's space-time is an efficient agency. Indeed, looking at Kepler's con-

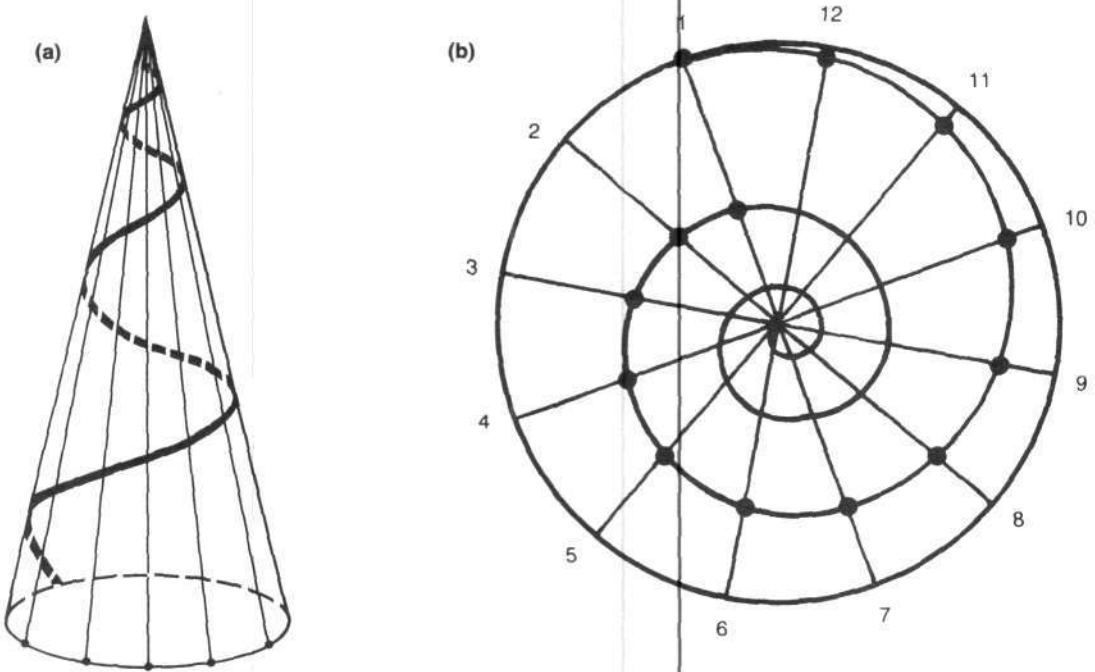


Figure 6

HOW THE GOLDEN SECTION FITS IN GAUSS-RIEMANN PHYSICAL SPACE

While visible space is based on multiply connected circular *action, Gauss-Riemann physical space-time is represented by multiply connected* conic *self-similar spiral action. The relationship of the two can be illustrated very simply by drawing a self-similar spiral (here one that grows by a factor of 2) on a cone (a) and then projecting that spiral down to a circle on a plane that corresponds to the perimeter of the base of the cone.*

If the circle is then divided into equal segments by 12 radii (b), the spiral will divide the length of the radii in accordance with the golden section. *For example, the length of the spiral arm from radius 12 to radius 3 is to the length of the arm from radius 3 to 7 and is to the length of the arm from 7 to 12 approximately as the golden section, ϕ. The radii from 12 to 3, 3 to 7, and 7 to 12 grow in the same proportion. Another way of putting this is that if the lengths of the first three radii are a, b, and c, respectively, then a/b: b/(a + b) : c/(b + c) = the golden section.*

If the 12 radii are thought of as the musical halftones, the intervals correspond to those between C and E-flat (minor third), E-flat and G (major third), and G and C-sharp (the fourth) or their musical inverses.

struction of his three laws with the eyes of Gauss or Riemann, there is no distinction among matter, space, and time in Kepler's physics. Matter is physical space-time. In that specific sense, but only that sense, we may say that space-time acts directly on matter. We continue to relate our references to Kepler's work as that work would be explained from the standpoint of a student of Gauss and Riemann.

All of the 17th and 18th century opponents of Kepler's methods and results were proven to be incompetent through the work of Gauss at approximately the beginning of the 19th century. Since these opponents of Kepler based the fundamental principles of their physics on the same premises used to attack Kepler, Gauss's proof showed not only that Kepler's physics was correct, relative to the erroneous arguments of Galileo, Descartes, and Newton; this proved also that the entire physics of Galileo, Descartes, and Newton was axiomatically wrong throughout.

The center of Gauss's empirical proof for Kepler, and against Galileo, Descartes, and Newton was the case of the asteroids' orbits.

Kepler had insisted that a planet had once existed between the orbits of Mars and Jupiter. Kepler had given both the location and harmonic orbital values for this planet. The fact that until the end of the 18th century, no rubble from a destroyed planet was found in such an orbit, was considered evidence of Kepler's error. Indeed, if it could have been proven that no planetary body had ever occupied that position, this would have shown a pervasive flaw in Kepler's work as a whole.

In each case, following the discovery of Pallas and Ceres, Gauss recognized that these were fragments of Kepler's missing planet. He used Kepler's orbital values for that planet to predict the next relevant appearance of each asteroid. This successful prediction vindicated the entirety of Kepler's work on principle; after that, there was no scientific basis for continuing to regard the work of Galileo, Descartes, and Newton as competent physics.

Thus, it was proven experimentally that our universe is not organized on the basis of "forces" through which bodies act upon one another at a distance. It was proven that our universe is not made up of separate qualities of matter, space, and time; only physical space-time exists, and to the effect that it must appear to our senses as if the geometry of empty space acted efficiently on ponderable, discrete bodies within it.

There are three features of Kepler's work which have the greatest relevance for the design of cities. (1) Although Kepler's calculations for orbits are not precisely accurate, his three laws are. These laws apply to the orbits of lunar bodies and to modern discoveries in astrophysics in other matters. Kepler's discoveries were all essentially sound, if imperfect ones, and his general hypothesis is correct. The Gauss-Riemann corrections in Kepler's physics point the way to refining the laws and the calculations. (2) Physical space-time is harmonically ordered according to a universal principle of least action, rather than organized by means of action-at-a-distance interactions through forces. The correct measurement of least action for visible space is the projection of Gauss-Riemann least action's effects upon the manifold of visible space. (3) The universe as a whole is *negentropic*, not *entropic*.

It is the last of the three points listed to which we turn our attention immediately.

All functions which have an harmonic ordering consistent with the golden section represent reflections of multiply connected self-similar-spiral action occurring in the domain of the complex manifold. These occur only in two kinds of cases within our universe. Either they are the products of action by living processes, or they represent least action as expressed at the extremes of astrophysics and microphysics.

All processes which are harmonically ordered in a way congruent with the golden section belong to a single class of phenomena. They are processes which statistical thermodynamics classes as "negentropic." Unfortunately, although we can explain, on the basis of Gauss's constructive geometric basis for probability, why such processes should appear to be "statistically negentropic," the usual statistical analysis of such processes is intrinsically an incompetent one.

Curiously, Isaac Newton was one of the first to warn of the incompetent results which result from attempting to explain fundamentals of physics from the deductive standpoint in mathematics, on which the statistical methods of Laplace, Boltzmann, et al., are based. The superimposition of a deductive mathematical schema upon the analysis of phenomena will seem to show that our universe is running down, in the sense of a mechanical timepiece. This fact, of which Newton warned the readers of his work, is the simplest, adequate definition of what statistical thermodynamics calls "entropy."

It is assumed, on such a statistical basis, that our universe is running down. It is widely assumed, that this is proceeding to such effect that the increase of the universe's entropy as a whole is both the direction and ultimate, natural measurement of the passage of time.

That assumption of "universal entropy" is directly contrary to the astrophysical evidence, as the construction of Kepler's three laws proves the case.

We must measure negentropy and entropy in a different way. We must discard deductive mathematics, statistical methods included. We must employ the only available alternative, constructive geometry. In the latter case, we have the following relevant results: (1) The sense of "negentropy" is supplied as processes undergoing harmonically ordered growth congruent with the golden section's ordering of the visible manifold. (2) This means that "negentropy" can be measured in terms of the increasing number of discontinuities generated by the continuing process of such harmonically ordered growth. Mathematically, this is expressed in the form of Cantor's transfinite functions as a harmonically ordered increase of the density of discontinuities within some arbitrarily small interval of action adopted as a unit of measurement. (3) This means that "entropy" must be measured as reversed "negentropy." As life is the paradigm of "negentropy," death and decomposition are the paradigm of entropy. Yet, entropy harmonically occurs in different geometric ordering than for negentropic processes.

That is sufficient description of the background to permit us to proceed to the matter of applications to the design of new cities.

Cities As 'Negentropy Machines'

Successful economic processes belong to the class of negentropic processes.

On first examination of its physical characteristics, a successful economic process is typified by a continuous process of increase of the combined quality and quantity of the standard market-basket of physical goods consumed per capita. This presumes a corresponding increase of output by the operatives producing these physical goods. It presumes technological progress causing such increases of the productive powers of labor and improvement of the varieties and qualities of products.

It is also an improved mastery of land area. This occurs to the effect that less land area per capita is required to sustain a population in a higher standard of living than the land area required to produce a relatively poorer standard of living at an earlier time.

So, the proper mathematical function in the science of physical economy is expressed in terms of rate of increase of the population's potential population density. This function is elaborated in terms of the set of constraints identified earlier. It is a "nonlinear," continuous function of the general form of a Riemann surface function.

Assume that a city satisfying this function's requirements has reached the limit of population growth built into that city's design. Let us consider the "equilibrium condition" so defined.

First, as to population. The fecundity remains constant, at the same rate after the population limit is reached, as earlier. So, the limit of population growth is expressed in terms of the number of households, and the number of persons limited only by the number of households comprising the total census of households. The "excess population" is deployed to populate new cities, including some on Mars.

Second, as to employment. The labor force is defined as a function of the total population of labor-force age. Of this, initially, on Earth, about half should be employed as operatives employed in production of household goods, producers' goods, or development, maintenance, and operation of basic economic infrastructure (transportation, water management, communications, production and distribution of energy supplies, and basic urban sanitation). About one-tenth or more are employed as scientists, engineers, in direct management of production as such, medical professionals, or in teaching of the young. Unemployed members of the labor force and persons in other occupations, combined, are kept within the limit of less than 40 percent of the total labor force, preferably less than 35 percent.

Within this composition of employment, several interrelated shifts occur as both the level and rate of technological progress are advanced. A smaller percentage is employed in production of households' goods, relative to growth in the ratio employed in the production of producers' goods. In production of producers' goods, there is increased emphasis on employment in the machine-tool class of production. The ratio of scientists and related professionals to the total size of the labor force rises. Gradually, there is a shift of employment from operatives' categories into science categories.

In social life. As technology advances, the average school-leaving age rises in the direction of equivalence to a terminal degree in physical sciences. As the working day is shortened, the leisure so generated is consumed largely in adult education; this is aimed significantly at upgrading the technological competencies of the labor force as a whole, but also for the enriched development of the character of the adult individual, through scientific "leisure hobbies" and participation in the life of classical forms of art, in addition to travel.

Hence, the "Sun" of our city is at the city's center, a complex of facilities for secondary and higher education, for conduct of classical fine art, and similar activities, situated in a park and garden zone in the center of the city. Knowledge in the form of science and fine art are the heart of the city, the driving force of the city's development. By affirming this in such a fashion, we make the development of the character of the citizen to the fullest of its potentials the mainspring of life within the city.

Such design of the city defines a knowledge-intensive society and knowledge-intensity as the driving force of the city's maintenance, growth, and economic as well as cultural development. The energy driving the city is produced in the outer orbit of the "outer planetary" region. This supply of energy is constantly increasing, per capita and per hectare, for the city as a whole. The effective energy-flux density with which this energy is applied to the target areas of work is also increasing. Yet, these energy supplies, their growth, and the shaping of their application, are always under the control of knowledge radiating from the city's "Sun."

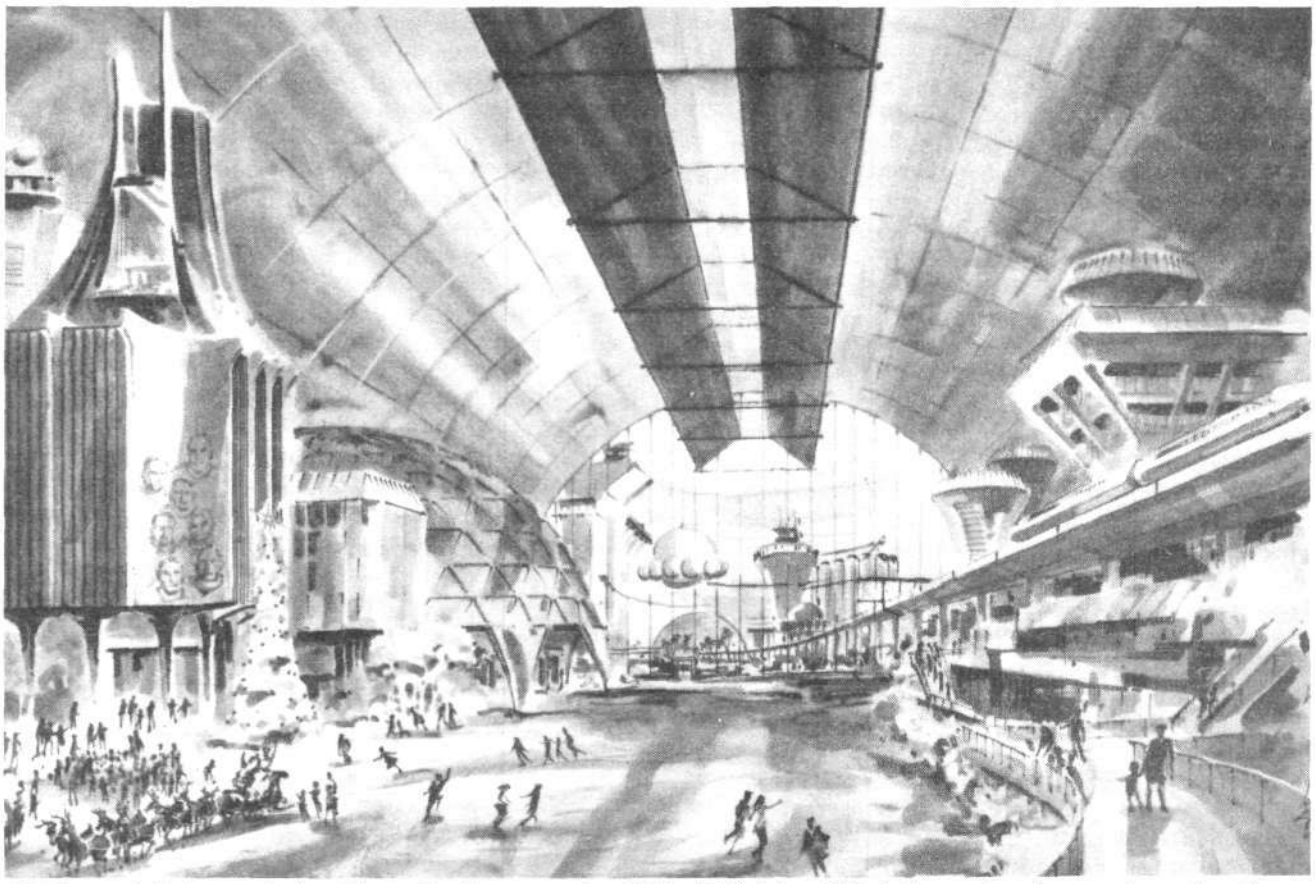
The administration and commercial functions of the city are most proximate to the central park. Here, the density of land usage, per capita unit of human activity, is at the highest, and the structures, correspondingly, generally the tallest.

As we move outward, the density of movement per square hectare attenuates harmonically.

Beyond the F to F-sharp orbit separating the inner from outer city, we reach first the orbit of densest land use by the labor force's productive activities. The three farther orbits each represent a less dense employment per unit of productive activities, including the power-generating complex for the city.

Beyond the last orbit, there is permanent agricultural, forest, and related uses of land, until the outer boundaries of the next city or township are encountered. No suburban sprawl is to be permitted, for ecological reasons as well as economic ones.

Agriculture is at the verge of a fundamental revolution, and the agricultural needs of permanent colonies on Mars will be a goad to more rapid advancement in this direction. The amount of agricultural product per hectare is about to increase by an order of magnitude, through methods which popular opinion today would, somewhat inaccurately, as-



"Christmas in Selenopolis," an illustration by space scientist Krafft Ehricke of life in the major urban center on the Moon. At left, the Hall of Astronauts; at right, an elevated monorail train; behind the transparent insulation are a nodal dome with supplies, life support, and climatizing equipment.

sociate with large, multistory "hydroponics" factories. The social system which has served the United States so well, family- and intra-family-operated entrepreneurial farming, should be protected and preserved, thus ensuring the best rate of improvement of quality of product, together with the highest rates of effective innovation.

Yet, we know that the maintenance of highly productive biomass, in the forms of crops, pasturage, water management, and well-managed woodlands, is essential to maintaining the general environment. The best way in which to accomplish this is to entrust this work to entrepreneurial farmers, counting this maintenance of cultivated farm, pasture, and forest land as part of the necessary cost of agricultural production as a whole.

It must be our object to break the pattern of suburban sprawl, driven only by speculative gains, which is destroying so much of the land area of the United States today. We can effect all the qualities of beauty, privacy, and function, which might be sought through modes of surburban sprawl, in well-designed new cities, designed to remain viable for up to a thousand years or more. The initial investment per cubic meter of volume of dwelling constructed will be much higher (at first), but the average annual cost of possession, in terms of maintenance and amortization combined, will be much less.

The judicious channeling of very low cost public credit, loaned through the banking system and governmental capital improvements agencies and authorities, will make this change in construction policy feasible. The accelerated demand for the new types of materials and other products used for such construction will expand the turnover and investment rates in such industries to the point of fostering a rapid rate of technological advancement in those industries. This increase in productivity, in a large sector of the economy as a whole, will rapidly lower the effective average physical costs of construction, for the city-building and kindred programs as a whole; the expansion of investment in advanced technologies in that sector will spill over into the economy more generally. Within less than a generation, perhaps, the costs of housing and other construction for new cities' designs will fall to levels of per capita social cost below those of today.

The heaviest increment of cost in the building of the city will be the emphasis upon building the deep substructure first, and then putting the upper portion of the city upon that prepared substructure. This is the cheapest way of building the substructure of a city. With the proper designs and use of the proper materials, this substructure will be cheaper to maintain, and to improve technologically, than present alternatives. The cost of amortization and maintenance of this substructural investment will drop to below that of what is now considered a conventional city.

The utilities built into the city will last for centuries, and will be cheap to maintain for per capita unit of activity which those utilities support. The savings in movements of persons and goods will be greater than the apparent added initial costs of amortization of the investment, with none of the costs which the cities and their inhabitants of today endure in the forms of street traffic congestion, pollution, time delays, and costs.

It is not necessary, in this location, to detail the technologies involved in building the city. We know that such things can be done with technologies existing or in sight today. It is sufficient to supply the architects and their fellow professionals the set of criteria to be met, and leave it to such professionals to do what they do best.

We know, with a fair degree of certainty, the general nature of the scientific advances likely to occur during the next hundred years. A glance at some of the leading facts this involves, guides our attention to those principles which show why our new city should endure in its original design for a thousand years, or perhaps even two or more thousand.

For the coming 50 years, inorganic physics will be dominated by the development of controlled thermonuclear fusion as mankind's new energy source, and by increasing use of the technologies of *nonlinear* electromagnetic radiation. During the first half of the next century, the new levels of technology will be associated with per capita increases in energy consumption by up to 1,000 times that of today: space colonization will write "terawatts" for power units, where the largest power-producing units today measure output in "gigawatts." Technologies of production will increase the energy-flux density of process applications to the levels of coherent gamma-ray pulses, and coherent particle beam radiation in the direction shown by the free electron laser: effective energy-flux density will increase more rapidly than the quantity of energy consumed per capita.

For thousands of years to come, biological science will be dominated by the now emerging new science of optical biophysics. By the middle of the next century, mankind shall leap beyond the limitations of fusion energy, to more powerful technologies based upon what are now termed matter/antimatter reactions. Gigantic radio telescopes, many miles in diameter of effective aperture, placed in or near the orbit of Mars during the middle of the coming century, will enable astrophysicists to explore the most anomalous astronomical objects within our galaxy and beyond, and to assist thus in proving the discovery of new physical principles, previously unknown to physical science.

Powerful fusion engines will enable mankind to reach any destination within the region of the inner planets within days of flight. However, even the extraordinary efficiency of fusion power involves a delimiting factor of fuel load on spacecraft.

Special tricks would permit limited forms of manned exploratory flight into the region of the outer planets, and development of deeper space terminals based on the logistics of the Mars colony would assist the exploration of the outer region of the solar system. Yet, manned deep-space flights beyond the solar system must wait upon the development of a more powerful, more efficient propulsion system. The mastery of what we call the matter/antimatter reaction is the visible pathway for developing techniques for deeper space explorations.

So, the next 100 years' technological progress can be summed up as shaped by two successive singularities in the continuous development of improved "energy technologies." This implies, as I stress now, that there exists a *nonlinear* continuous function, through aid of which we can project, beyond a third and a fourth singularity, into hundreds of years yet to come, and might do this with as much accuracy as would be of any practical use to us in the coming decades' planning of the design of new cities to be built within our solar system.

With that in view, one can return attention now to the subject matter of foreseeable changes in the life of our new city, as a result of such technological progress.

We know two things:

(1) We know that the definition of man, as man is properly defined by knowledge up to the present time, will not change. Through aid of optical biophysics' mastery of the spectroscopy of the mitotic process, we will be enabled to improve greatly the maintenance and repair of the human organism, to control the aging of tissue to significant degree, as well as achieving early conquest of cancer and the most challenging kinds of viral infections. The increase of mean life expectancies to the age of 120 years or more, and kindred extension of the upper age limit for defining the active labor force, are likely changes. However, no foreseeable change would change the required mean free-pathway of the motions of human beings. The nuclear family household must persist, unchanged, for thousands of years to come.

For such reasons, the spatial organization of the new city need not be changed from those specifications of spatial organization which are optimal for today's technologies.

(2) Currently developed levels of knowledge in the Leibnizian science of physical economy enable us to foresee how the foreseeable directions of advance in technology will introduce modifications of technologies integral to the functioning of the city as such. The six constraints, cited above, for the LaRouche-Riemann function in physical economy, permit us to foresee these changes with as much accuracy as is required for the design of the new city.

Essentially, the spatial requirements of organization of the city will not change. What will change is the per capita (and per square meter and per cubic meter) quantity of energy consumed and the effective energy-flux density of the use of that flow of energy supplies.

Think of the spatial structure of the new city as the basic structure of a machine. This does not change. Think of the changes introduced as analogous to alterations of the tools developed for attachment to that machine, in company with rather continual increases in energy flows into the machine as a whole.

All of the changes will take the form of a combined, interdependent increase of energy density and energy-flux density per cubic meter in the volume of structure represented by the new city as a unified machine for living.

In designing the new city today, the architects must think

clearly of both the kinds of modifications to be introduced to the city's spatial organization of structure over the coming centuries, and think also of how we can ensure that the needed kinds of improvements in energy and energy-flux densities can be installed with the least time and effort.

Consider again some things that will not change. The physical-geometrical function of a chair, a bed, a table, and of personal "space for mean-free-action" by persons, in all functions, will not change. The amount of fresh water required will not exceed the proper design limits specified for a new city today, even though there may be qualitative changes in the technology of fresh water management. The amount of air required will not change, although cleaner air will be achieved by aid of qualitative changes in technologies.

Within the city, and in travel to nearby population centers, a maximum speed of about 300 miles per hour, achievable with magnetic levitation, will remain acceptable specification for generations yet to come. It is probably the case, especially on Mars but also probably on Earth, that supersonic or even hypersonic speeds of continental travel of pressurized cabins through long reaches of evacuated, subsurface tube may appear during the next century. This will not affect the internal and nearby requirements for the new city itself.

The spatial design impact of the changes is foreseeable. Today's architects must simply leave room for installation of such changes within initial structures, and must provide the ready access needed for effecting such installations with the relatively greatest economy of labor.

The harmonics of the design will never change. What will change is the level and rate of increase of effective negentropy, per capita and per cubic meter.

A Beautiful City

The general requirement must be that wherever each function of human activity is to be served, the form of design employed shall be the principle of harmonic ordering congruent with the golden section.

This includes the proportions of rooms, the relative scales of the rooms of a dwelling place, the relations of windows to room sizes, and everything else blended into a harmonic unity. Here, the architect must become at once a composer of classical polyphony, a painter with the informed eye of a Leonardo, a Raphael, a Rembrandt, and a physicist in the spirit of Kepler.

Such harmonic composition will coincide with the optimal agreement with the physiology of human least action. It will provide the optimal acoustics, the optimal distribution of light, of air movement, and so forth. The physiological requirements, so addressed, are consistent with the psychological ones.

Contrary to the cults of Romanticism and Modernism which have spoiled our great Western European tradition of classical art, nothing is beautiful unless it is consistent with harmonic orderings based on the golden section. Such is the beauty inherent in all living animals and plant life. Art must emulate the principle of life on this account, but it is not art unless it does something more than that.

The composer of classical fine art must start with principles of beauty, and must never conclude with any result which is not congruent with beauty. Yet, this defines the character of the particular medium in which the artist works; it does not suffice to define the stirring of that medium of beauty as art. Art is not a business of selecting by mere intuition those random stirrings of the medium seen to have the pleasing quality of beauty.

Beautiful art is art because it is composed by an accomplished artist. What defines such a composer of art is the exact same mental quality which defines the accomplished scientific discoverer: the development of the composer's creative powers of mind, together with the composer's moral character. The composer of great art works in the medium of beautiful harmonic orderings as the scientific discoverer works in his or her medium. The same powers of mind, perfected to such work in the one medium or the other, are at work.

It is this creative endeavor, in the medium of beauty, which defines great art.

For that reason, the general quality which all great art shares in common, in whatever artistic medium, is that it contains nothing not fully susceptible of intelligible representation, as I have identified "intelligible representation" above. Furthermore, the entire composition is itself susceptible of such intelligible representation, to such effect that the uniquely creative features of the development of the composition are the kernel of the artistic idea.

There is never anything arbitrary, "Romantic," in classical art. It is always delimited by the principles of harmonics associated with the golden section in visual space, and perfect well-tempering in classical musical composition. No principle contrary to that definition of classical beauty, no deductive sort of arithmetic principle (for example, the 12-tone system of the musical "modernists"), must be tolerated. The "idea" associated with classical art is never akin to what we encounter so often in the Romanticist "program notes" of the concert program, record jacket, or art exhibition. The idea of a classical artistic composition is the elaboration of the specifically creative feature of the composition's development.

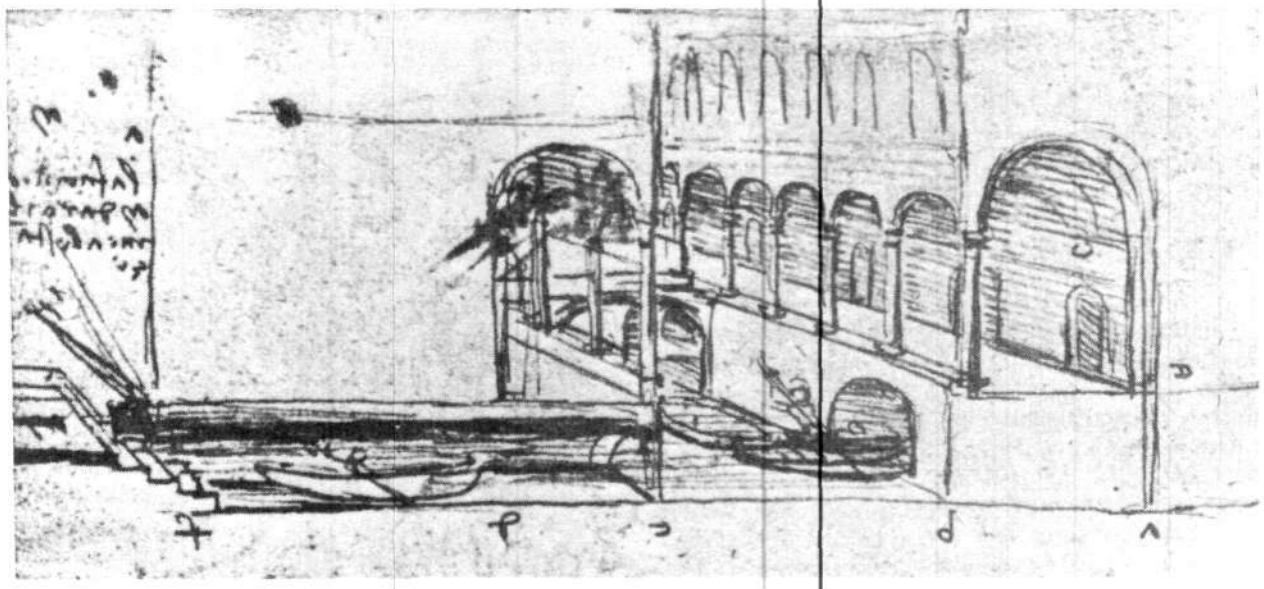
A great architect, like a great classical painter—such as Leonardo or Raphael—is thus a professional who might have become a great musical composer or performer, who applies the same intelligible creative principles to a different medium. The architect's medium is the humanistic science of physical economy expressed as art, governed by the same principles as great classical art.

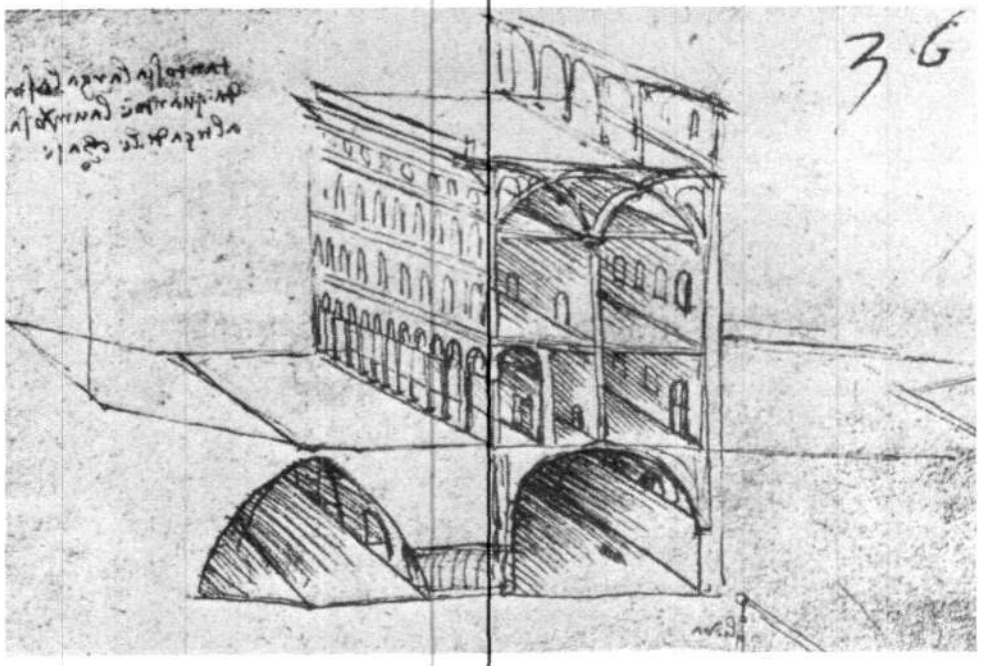
We must free ourselves of the heritage of both Kant's *Critique of Judgment* and the evil Prof. Karl Savigny's arbitrary, irrationalist separation of science (*Naturwissenschaft*) from the arts (*Geisteswissenschaft*). This means, inclusively, that in architecture, there is no proper distinction between "art" and "function." It means, as I have stressed throughout this article, that the principles of classical artistic composition are always in implicit agreement with the best solution to a problem of function, so much so that wherever a purported functional design deviates from the rigorous standards for classical beauty in artistic composition, the deviation represents an elementary error in the principles of functional design adopted.

All architecture is a machine for use by human beings. It must agree with the requirements of the whole human being. This wholeness is expressed by human activity in its wholeness. All human activity is activity directed by the self-developmental characteristics peculiar to the human mind. As I have shown as a matter of principles, both the physiology of individual mean-free-pathway least action, and the characteristic human creative mental activity are forms harmonically ordered in congruence with the golden section in visual space. That architecture which is defective as classical art, is therefore also defective in function.

Reference Johannes Kepler's famous dissertation on the subject of the snowflake. Focus, within that paper, on the discussion of the constructions by the bees, constructions which are excellent for bees but not for human beings. The construction is not harmonically ordered in congruence with the golden section. This case illustrates an absolute separation in principle of architecture for lower forms of life and for humanity.

The most sensitive architects and students of classical painting are more notably aware of the fact that the experiencing of the visual space in which persons' activity occurs has an important psychological effect upon the persons experiencing that organized space. Leonardo and Raphael are of outstanding importance in any systematic study of this matter, particularly so because their own recognition and use of this principle is so directly, immediately situated with respect to the underlying principles involved.





These two urban designs by Leonardo da Vinci show towns with a two-level construction. The lower level of the houses would be accessible by a network of canals, allowing complete separation of services and utilities from the living activities above ground. The drawings are from the Institut de France, manuscript B (folio 36).

In the experiencing of the organization of visual space, our minds draw upon the same kinds of powers of judgment we experience in the beauty of well-performed classical polyphony. Today, because of important researches into the organization of the relationship between the eye and the visual cortex of which it is functionally an integral part, we can understand the validity of Leonardo's principles of hemispherical perspective in a refined way. Although, to the extent of my present knowledge, the study of the acoustical functions of the brain are less well mapped than those for the visual cortex, we know that Riemann's approach to the physiology of hearing was sound on principle; and, from knowledge of well-tempered polyphony, we know that the principles adduced for vision are congruent with those for the sense of beauty in hearing.

So, we know that the same principles of creative composition expressed by such as Bach, Mozart, Beethoven, Schubert, Chopin, Schumann, Verdi, and Brahms—although not those of Romantics such as Liszt and Wagner—express in a musical medium the same underlying, proper principles of a great architectural composition. We should speak, without a sense that we might be indulging ourselves with mere metaphor or even hyperbole, of architects as composers. We should say this with an eye cast directly toward Leonardo and Raphael, but also with a sense that the musical reference is not merely analogy.

The standard should be: "intelligible representation of a beautifully artistic fulfillment of nothing but the functional purpose of the construction." The architect must start with function. By applying "Keplerian" harmonics to the understanding of that human function as an integrated whole, the problem to be solved, function, is stated also, and by no accident, in precisely the form which transforms a science of architecture into a practice of classical artistic composition, without moving one millimeter from science.

The creative solution is always in response to a problem posed in terms of satisfying the need of a human function, rather than decoration superimposed, as a kind of flamboyance, upon the structural "cake." No arbitrary sort of "pleasing effect" is to be sought as mere decoration.

Since the architect is a human being, as the great classical composer is a musician, the architect designs by aid of traveling in his imagination through each mean-free-pathway activity of the persons inhabiting the city. He visualizes, in this imagination, using each part of the city for one or another of the functions of which the totality of their lives are each composed. He does this with a refined eye, doing from his more advanced standpoint in professional knowledge, more or less what I first learned to do in economic science standing, still at the age of 15, at the dinker's bench in that slipper factory.

The principles of beautiful harmonics he carries with him on this tour of the imagination, thinking of these principles not so much as ideas of beauty but rather in terms of the harmonics of least-action movements of human individuals. The examination of each of the movements along this tour from the standpoint of golden section harmonics defines for him an array of problems in geometric topology. The summation of these problems is the total problem of this same form, the topology of the city as an integrated whole.

So, the composition of architectural design occurs in such a way that it could be explained entirely as creative solution to the functional problem of topology so defined. It could be provided an accurate intelligible representation so.

Nonetheless, the result is a classical artistic composition in the strictest sense.

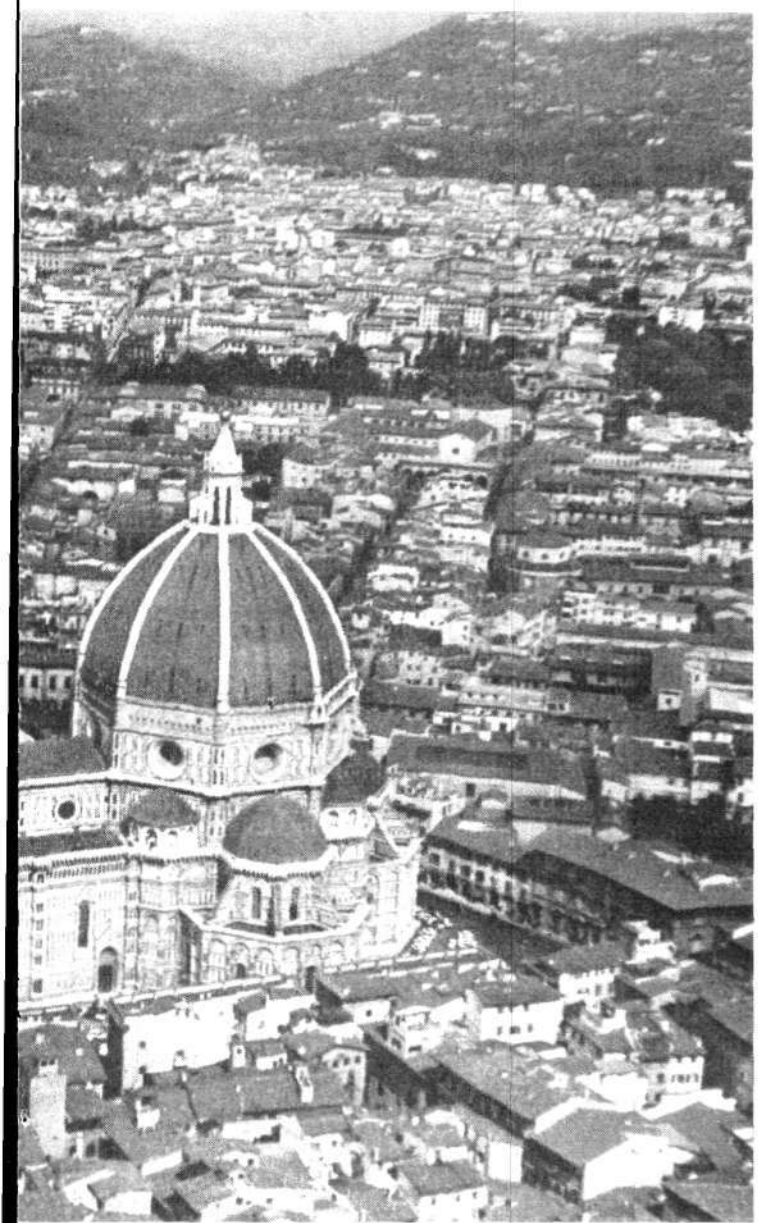
The successful solution to the topological problem of ordering human least action, will always be a "Keplerian" kind of harmonic ordering, with the included types of qual-

"Brunelleschi's successful invention in architecture, completing the construction of the dome on the cathedral at Florence, was a signal point of reference throughout the 15th century." Here, the dome as it appears today.

ifications I have noted earlier in this report. The optimal result will seem to borrow from classical strophic forms of poetry, as does classical musical composition. Every human movement within the city will have a characteristic harmonic value in a "Keplerian" system; the idealized, least-action form of movement facilitated by the design is susceptible of being stated in terms of "Keplerian" harmonics.

Consequently, the coherence of design, incorporating all of the topological solutions included, can be expressed in the manner of classical musical composition. This is more or less the same as to say that we can represent the composition of major paintings by Leonardo and Raphael in terms of principles of classical musical composition.

The architect intrudes personally, as a classical artist, into the composition as a whole—puts the artist's signature on the composition—by the way in which he elaborates the composition as a whole.



The most famous case of this from classical music is the history of compositions based on treatment of a collaboration between Frederick the Great and Johann Sebastian Bach, "The Musical Offering." This represents a solution to a central problem in well-tempered polyphony, a solution which played a leading role within the later development of classical composition.

Major composers based some of their outstanding works on this: Mozart, Beethoven, Schubert, and Chopin, for example. A few examples from this history are sufficient to illustrate the point I have made on the architect's personal artistic signature on a design.

Mozart's intensive study of Bach's method of composition is reflected most strongly among compositions presented beginning 1783. He took up Bach's "Musical Offering" discovery directly in his famous keyboard sonata, K. 457. Then, he improves greatly upon Bach's discovery in his "Dissonant" quartet, and sums up that result in the Fantasy (K. 475), which he prefixed to the sonata K. 457 (Figure 7). Mozart's principal musical-scientific advancement beyond Bach, on this point, is his introduction of the "Keplerian" F-sharp, omitted in Bach's treatment and in his own K. 457. The implications of this F-sharp addition shaped the treatment of this Bach subject by later classical composers.

Mozart's advancement in treatment of this appears famously in Beethoven's "Pathétique" fortepiano sonata and in other works, including his last fortepiano sonata, Opus 111. The Opus 111, in turn, supplied Chopin the reference point for his "Funeral March" sonata. Schubert's posthumously published C-minor fortepiano sonata is another treatment of the same subject.

From the standpoint of the topology of a "Keplerian" harmonic domain, the subject to which each composer addressed himself was the same musical-scientific problem. Yet, each introduced different sets of consideration in musical-scientific knowledge to the treatment of the subject. The compositions each differed thus, not only from those of other composers, but from the same composer's other settings of the same subject.

The most immediate difference among these compositions is shown by comparing the K. 475 with the K. 457 to which Mozart prefixed it, or between Beethoven's "Pathétique" and his Opus 111. There is, in these compared cases, a different choice of pathway of development. So, in those indicated cases, as in the others which might be cited, the creative mental activity, although applied to the same general subject, was elaborated along a different pathway, to the effect that each of the compositions represents a unique sort of constructive geometric intelligibility.

The architect's imbuing artistic coherence into the raw form of solution of the topological problem is in no sense "mere decoration." The mind of the city's inhabitant requires that the city as a whole have the quality of intelligible coherence.

The human individual has, from birth, a double character. In the one aspect, the newborn infant is like a beast, seemingly controlled by what British philosophical liberalism denotes by "original and immediate instincts," as Adam Smith puts it, for "seeking of [sensual] pleasure, and avoid-

Renaissance Architecture and the Golden Section

"Wherever each function of human activity is to be served, the form of design employed shall be the principle of harmonic ordering congruent with the golden section."

Here, the temple that forms the backdrop of Raphael's painting "The Marriage of the Virgin," signed and dated 1504, when the artist was only 21 years old.

The composition is based on the octave, the 2:1 ratio that is the first ratio of the Fibonacci series, a series that rapidly converges on the golden section. This ratio is given by the rectangle in the building, as defined clearly across its short side by the placement of the artist's signature, which is a 2:1 rectangle. All the other rectangles of the structure are related closely to this proportion, which, by its repetition, gives the sense of self-similarity.

As seen in the projection, the building as a whole is divided by this same octave ratio, with the cornice of the bottom story rising from the platform the same distance as the height of the upper story up to the springing of the dome. Likewise, the height of the dome (as a ratio on the surface of the painting) is equal to the height of the steps that lead to the platform, giving another "octave" between the lower story plus the steps, and the upper story plus the dome.

Throughout the Renaissance period, architects calculated the visual effect of their creations as seen in projection, which makes our observations based on the linear surface ratios perfectly legitimate. The height of the painting is also divided into octaves, as the imaginary line separating the architecture from the group of figures occurs exactly halfway up.

The ratios of 2:1, 3:2, 5:3, and so forth, converging on the golden section, were always employed by Leonardo da Vinci to create the outer boundaries and major internal divisions of his paintings. The most famous example, "The Last Supper," begins from the 2:1 ratio, which defines the rectangle of the picture as a whole. The architect Bramante, a close friend of both Raphael and Leonardo, built a small, two-story circular monument known as the "Tempietto" in Rome in 1501, which also pivoted around this octave ratio. It is often compared to Raphael's 16-sided building in this picture, and ranks as one of the few creations of the High Renaissance architectural style that was not only conceived, but actually built.

—Nora Hamerman

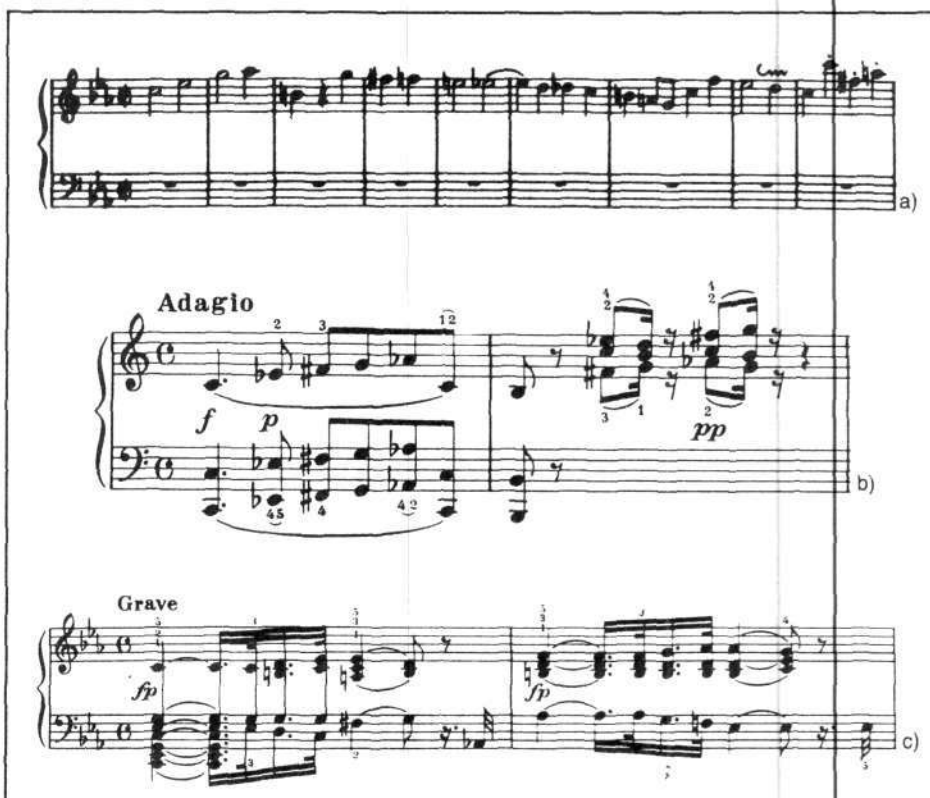


Figure 7
KEPLERIAN SOLUTIONS IN MUSICAL COMPOSITIONS

The harmonic ordering that characterizes a successful solution to a topological problem in architectural design is the same as that for solving problems in musical composition. The three examples here demonstrate a problem in well-tempered polyphony and its harmonic solution by Bach, Mozart, and Beethoven. Mozart took up Bach's "Musical Offering" (a), and used a Keplerian F-sharp to shape his treatment of the theme in his Fantasia K. 475 (b). The implications of Mozart's added F-sharp were then developed in Beethoven's "Pathétique" fortepiano sonata (c).

ance of pain." The emotional correlative of this in the child and adult, is what we associate with the erotic impulse—something which explains Sigmund Freud, but which Freud is incapable of comprehending except in a perverted way. Yet, that same child or adult has a directly opposing character, associated with an opposing quality of emotion, designated in classical Greek by *agapē*—love of God, love of mankind, love of beauty, and love of truth.

The development of the individual character requires that the person become conscious of the distinction between the two qualities of experienced emotion, strengthen the *agapic*, and subordinate the erotic impulse entirely to those restricted occupations in which it is deployed under firm control of the *agapic*.

This *agapic* emotion is easily recognized in a child at constructive play. When that child discovers for the first time a solution to a type of problem, the normal child is elated. "A light seems to turn on inside the mind of that elated child." Insightful adults observing this may find themselves close to "tears of joy." In contrast, the child, instead of solving the problem in, for example, block building, may strike angrily at this construction, scattering the blocks in his rage; that is erotic.

All creative mental activity is not merely associated with the *agapic* quality of emotion, but is energized by that emotional force, without which the "mind would turn off" and the solution not be discovered. Contrary to some mystical speculations, the *agapic* emotion does not occur without a task orientation in reality—although the erotic often does. It is a task orientation associated with ideas of love of God, of truth, of beauty, and of mankind, which evokes this higher quality of emotion within us.

To produce a citizenry which is capable of greater use of these creative mental potentials, it is urgent to create a physical space-time for them in which the dominant ideas expressed by human activity are those in agreement with the *agapic* force.

At this point, I can report without further argument of the point that the *agapic* corresponds to the negentropic, and the erotic to the entropic. The city must be a visual space, so composed as to envelop the activities of its residents in a sense of artistic beauty. It achieves this not by decoration, but by means of beautiful solutions to topological problems of essential functions.

A citizenry should have the means to speak only beautifully literate prose and poetry, as Dante Alighieri famously argues the importance of this. It should be subjected to nothing musical but the mastery of beautiful music. It should be surrounded with inspiring scientific and historical knowledge. The character of its young should be nurtured to the highest level of youthful potentials, by a classical-scientific, nonspecialized secondary education along the lines outlined by Wilhelm von Humboldt. It should be imbued with familiarity of principles of beautiful artistic composition in visual space and should be enveloped visually in such beauty.

The physical cause for the effect known as man's increase of society's potential population density, and for the accompanying increase of the productive powers of labor, is *"purely psychological"*: It is the production of advances in ideas in a way consistent with scientific and technological progress. It is the manner in which such progress in ideas

reshapes human practice that the power to perpetuate human existence is derived. Whatever increases the development of the individual character, such that *agapē* and scientific creativity are fostered, is the greatest force which society might summon to solve all the so-called practical, physical problems of life.

Nothing could be greater folly than to act on the assumption that *agapic* beauty is not essential to architecture, but merely spiritual, psychological. How could man exist without command of that within himself on which the existence of society depends absolutely?

Artistic beauty, thus deployed, enriches the mental powers of the population, fosters the strengthening of the *agapic* quality in human relations, and adds greatly to the strength of the city as a negentropic machine for promotion of advancement in the quality of human existence.

A Sense of Purpose

A city must not degenerate into a mere place for living and working. A city's existence must be ennobled by a higher purpose, as President Charles de Gaulle sought to uplift the French citizenry from cattle-like chewing of its own national cud, to a sense of France's unique purpose in service of the cause of civilization. Back to Cusa's *De Docta Ignorantia*: The city is a microcosm, which must consciously locate the meaningful purpose of its existence in the macrocosm.

Among all new cities, a citizen, asked what the city does, would respond automatically to the general effect, "We are essential for making the world and mankind better." The products of the city enrich the nation and the world. The citizen's contribution to the city's contribution, to the nation and civilization generally, imbues the simplest of his or her contributions with the moral and efficient qualities of universality.

We wish that no person be homogenized by a city. We must impart the sense of the worth of individual, personal uniqueness in service of the universal, durable good. The citizen must have sound grounds to say, "I am unique, and I exist so because the general good needs the service of my uniqueness." This uniqueness is practically situated, not an arbitrary choice of "being different." There is always another task to be undertaken in the work of perfecting service to the good; there is always needed yet another person, peculiarly suited by commitment and development, to master the work of serving that unique, added need. What if that particular sort of work were no longer needed? The citizen would reply, "Then I should find something which required my unique dedication to service of the good."

The image of the working scientific seminar is a useful one in further clarification of this point. In general, true scientific workers assemble in such seminars, not so often for a previously well-defined task; more often, the best practical results emerge simply from assembly to the vaguely defined common sense of sharing contributions to whatever useful purpose this process of sharing might itself suggest. The right quality of such seminars is recognized among all accomplished scientific workers—at least, that is generally so. The exchange of published scientific papers approximates such seminars in some degree, but there is no adequate replacement for what such seminars contribute.

In the most fruitful seminars, what is exchanged is a discussion of preliminary experimental hypotheses. Finished results are brought in as they bear upon this; but it is the discussion of preliminary hypotheses which is the most essential activity. The presentation of completed work, or work in progress, is usually the means for sparking the discussions; it is the discussions themselves, often moving in directions not anticipated by any among the participants beforehand, which are often the most notable benefit.

Unfortunately, in academic liberal arts today, one finds nothing comparable to the quality of such scientific seminars. In academic liberal arts today, there is no rigorous principle of reasoning comparable to that in serious scientific work, and few trained in the liberal arts' professions are willing to tolerate the attempt to introduce Socratic standards of rigor into the deliberative process. The new city must be designed to foster a change in that and to spread the benefits of such change into the habits of exchanges of ideas among the citizenry generally.

The work of each and all of the citizens of the city must be integrated in a fashion akin to that of working scientists from various specialties attacking the problems of a common subject of interest in the most productive sorts of scientific seminars. This is another way of saying that the *agapic* mood must rule: love of God, of truth rigorously sought and served, of mankind, and of beauty, is the shared motivation which binds social relations at higher levels of quality and which thus fosters true freedom: the commitment to serving the common *agapic* purpose in one's own best way.

I do not recall a case of a friendly, serious exchange with any person along such lines from which I did not benefit in useful knowledge. Like my adolescent experience with the dinker's bench, there is nothing useful from which something of value is not to be learned, sometimes with beneficial results far beyond what the circumstances might initially suggest. I love and treasure the uniqueness of each individual person when the uniqueness is located in such a way.

That is the proper general mood and sense of social values in the new cities I wish to promote.

Do we wish to assemble forces for mastery of some important scientific problem? Build a new city with dedication to that and to future related sorts of tasks. For each other sort of important kind of purpose in service of the nation and humanity, build such a new city dedicated to that kind of work. Build new cities so to uplift the quality and pride of entire nations, entire regions of this planet. We shall build new cities on Mars around precisely such conceptions of function and purpose. Now, therefore, let us begin to design and build.

Lyndon LaRouche recently authored a videotape, "The Woman on Mars," which presents a 40-year plan for colonizing Mars and the beneficial effects that such a mission will have here on Earth. A version of this article appeared in the Executive Intelligence Review, *Sept. 11, 1987.*

Jacob Steiner's Legacy

A Synthetic Geometry Curriculum for All Ages

How can we develop genius in children? Teach them to think geometrically.

by Robert Gallagher

If the recent surveys documenting the scientific illiteracy of American youth have you worried, this constructive geometry curriculum developed by Jacob Steiner in the 19th century provides an antidote. American science and mathematics education has see-sawed over the past 50 or more years from the so-called basics to New Math and now back to basics, but the underlying problem has remained constant: a methodology based on rote learning of facts and formulas and logic chopping. Even the excitement of the space program, which sparked a kind of renaissance in science education and student performance, failed to correct the underlying problem of pedagogy.

Steiner and his collaborators faced a similar situation in 19th century Prussia: a drill-and-grill method of education that was producing generations of nonthinking citizens. Their solution centered on Steiner's synthetic geometry curriculum, which used the simple laboratory tools of paper, pencil, compass, and ruler—but which produced a generation of creative scientists in the tradition of Bernhard Riemann.

A beginning curriculum in synthetic geometry, based on Steiner's approach, is presented here.

INTRODUCTION

The great Swiss geometer Jacob Steiner (1796-1863) led a revolution in the teaching of geometry and science in Prussia early in the 19th century, as part of the education reform movement initiated by J. G. Fichte, Baron vom Stein, and Prussian Education Minister Wilhelm von Humboldt. The reformers targeted the stuffy Prussian academic establishment and overthrew its prevailing reactionary teaching practices that emphasized memorization—"drill and grill." Instead, the reformers promoted a program for the many-sided development of the cognitive powers of the student via the Socratic method of instruction. The leading feature of the new approach was the teaching of "synthetic geometry" as a language for concept formation, distinct from verbal language per se. Synthetic geometry is based on demonstration by construction rather than deductive "proof."

With his fresh outlook, Steiner also produced a grand synthesis of all the work of geometry and mathematics up to his time, under a unified conception of human creative mentation. The impact of his work swept across the European continent like a tidal wave, reverberating in the labors of Bernhard Riemann, Georg Cantor, Ludwig Prandtl, and many others. When Steiner died, Ludwig Crelle's *Journal for Pure and Applied Mathematics* praised him as "the greatest geometer of his time."

The Swiss Steiner came to prosper in Berlin only because of the educational reform movement launched by Fichte after Prussia's devastating defeat by Napoleon's armies in 1806. The reformers argued that the soldiers of the Prussian army turned and ran when the fighting started because they had no conception of what they were fighting for, and that this was the underlying cause of the defeat. The reformers went to the heart of the matter: *It is necessary to teach our citizens how to think*. They called for introducing into Prussia the Socratic teaching methods of the Swiss educational reformer Johann Heinrich Pestalozzi in order to instill patriotism in the citizens of the next generation.

Their reasoning was that if the student can be guided to experience the creative power of his own mind, he will appreciate the value of a republic and the need to defend its freedom. Fichte went so far as to say that applying Pestalozzi's pedagogical principles would "awaken the civic and military spirit of the nation" and that it was "the only possible means of saving German independence." All of these goals were anathema to G.W.F. Hegel, who was entrusted by the Vienna powers to use his influence in education to suppress republicans across the continent. Pestalozzi's followers became Hegel's chief opponents.

The Pestalozzi Method

Pestalozzi placed emphasis on bringing out the capabilities of the individual student through instruction in synthetic geometry. "All knowledge is to be earned, discovered, produced by the student himself; the teacher is only to guide the independently thinking student in the right direction," wrote the mathematician and educator Felix Klein on the Pestalozzi method. To guide the students, the teacher asks questions in order to promote their reflection on a problem in precisely the same way that Socrates uses this method in the *Meno* dialogue to lead a slave boy to discover the solution of the Pythagorean theorem. Pestalozzi wrote:

> Ignorance is better than knowledge that is but prejudice, a glass through which to view the world. To arrive at knowledge slowly, by one's own experience, is better than to learn by rote, in a hurry, facts that other people know, and then, glutted with words, to lose one's own free, observant and inquisitive ability to study. . . .
>
> The higher purpose of education is to prepare the individual to make free and self-reliant use of all the faculties with which the Creator has endowed him, and then to direct these faculties that they may perfect all human life.

Fichte, Vom Stein, and Humboldt sent many of their followers to Pestalozzi's institute in Yverdun, Switzerland, to master his method. In addition, some of Pestalozzi's own assistants emigrated to Prussia to join in the reform movement, working at its centers in Berlin at the Cauer and Plamann educational institutes and the Friedrichs Werder trade school, all established by disciples of Pestalozzi and Fichte.

Into the middle of this reform movement in Switzerland and Prussia walked Jacob Steiner at age 18. The young Swiss farmer had finally got the support he required for beginning his formal education at Pestalozzi's Yverdun academy in 1814. Felix Eberty, whom Steiner later tutored at the Cauer Institute, described how Steiner displayed his inherent aptitude for thinking in the language of synthetic geometry when he was a student with Pestalozzi:

> That he already as a youth saw eight triangles, where the teacher had asked for only one, is, so to speak, a typical example of his method. His mind possessed with respect to geometrical propositions, one might say, a kaleidoscopic power. The simplest one shaped itself before his inner eye into a many-sided harmonic vision. One hexagon became 15 hexagons, whose radiating rays met again at nodal points, and these points connected by further lines, form new figures. He could construct most of his theorems only in the head, because no illustration was able to adhere to its complexity.

After a year and a half of study, Steiner was appointed by Pestalozzi to a teaching position at his institute. At this time, Fichte's 10 followers who were to found the Cauer Institute in 1817 were studying at Yverdun, and they may have then recruited Steiner to join them in Berlin. In 1818, Steiner left Yverdun for the University of Heidelberg to familiarize himself with the formal branches of mathematics in preparation to joining the reform movement in Prussia.

As a teacher, Steiner did not lecture in the ordinary way. In accordance with Pestalozzi's method, he conducted his

classes in the form of a Socratic dialogue with his students. Typically, Steiner would present a problem in construction to his class; for example, how to map one circle onto another, so that for each point of one circle, there could be found a definite corresponding point of the other. The entire attention of the class would be directed toward generating the solution. Steiner would intervene only to direct a process of education through problem solving, largely carried out by the students themselves. The outcome was a process that made the most ordinary student capable of thinking with scientific rigor.

Geometry and Socratic Dialogue

The primary result of instruction was not that the students mastered individual problems, but rather that in solving problems, they began thinking in terms of relationships instead of fixed objects. Steiner emphasized that the relationships discovered to exist between geometrical constructions were primary to the individual constructions themselves. In order to encourage the students to make full use of their imaginations, Steiner "used no figures in his classes," Felix Klein reported. "The active thinking of the listener was supposed to generate such a clear picture in his imagination that no material image would be needed."

Already while a student at Yverdun, Steiner had sought to advance the method of teaching geometry as well as the subject matter itself. He described the early evolution of his thinking in applications for financial support he made later in 1826 and 1827:

> The method brought into practice at the Pestalozzi Institute to treat the mathematical truths as subjects of free reflection (Nachdenken), caused me, as a student there, to search in place of the propositions put forward in the instruction, for other, where possible more profound grounds than those which my teachers at that time advanced, and in which I was often so successful that the teachers preferred my proofs to their own. . . . My many-sided occupation with mathematical instruction, combined with my own intense scientific efforts, gave my activity in this domain a direction which began early to depart from the usual one.
>
> As a student, what was thrust upon me, after I studied several textbooks of geometry, was the arbitrary nature of the order that, from the want of substantive connection, arose from relating individual propositions as such: I found somewhat arbitrarily, somewhat empirically, that the necessity of science is proven from its substantive content, and—according to a feeling mysteriously enlivening me—that the entire manifold of material must follow from its general unity and must be exhausted accordingly.
>
> It was clear to me, that so long as the synthetic method was sought in this external, arbitrary connection of individual propositions, we mislead the student in the presentation that the individual propositions as such were the object of science, and to him the perception of its general synthetic unity is so obscured, that he learns to comprehend its evidence always only as the individual, dependent propositions, never in its substantial originality. As teacher the problem therefore placed before me, was if possible, to treat every discipline as a few concepts, and to allow the individual propositions of each to emerge only as results of the development of these few concepts in their area.
>
> Accordingly, the notion of systematization, as it is taken from the existing geometrical textbooks, is completely transformed; I strove for the connectedness of the views (Anschauungen) from the unity of the means of [geometrical] construction themselves; without it being specially shown to me, I strove for the proper genesis, which lay at the basis the synthetic method, to join views with each other, and on which all geometrical discovery rests. The great mass of problems and propositions, which were given with their manifold solutions and proofs, lightened not only my efforts, but made it all possible. . . . However, the way that they had been fixed until now, appeared to me more as a means to connect them in the memory with one another, or to make individual applications of them, than to derive them by an exhaustive method from their principles.

Conflict with Hegel

An unusual circumstance combined to bring Steiner to Berlin in 1821 and put him in immediate conflict with Hegel and the educational establishment. The Friedrichs Werder Gymnasium faced the departure of several teachers in one brief period. Upon the recommendation of Steiner's friend Heldenmaier, gymnasium director Zimmerman, without the knowledge of the school's governing board, extended an invitation to Steiner to come from Heidelberg and take up a position teaching elementary geometry. Zimmerman then informed the board that he had hired "a skillful and suitable teacher" based on "glorious recommendations, one from the university [of Heidelberg], another from Pestalozzi." The governing board wrote back two weeks later reprimanding Zimmerman for hiring the disciple of Pestalozzi "on your own authority" and demanded that Steiner be examined. Steiner was subsequently examined on mathematics and philosophy of education. On the latter, Hegel, professor of philosophy at the University of Berlin, personally graded Steiner's written response to the following question on the relevance of "drill and grill" in education: "Do the exertion and exercise of the memory, which is accustomed to occur in early instruction, hinder or promote the development of the intellect?"

Of course, the Prussian educational establishment argued that "drill and grill" "promoted the development of the intellect," and Hegel used this to justify failing Steiner for promoting the Socratic method. The famous philosopher wrote on Steiner's essay, "The author displays nothing of the conception, that the intellect and memory have an intrinsic essential connection, grounded in the nature of spirit, and that only from the recognition of this connection can something fundamental be said on the assigned topic."

Having thus summarily rejected Steiner's method, Hegel succeeded in denying him a teaching position in 1822 because of alleged deficiencies in Steiner's general educa-

From left: Johann Heinrich Pestalozzi (1746-1827), the Swiss educator whose emphasis on the Socratic method was at the center of the Prussian educational reforms; Johann Gottlieb Fichte (1762-1814) who led the reform movement; and Wilhelm von Humboldt (1767-1835), the Prussian education minister whose sweeping reforms included Steiner's constructive geometry curriculum.

tion, even though he was accredited by the other examiners. Steiner then tutored privately and at the Cauer Institute until offered a permanent position at the Pestalozzian Friedrichs Werder trade school in 1825. In 1827, he received financial support for his research from the Berlin Academy. Beginning that year, the young geometer's essays accounted for fully one-third of the papers published in the leading scientific periodical of the time, *Crelle's Journal*.

After Steiner's 1832 book, *Systematische Entwicklung der Abhängigkeit geometrischer Gestalten von einander* (Systematic Development of the Interdependence of Geometrical Forms), received wide acclaim, a special professorship in geometry was established for him at the University of Berlin. There Steiner educated an entire generation of German scientists, and laid the basis for the great advances in mathematics and mathematical physics carried out after him.

Elementary Synthetic Geometry

Within geometry, one of Steiner's main contributions was to unify the existing body of theorems and geometrical constructions into a "general theory" based on relations among circles and spheres. He achieved this in the mid-1820s in his *Allgemeine Theorie Über das Berührens und Schneiden der Kreise und der Kugeln* (General Theory of Tangency and Intersection of Circles and Spheres), which was published after his death. Aspects of Steiner's *General Theory* appear throughout his work, such as his essay "Einige geometrische Beobachtungen" (Some Geometrical Observations). (Unfortunately, only one of the works cited here is available in English.)

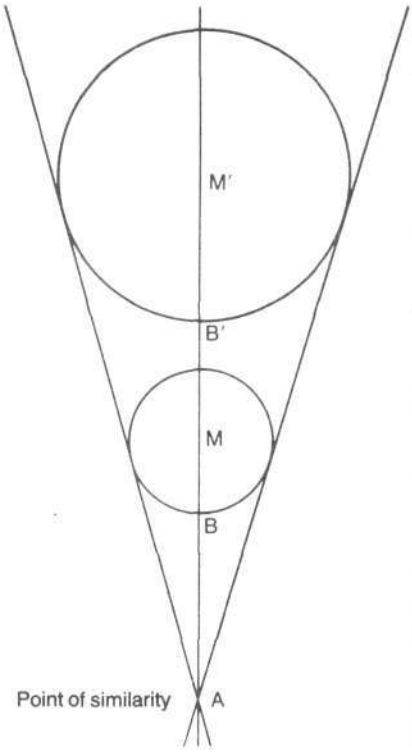
The constructions with compass and straight edge developed below out of his *General Theory*, can form the basis for a series of four to eight 1-hour classes conducted with students who have no previous study of geometry. I taught such a class to high school students in order to develop a pedagogy for the teaching of Steiner's geometry to persons of all ages.

The young men and women who attended this first series of classes lacked the inhibitions that adults acquire against asking questions and against accepting what a teacher may say at face value. In the first class I was pelted with questions and comments from all directions. I quickly learned that the only way to teach anything under such circumstances, was to place the responsibility for the progress of the class upon the work of the students themselves. I became the questioner and they the questioned. Of course, this is nothing other than "the Socratic method of teaching."

I would give a brief-as-possible exposition and then begin to pose problems. The students became intensely absorbed in solving the problems. In fact, they invented new solutions and developed new constructions that do not appear in Steiner's work.

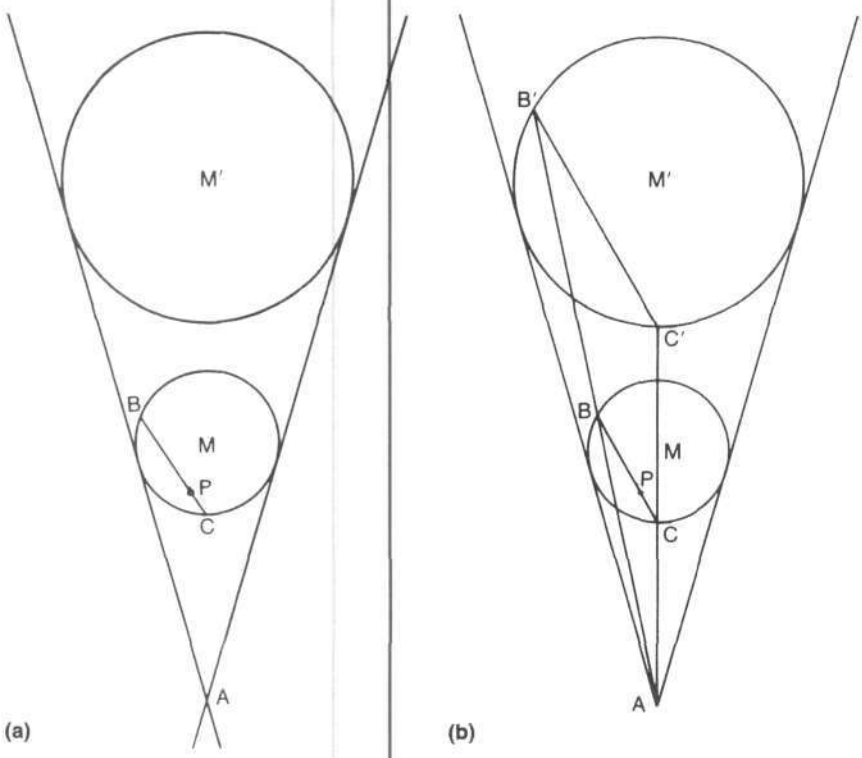
Next, I applied the same technique to teaching adults. This is a harder job, for adults are afraid to reveal their ignorance in front of their peers, but the Socratic method changed the psychology of the classroom for the adults as well. Persons who had previously never been able to think geometrically were cured by Steiner's method. The students also learned to teach each other.

FIGURE 1



Constructing the External Point of Similarity of Any Two Circles

FIGURE 2



Constructing Parallel Lines and Similar Triangles

A CONSTRUCTIVE GEOMETRY CURRICULUM

Steiner's development of synthetic geometry in his *General Theory* begins with this elementary construction: Draw two circles, M and M', and draw tangents common to both circles—straight lines that touch each circle only at one point (Figure 1). The tangents intersect at a single point, which Steiner called the "external point of similarity," A. Notice that the axis drawn through the centers of both circles intersects this point of similarity A. With the point of similarity, we can relate or map one circle to the other. For example, the point B in the smaller circle M corresponds to the point B' in the larger circle M with respect to the external point of similarity A. We can find corresponding points in the circles using the property of the similarity of all circles to each other.

Take an arbitrary point P within the smaller circle M. How do we rigorously construct or determine the corresponding point P' within the larger circle M'? Draw an arbitrary line (or secant) through P intersecting the circumference of the circle at two points, B and C [Figure 2(a)]. We then must find the corresponding secant in the larger circle M'. Corresponding point P' must lie on this corresponding secant, according to the principle of similarity of circles. From the external point of similarity, project points B and C, the endpoints of the secant in M, up to the large circle and determine points B' and C' at the intersection with the circumference of circle M' with the lines of projection from A through B and from A through C. Then draw the corresponding secant $B'C'$ in the larger circle, as in Figure 2(b).

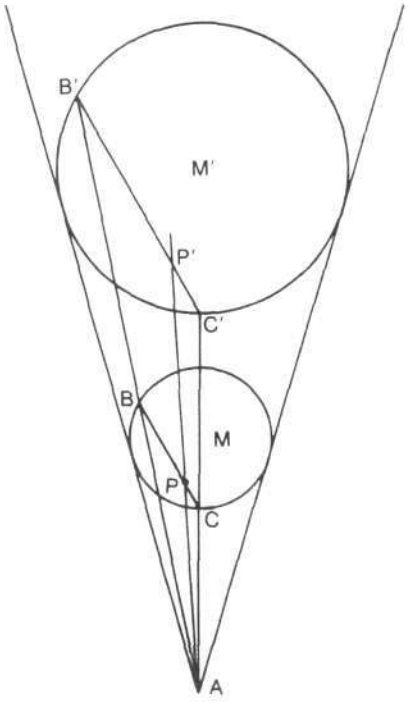
With this construction we have constructed parallel lines and similar triangles *using only the property of similarity of circles*. Lines $B'C'$ and BC are parallel because they are corresponding secants of the two circles. Thus, there is no need for the parallel postulate in synthetic geometry!

Triangles ABC and $AB'C'$ are similar because parallel secants make the same angles with the lines of projection AB' and AC'. We therefore have also constructed equal angles. With these simple steps, we have determined an elementary mapping of circle M onto M', which is "conformal," that is, a mapping that preserves the sizes of angles of figures mapped from one surface to another.

Little remains to determine the corresponding point P' on circle M'. Draw projection line AP through the larger circle to intersect with the secant $B'C'$ to find point P', as in Figure 3.

This same procedure can be carried out to map any point in either of the circles onto its corresponding point in the other circle. That is, we can map either circle onto each other with no points of exception. And all this is based solely on the property of the similarity of all circles and the determination of the external point of similarity by drawing

FIGURE 3



Locating Similar Points

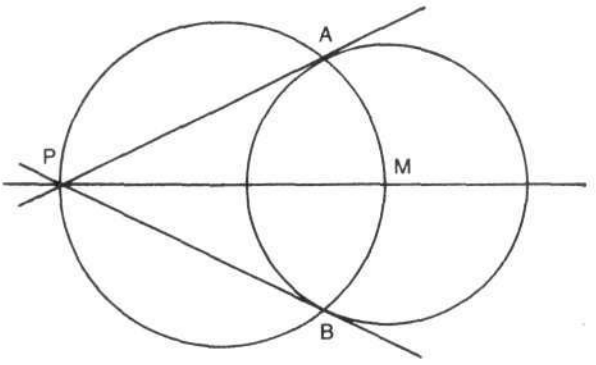
the common external tangents to two circles. We have used no axioms in making the construction in Figure 3. The only geometric property we have used is the property of the similarity of all circles to each other.

The reader may object and argue, "No, we have also used the ability to draw tangents to the circles, and since the location of a tangent in a construction can vary with the placement of a straight edge, the determination of the point of similarity is not rigorous."

However, Steiner showed in a very simple construction in his *General Theory* that the concept of tangents is *rigorously* based on relations among circles. The tangent to a given circle M from a point P is determined by another circle M' whose diameter is the distance from the point P to the center of the given circle, as shown in Figure 4. The figure shows that the two points on either side of a circle M to which tangents can be drawn from the point P are the same as the intersections of M and a circle with diameter of length PM.

The projective relationship that we have established between the two circles extends outside of them. We can find points of correspondence that lie outside of them. In other words, the relationship between the two circles can be used to map the entire surface onto itself. For example, we can find for a point P that lies outside the smaller circle M, a corresponding point lying outside the larger circle M' (Figure 5). The method for extending the mapping outside the

FIGURE 4



Constructing Tangents

circles is the same as presented in Figures 1-3. Choose an arbitrary point P outside of circle M. We will find the point that corresponds to it, with respect to the circle M'. Draw an arbitrary line through the circle M intersecting the point P. That extended secant intersects the circumference of circle M at points B and C.

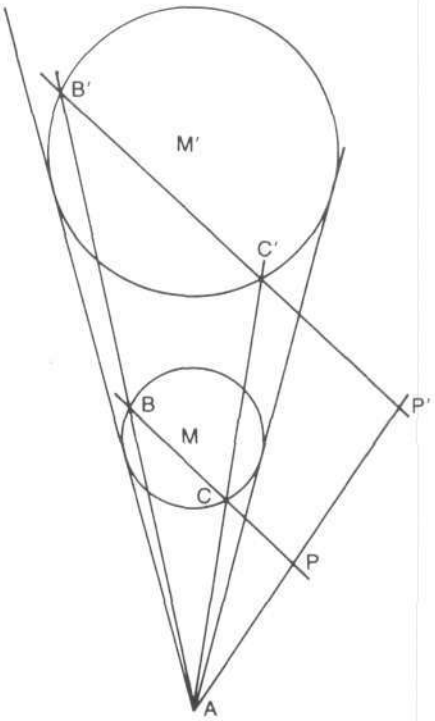
Project those points from the external point of similarity A onto the larger circle M' to find the corresponding points B' and C'. Then draw the secant $B'C'$ extending out of the circle as shown, and draw the line of projection AP that intersects the extended secant $B'C'$ at the desired corresponding point P'. This construction combines the steps of Figures 1-3 into a single figure.

Now examine the properties of our original mapping construction. We begin with two circles and establish a projective relationship by which we can map the entire surface on which they reside onto itself. For every point on the surface taken in relation to one of the circles, there is a corresponding point that can be determined in relation to the other circle. In this way, the circles impose a metric upon the space of the plane surface. The mapping also has the interesting property that there is one point that has itself as its image or corresponding point under the mapping, namely A, the point of similarity.

Based on the construction of similarity with two circles (Figure 1) and the construction of similar triangles (Figure 2), we see in Figure 5 that distance AB is in ratio to distance AB' as the distance BC is in ratio to $B'C'$. In other words, corresponding points in the mapping are distant from the point of similarity A in proportion to the relative sizes of the two circles. Therefore, distance AP' is to distance AP as the diameter of the large circle is to the diameter of the small circle.

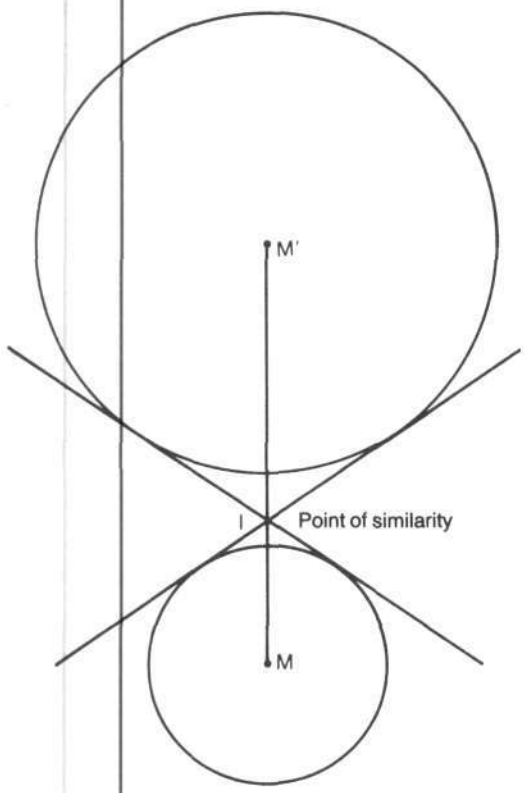
For any two circles we can find other points of similarity; for example, the "internal point of similarity," as Steiner named it, which is determined by drawing the tangents common to the two circles that cross internally between them, as shown in Figure 6(a). The internal point of similarity I is the intersection of these two common internal tan-

FIGURE 5

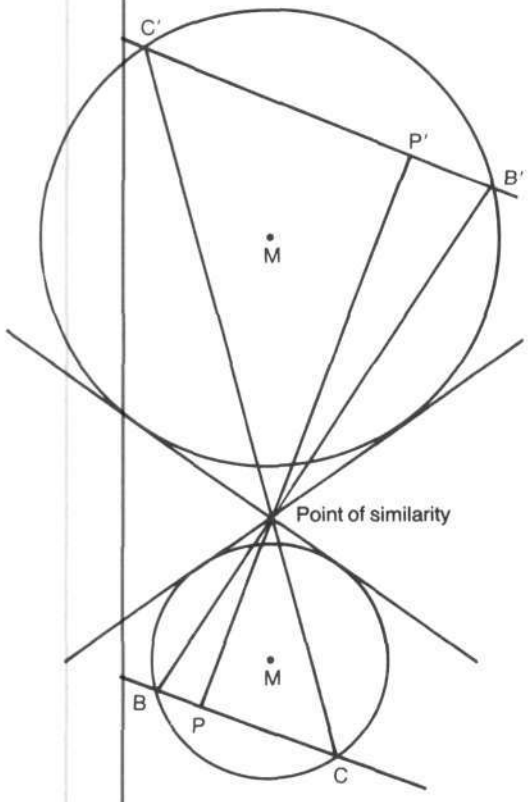


Mapping Surfaces onto Surfaces

FIGURE 6



(a)



(b)

Constructing the Internal Point of Similarity

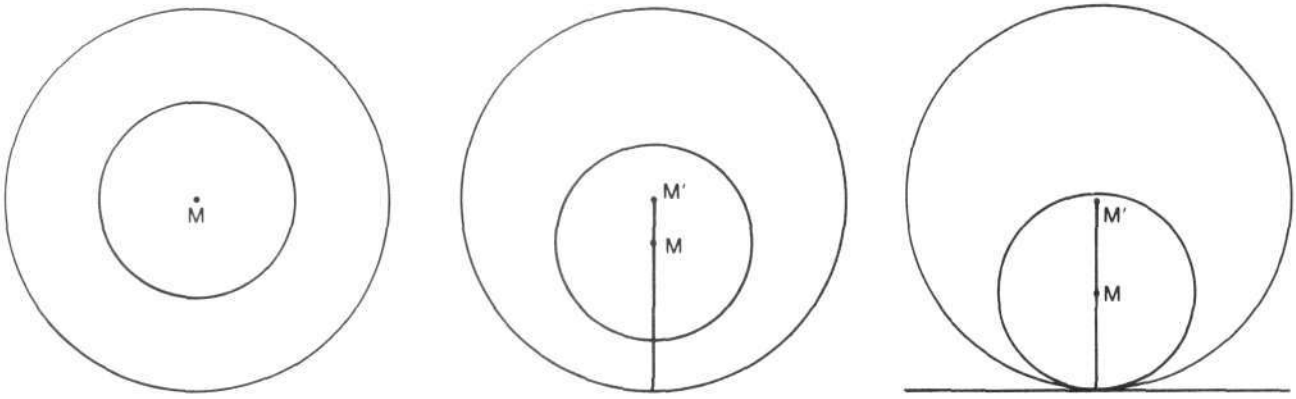
gents. Like the external point of similarity, it also lies on the axis connecting the center of the two circles. We can use the internal point of similarity to map one circle onto the other using the same principles as in Figures 1-3, but with a slightly different result. By using the *internal* point of similarity, we produce a "mirror" mapping of the circles, where the left half of circle *M* is mapped onto the right half of the larger circle *M'*, and vice versa.

To map point *P* on circle *M*, draw through it an arbitrary secant *BC*, which intersects with the circumference of circle *M* at two points [Figure 6(b)]. Then project these points *B* and *C* through the internal point of similarity to find corresponding points *B'* and *C'* on the circumference of circle *M'*, and draw the secant there that corresponds to *BC* and intersects the circumference of *M'* at points *B'* and *C'*. Finally, project point *P* through the internal point of similarity to intersect with the secant of the larger circle *B'C'*, determining point *P'*.

As in the previous constructions, this demonstration also provides a rigorous definition of the notion of parallel lines as well as equal angles and similar triangles. Also, as in Figures 1-3, the mapping produces a conformal mapping of circle *M* onto circle *M'*.

Two circles need not lie outside each other, as they do in Figures 1-3, to form the basis for establishing a mapping of a surface onto itself. A rigorous mapping can be defined just as well if the circles intersect or lie inside of each other. There are four distinct cases, shown in Figure 7: (a) two concentric circles; (b) two circles whose centers are eccen-

FIGURE 7



(a) Concentric circles **(b)** Nonconcentric circles **(c)** Tangent circles

Concentric, Nonconcentric, Tangent, and Intersecting Circles

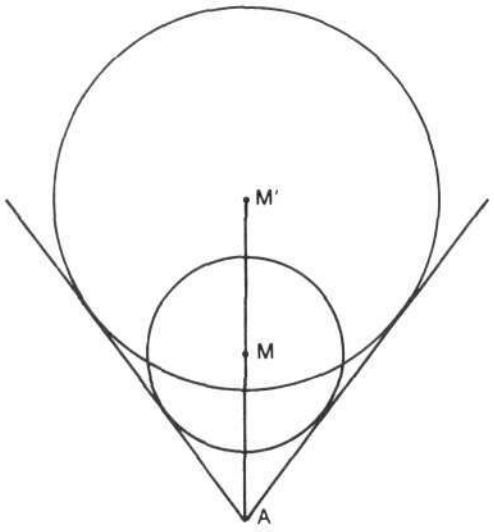
tric, that is, one circle is completely inside the other but not concentric; (c) two circles tangent to each other internally; and (d) two circles intersecting. Each of these cases corresponds to a distinct type of projective transformation that comes up in wave propagation, as discussed below. Examining their properties enables us to broaden our understanding of the nature of conformal mapping.

The first task in these four constructions is to identify the location of the points of similarity. In the case of Figure 7(d), the method used in Figures 1-5 can be applied to determine the external point of similarity, but with Figure 7(a), (b), and (c) it is not perhaps obvious how we can find a point of similarity since we cannot draw a pair of tangents common to the two circles.

Let's start with Figure 7(b), nonconcentric circles, to illustrate the method of solution. First, refer back to Figures 1-3. Notice that in these constructions, any lines connecting any pair of corresponding points intersect at the point of similarity. To find the points of similarity in Figure 7(b), it is only necessary to find pairs of corresponding points and connect them; they will intersect at a point of similarity.

The axis $M'M$ connecting the centers of the circles can serve as one such "line of similarity," as Steiner called any line connecting two points that correspond. We need find only one other line of similarity. Since circles are self-similar, their radii mark off similarly proportional arcs along their circumferences. Figure 8 shows a construction that illustrates this.

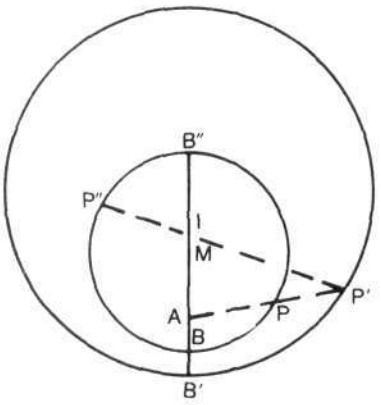
Using a compass, open it to the radius of the small circle. Then we place its foot on point B of the small circle and mark off on the circumference, the point P where the compass intersects it. Then open the compass to the radius of the large circle, place its foot on point B' which corresponds by the axis connecting the centers of the circles, to point B, and mark off on the circumference the point P' where the compass intersects it. Points P and P' are corresponding points. By connecting them, we find the external point of similarity of the two nonconcentric circles A, which, as can be seen in the figure, lies inside both circles. (By *external* point of similarity, Steiner means one that does not lie between the centers of the two circles.)



(d) Intersecting circles

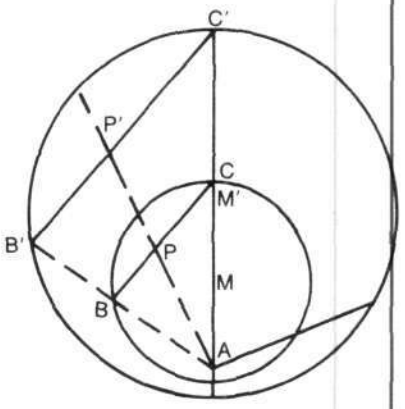
In a similar way, we can find the internal point of similarity I of the two circles. Recall that projection with the internal

FIGURE 8



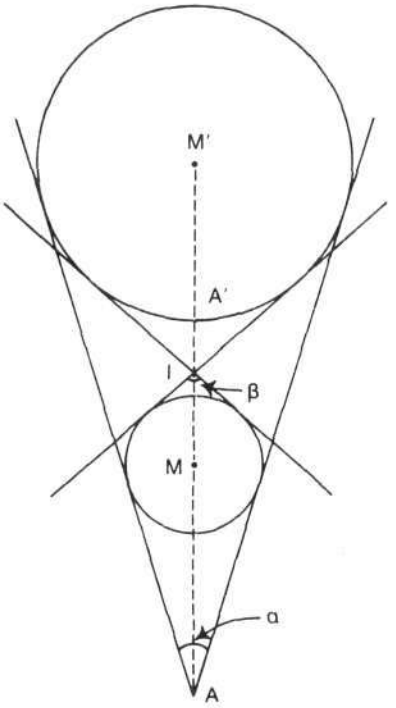
Finding the External and Internal Points of Similarity for Nonconcentric Circles

FIGURE 9



Mapping Corresponding Points Between Nonconcentric Circles

FIGURE 10



Any Two Circles Determine Harmonic Proportions

point of similarity, produces a mirror-image mapping of one circle onto the other, so that points along the axis on opposite sides of the two centers correspond, such as points B' and B'' in Figure 8. We now open the compass to the radius of the small circle, place its foot on point B'' and mark off point P'', on the opposite side of the axis from point P'. In the mapping of one circle onto another via the internal point of similarity, corresponding points that do not lie along the axis, lie on opposite sides of it. The line connecting points P' and P'' intersects the axis at the internal point of similarity.

We map the surface onto itself when the circles are inside each other in the same way as when they are outside of each other (Figure 9). Point P of the smaller circle is mapped onto point P' of the larger circle by constructing parallel secants BC and $B'C'$ and then projecting point P onto secant $B'C'$ to find point P'.

Hydrodynamic Applications

In the progression from Figure 7(a) to 7(d), the external point of similarity migrates from the common center of the circles 7(a); to a point within them along the axis connecting their centers 7(b); to the intersection of this axis with their single common tangent 7(c); to the intersection of their two common tangents 7(d).

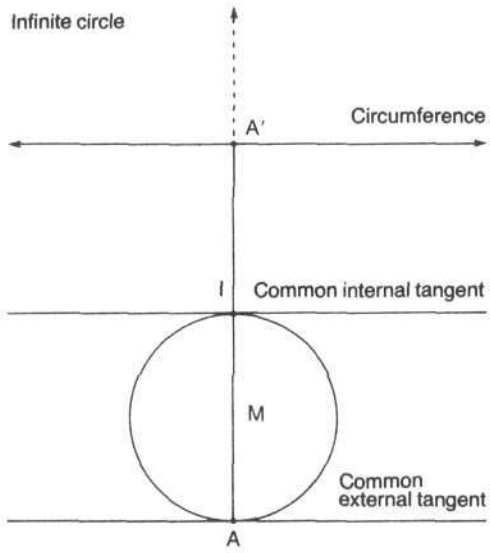
Hydrodynamics, the propagation of water waves, provides an example of the occurrence in nature of the series of projective transformations shown in Figure 7. Figure 7(a) represents concentric or spherical waves propagating outward from a fixed point M. Figure 7(b) represents spherical waves emanating from a source moving from M' to M and whose speed is slower than the speed of wave propagation in water so that the waves always move out in front of the source. Figure 7(c) represents spherical waves produced by a source moving from M' to M at the speed of wave propagation in water, so that the waves propagate at the same speed as the source. The source is moving too fast for the waves to propagate in front of it. They pile up and form what is called "a surface of discontinuity" at the source, where they all become tangent to each other. Figure 7(d) represents wave propagation where the source of the propagating waves is moving faster than the speed of wave propagation in water, and the source moves out in front of the spherical waves that it produces, forming a conical bow wave the way a motor boat does.

In each of these cases the source can be conceived of simply as a stick poked into a stream of water that is stationary as in Figure 7(a), or moving as in Figures 7 (b-d). The location of the source at any instant is that of the external point of similarity of any two wave-circles as they exist at that instant. In the case of concentric waves, this coincides with their common centers. For waves produced by a moving source, the source is at any time always at the external point of similarity of the waves.

The Harmony of Vision

Steiner's elementary projective synthetic geometry begins with constructions that develop the intrinsic relations

FIGURE 11



Locating the External and Internal Points of Similarity Between Finite and Infinite Circles

between two circles. If we draw two circles *M* and *M'* that lie outside each other (Figure 10), these circles will determine two unique pairs of tangents. These are the pair of tangents that crosses between the two circles and intersects at point *I*, and the pair of tangents that envelops the circles and intersects at point *A*. These two points *I* and *A*, the internal and external points of similarity, and the centers of the two circles, form what Steiner called "a harmonic range." The points *I* and *M* divide the distance *AM'*, so that *AM:MI* :: *AM':IM'*. This relationship corresponds to the recession of the size of objects in harmonic proportion that we experience in vision.

For example, when we look down a railroad track of equally spaced railway ties, the eye and brain contract the distances between the ties so that the proportion or ratio of the distance from the first tie to the second (*AM*) to the distance from the second to the third (*MI*), equals the ratio of the distance from the first to the horizon (*AM'*) to the distance from the third to horizon (*IM'*). The distances recede toward the horizon in such harmonic proportion.

This geometric relationship is ordinarily defined algebraically. Four points are considered harmonic, if they satisfy the relation: *AM:MI* :: *AM':IM'*. Steiner's simple construction shows how the property of "optical" harmony, directly follows from the intrinsic relations between two circles. This is the point of constructive synthetic geometry: It dispenses with Euclidean albegraic "proof" through the method of direct construction. It defines the sought-for geometric relation with a construction, not a formula. (Those who seek the algebraic "proof" that this does produce a harmonic range, can notice that this can be shown by the fact that *AM:AM'* :: *D:D'* :: *IM:IM'*.)

Steiner developed all of geometry in this fashion, by investigating elementary relations among circles, spheres, and other geometrical objects.

In his *General Theory of Tangency and Intersection of Circles and Spheres*, Steiner presents two particularly important and interesting cases of projective relations among circles. In one case, one circle is "infinitely large" and the other finite; in the other case, one circle is "infinitely small."

Imagine that circle *M'* in Figure 10 grows in size indefinitely while the point *A'*, where its circumference intersects the axis connecting the centers of circles *M'* and *M*, remains fixed. As circle *M'* grows, its radius lengthens and its center is pushed farther and farther away from the smaller circle. Ultimately, the center is infinitely distant, the radii are infinitely long, and the circumference of the circle, which is itself infinitely long, is perpendicular to the axis connecting the centers at point *A'* as shown in Figure 11. The founder of modern synthetic geometry, the great Cardinal Nicholas of Cusa, writes in his *On Learned Ignorance*:

> Now, as the curve of the circumference becomes less curved as the circle expands, the circumference of the absolutely greatest possible circle will have the smallest possible curvature; it will be, therefore, absolutely straight. . . . In the infinite there is the absolute maximum of straightness with the absolute minimum of curvature.

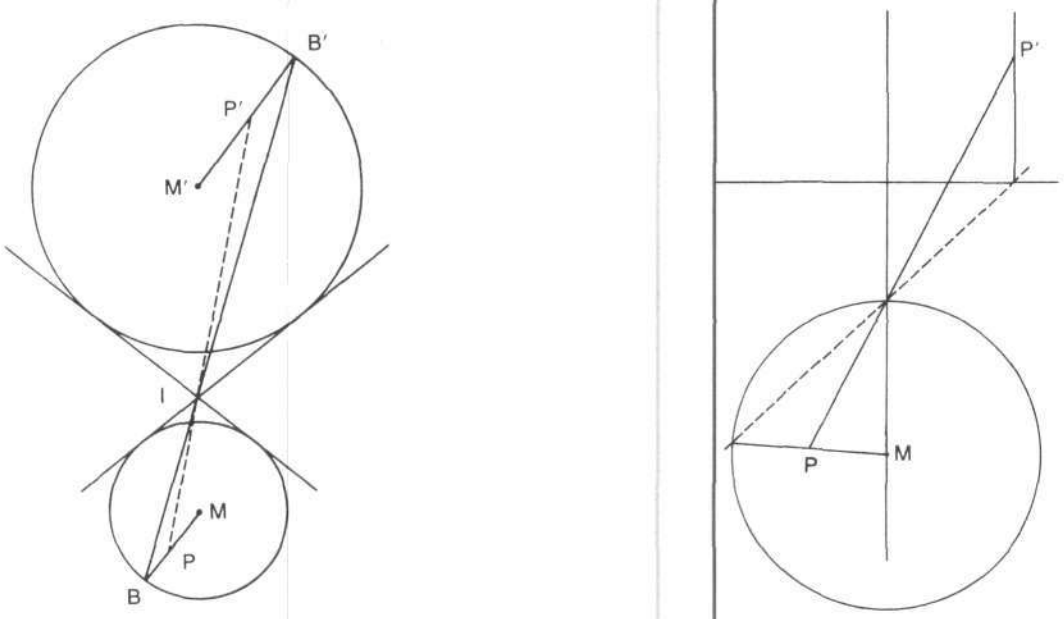
In this transformation of circle *M'*, how are the positions of the points of similarity affected? As circle *M'* becomes larger and larger, the angle α between the external tangents becomes larger and larger as they open up to accommodate the growing circle *M'* (Figure 10). The finite circle *M* fits more and more into the apex of the angle made by the tangents as that angle widens. The external point of similarity consequently moves closer and closer to the circumference of circle *M*.

Finally, when circle *M'* becomes "infinitely large," the angle between the two tangents opens up to 180 degrees, and the two tangents collapse into a single tangent: a straight line perpendicular to the axis *M'M* where that axis intersects the small circle at *A* (Figure 11). It will touch the infinite circle at only one point—a point at infinity. Point *A* at the intersection of the circumference of circle *M* and the axis connecting the centers of both circles, is the external point of similarity.

In the same way, the angle β made by the internal tangents also must open up to 180 degrees (Figure 10); these tangents also collapse into a single tangent, perpendicular to the axis connecting the centers of the circles, at point *I* (Figure 11). This point *I* on the other side of circle *M* from point *A*, is the internal point of similarity of the finite and infinite circles *M* and *M'*.

This extreme case leads to some interesting results. In moving from the finite to the infinite circle, we have passed

FIGURE 12



(a) (b)

Mapping Corresponding Points Using Corresponding Radii

through a discontinuity. We now have the following situation:

(1) Straight lines in either circle (except for radii) correspond to curves in the other circle.

(2) There seems to be no way to construct secants that correspond to each other between the two circles. A secant through the finite circle *M* would correspond to a curve connecting two points of the infinite circumference of infinite circle *M'*, but there seems to be no way to determine the path that that curve would take.

(3) Thus we must map corresponding points by using corresponding radii or arcs or some other method besides mapping corresponding secants. Radii intersecting the circle at only one point can still be found that correspond between the two circles. But the third sign that we have passed through a discontinuity is that corresponding radii are not parallel, as they are in mappings between finite circles. All the radii of the infinite circle radiate from its infinitely distant center. As a result, all are perpendicular to the straight line that forms the visible portion of its circumference and intersects the axis connecting the circles at point *A'* (Figure 11). On the other hand, the circumference of the finite circle is not straight; its radii are therefore not parallel to each other.

(4) Last, but not least, only half of the points on the axis connecting the infinite and finite circles can be mapped onto each other.

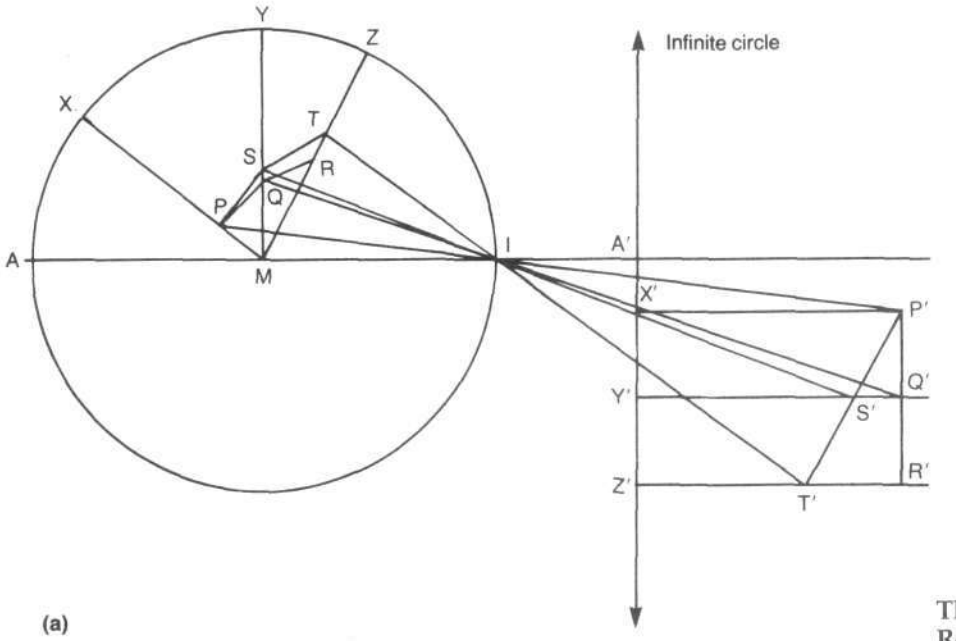
First, how do we now map points within and on the circles so that they correspond? Figure 12(a) shows how to map points of finite circles onto each other through the internal point of similarity, by means of constructing the corresponding radii on which they lie. We will use this technique to map the infinite circle onto the finite. To map point *P* of circle *M* into circle *M'* in Figure 12(a), draw the radius *MB* on which it lies, then project the point *B* at which that radius intersects the circumference, through the internal point of similarity to find on the circumference of circle *M'* the point *B'* to which *B* corresponds. Then draw the radius that intersects *B'*, and draw a line from the point *P* in circle *M* through the internal point of similarity to intersect radius *M'B'* in circle *M'* at the point *P'* that corresponds to *P*.

We will use this method to map the infinite circle onto the finite circle, keeping in mind that in this case corresponding radii will not be parallel. Figure 12(b) shows how to map a point *P'* in the infinite circle onto its corresponding point *P* in finite circle *M*. Figure 13(a) shows this method applied to project triangle *P'R'T'* from the infinite circle into the finite circle.

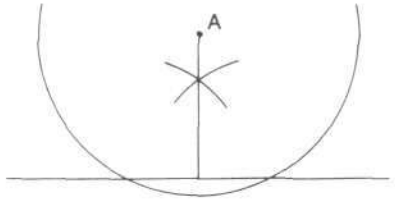
The first thing to notice is that the points that correspond to points *P'*, *Q'*, *R'* and *P'*, *S'*, *T'*, which lie on straight lines in the infinite circle, do not lie on straight lines in the finite circle; they lie on curved arcs. This reflects the discontinuity in passing from the finite to the infinite.

The mapping procedure in Figure 13 is identical to that used in Figure 6(b) with the exception that corresponding radii are not parallel. Points *P'*, *Q'* and *R'* in the infinite circle are connected to its circumference via perpendicular lines, segments of the infinite radii on which they lie. The points where these radii intersect the circumference *X'*, *Y'*, *Z'* are then projected through the internal point of similarity

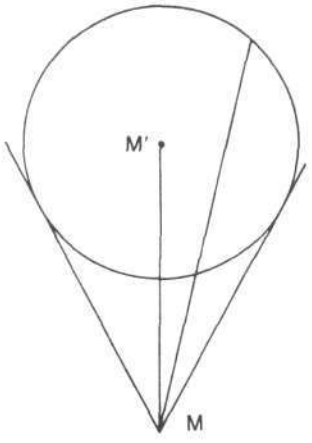
FIGURE 13



(a)



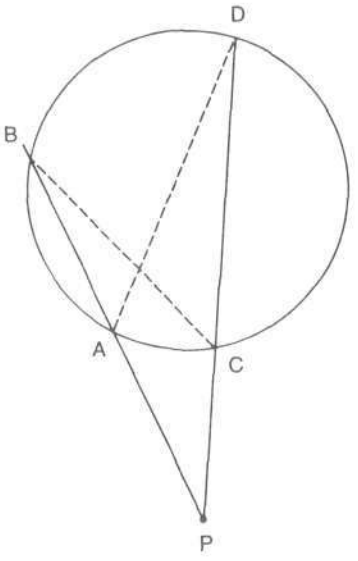
(b)



(c)

Straight Lines Map into Curves

FIGURE 14



The Power of a Point with Respect to a Circle

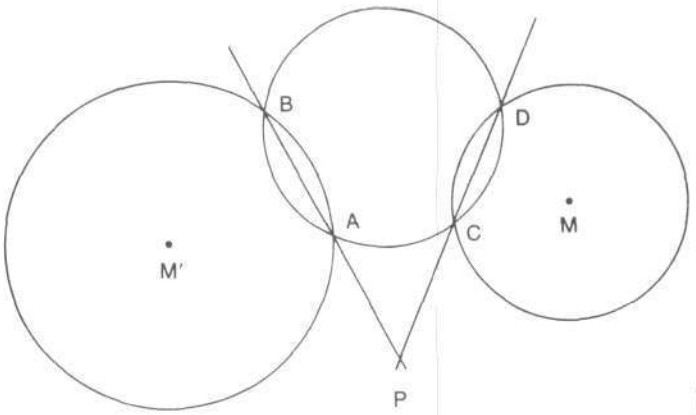
I onto the circumference of the finite circle to find corresponding points *X, Y,* and *Z*. The radii of the finite circle that correspond to radii *P'X', Q'Y'* and *R'Z'* of the infinite circle, must intersect the circumference of the finite circle at points *X, Y,* and *Z*. Now draw these radii *MX, MY, MZ* from the center *M* of the finite circle. The points that correspond to *P', Q'* and *R'* of the infinite circle, are found by projection through the internal point of similarity onto these corresponding radii.

The projection, if done on a large enough scale, will show that straight lines (other than radii) do not project to straight lines in going from the infinite circle to the finite circle. The projection is not conformal (angle preserving). The right angle *Q'R'T'* in the infinite circle is projected to the obtuse angle *QRT* in the finite circle. The projection models in a simple way what Leonardo da Vinci called the "natural perspective" of vision, where linear features are actually mapped onto the inner surface of the eye, or retina, as curved ones; the brain, of course, corrects for this, and we see linear structures as linear.

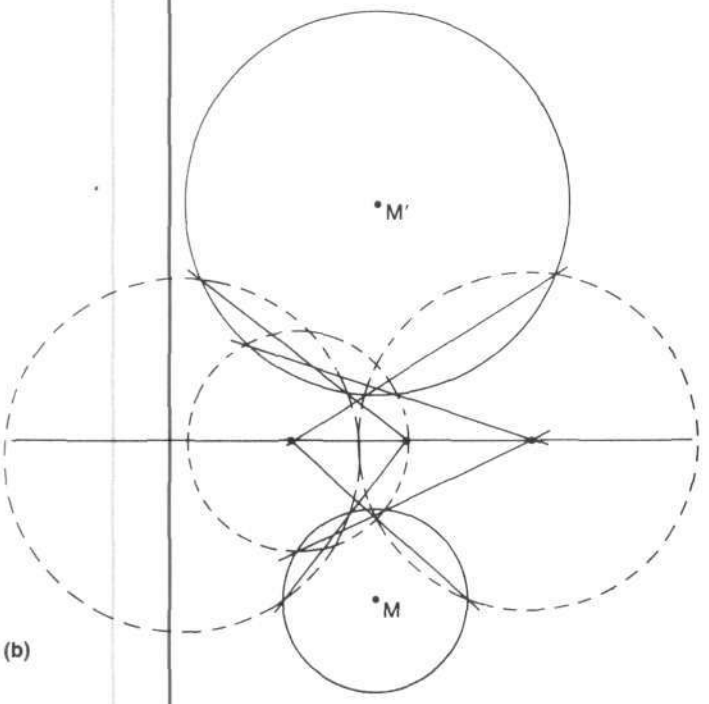
Haven't we assumed the ability to draw perpendiculars through an arbitrary point inside the infinite circle, to carry out this construction? These perpendiculars to the circumference of the infinite circle are constructible by drawing about the point a circle that intersects the circumference of the infinite circle at two points [Figure 13(b)]. Then, using a compass, bisect the segment of the circumference so determined. The line connecting the midpoint of this segment with the given arbitrary point is perpendicular to the circumference of the infinite circle.

There is another important case of a discontinuous mapping between two circles that is related to a series of important geometrical properties, namely, the case in which one of the two circles has shrunk to a single point and become infinitely small [Figure 13(c)]. The point-circle en-

FIGURE 15



(a)



(b)

Constructing the Line of Equal Powers

closes both internal and external points of projection, as well as its own center and circumference; every point of the finite circle is mapped onto its one point.

Steiner called the projective relationship of the point-circle to the finite circle its "power." Any point *P* has a "power" that is constant with respect to a given circle (Figure 14). The product of the distance from the point *P* to the circumference of the circle, times the distance from the point through the circle, is constant for any line drawn through the circle. As shown in Figure 14, $PA \times PB = PC \times PD$ = the square of the length of the tangent *PT* from point *P* to the circle.

This can be easily seen based on similar triangles: Triangles *PBC* and *PDA* are similar because their angles are equal. They share angle *P*, and angles *PBC* and *PDA* are equal since they encompass the same arc of the circle. If two angles of the triangles are equal, then the third pair of angles, *PCB* and *PAD*, must also be equal. The lengths of corresponding sides of similar triangles are in a constant ratio, so that the short sides are in the same proportion as the long sides, that is, $PC/PA = PB/PD$. By simple algebra therefore, $PA \times PB = PC \times PD$, for any positions of lines *PAB* and *PCD*. Steiner did not view this construction algebraically, however, but rather as another simple *definition* of similar triangles.

For any two circles, *M* and *M'*, we can find points that have the same power with respect to both circles (Figure 15). Simply draw a third circle that intersects both circles *M* and *M'*. Then draw the lines *AB* and *CD* through the four points of intersection of the three circles. These two lines intersect at point *P*. We already know that $PA \times PB$ is the power of *P* with respect to circle *M'*, and that $PC \times PD$ is the power of *P* with respect to circle *M*. But these two lines *PAB* and *PCD* also exactly intersect the third circle we have drawn. Then *P* has the same power with respect to all three circles. The third circle links circles *M* and *M'* so as to determine "a point of equal power."

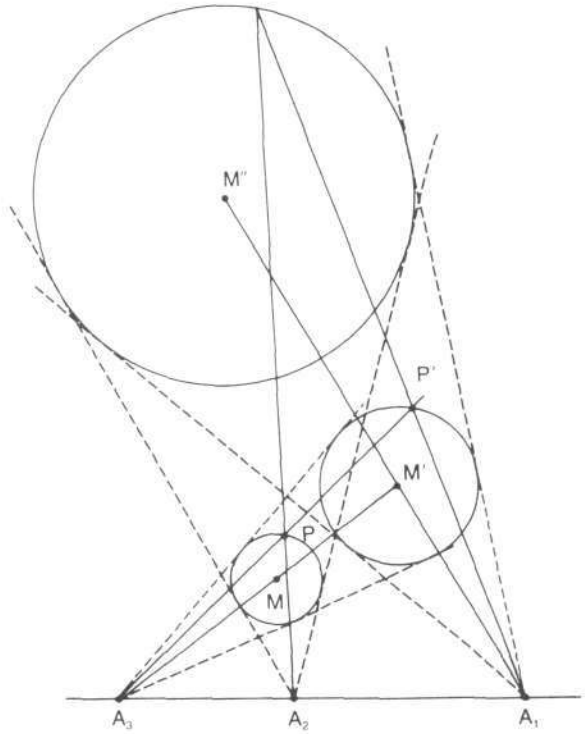
We can find an indefinite number of points that have equal power with respect to two circles *M* and *M'*. They form a line called "the line of equal powers" by Steiner, or the "radical axis" by Cremona [Figure 15(b)]. Each point has equal power with respect to the circles, but their individual values are not equal. Three circles are used in Figure 15(b) to show how to construct Steiner's "line of equal powers."

In order to take this discussion of Steiner's "power" construction further, we must examine simple projective relations among three circles. Figure 16(a) shows three circles to which we have drawn the external tangents that each pair determines and have located the three external points of similarity, A_1, A_2, A_3, in the same way as this is done in Figure 10. These three points lie on a straight line. Steiner derived this fact by considering the projective relationships among three spheres.

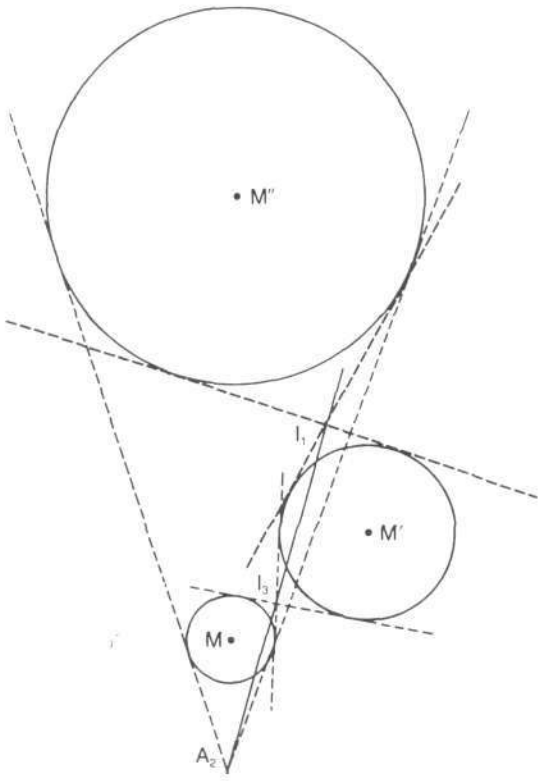
Given any three spheres, their three centers will all lie in a single plane. Construct planes tangent simultaneously to all three spheres. Such planes will intersect the plane determined by the centers of the spheres at a line of similarity, either the line determined by the three external points of similarity [Figure 16(a)], or one of three lines of similarity determined by an external point of similarity and a pair of the internal points of similarity.

Figure 16(b) indicates for one case the points of internal

FIGURE 16



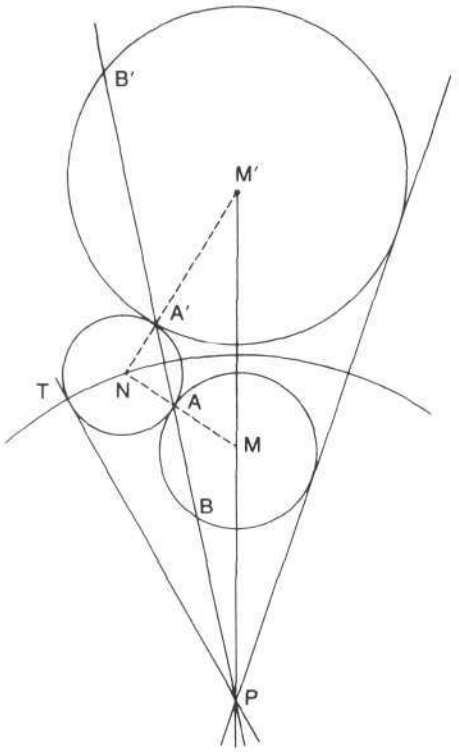
(a)



(b)

Projective Relations Among 3 Circles

FIGURE 17



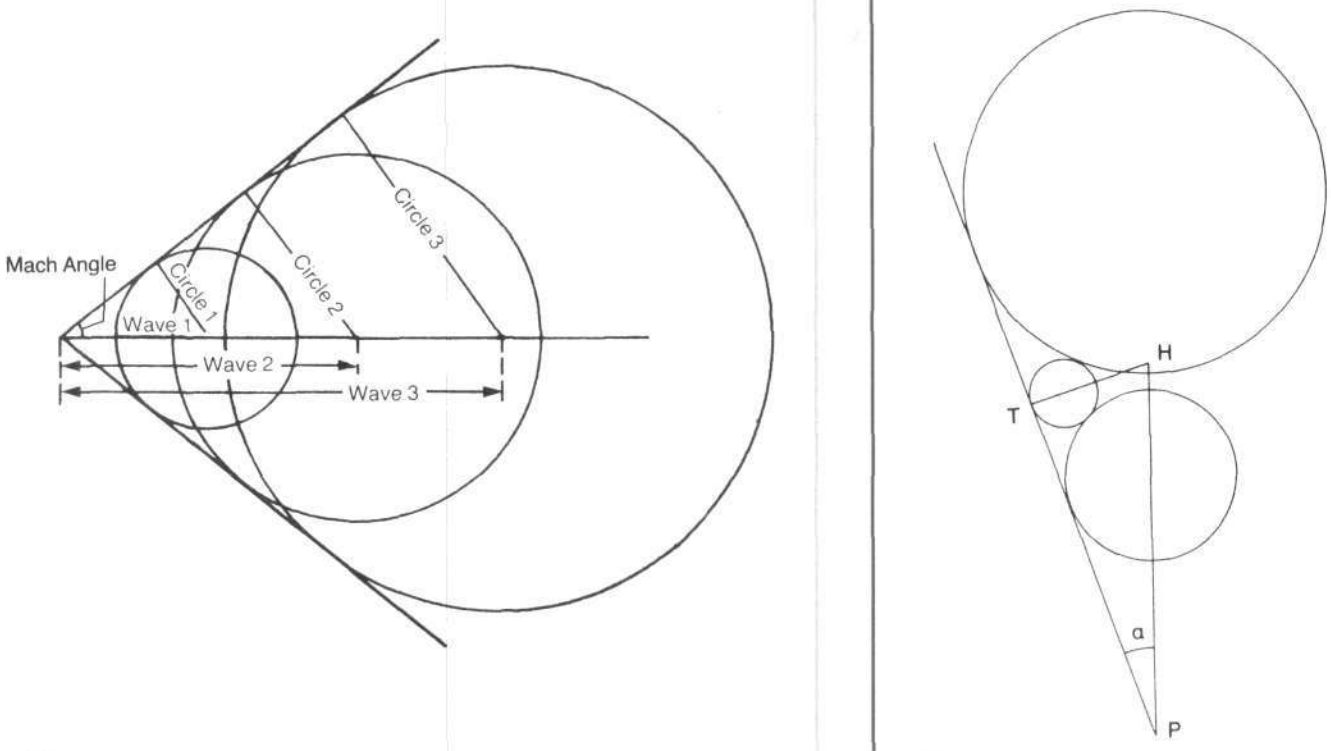
Constructing Tangent Circles

similarity for two pairings of the three circles. Notice that these two internal points of similarity lie on a straight line with one of the external points of similarity constructed from another pairing of the circles.

Steiner's Influence on Cantor

The line connecting the three external points of similarity in Figure 16(a) is called a "line of threefold similarity." By means of it, the three circles form a closed projective system. Map a point *P* from circle *M* to circle *M'* and find its image *P'* with respect to external point of similarity A_3; then map that image point *P'* onto the third circle M" and determine its image point P" by means of external point of similarity A_1. Finally, map that image point *P"* back to the first circle from which we started, circle *M*. We find that we end up at the same point *P* from which we started the series of projections. This illustrates that the space determined by three circles (or spheres) or any number of circles (or spheres), projectively related in this way, is closed—something upon reflection we would expect from the similarity of all circles to each other.

FIGURE 18



(a) (b)

The Common Power of Two Circles and Supersonic Flight

The case of relations among three circles enables us to easily introduce a concept that Steiner developed and that inspired Georg Cantor in his development of the theory of the transfinite: If two circles are touching, the point at which they touch is one of their two points of similarity; it is a point at which they have a common tangent. If they are touching externally to each other, this point is their internal point of similarity. In Figure 17, circle N has been brought close to the two other circles, M and M', so as to touch them at points A and A'. The two points of tangency of the circles must lie on a straight line with the external point of similarity P of circles M and M', since they are internal points of similarity among circles M and N, and M' and N [see Figures 16(b) and 17].

Such tangent circles provide one way of representing a "counter-corresponding" mapping of circle M onto M' in which point A is mapped onto point A' rather than point B', as we have mapped circles with their external point of similarity up to now. Any line $PBAA'B'$ that we draw through circles M and M', determines counter-corresponding points A and A', which determine circles tangent to M and M'. To find such circles (N), draw radii out from M through A and from M' through A'; these two radii will intersect at a point N, the center of a circle with radius $NA = NA'$, tangent to M and M'.

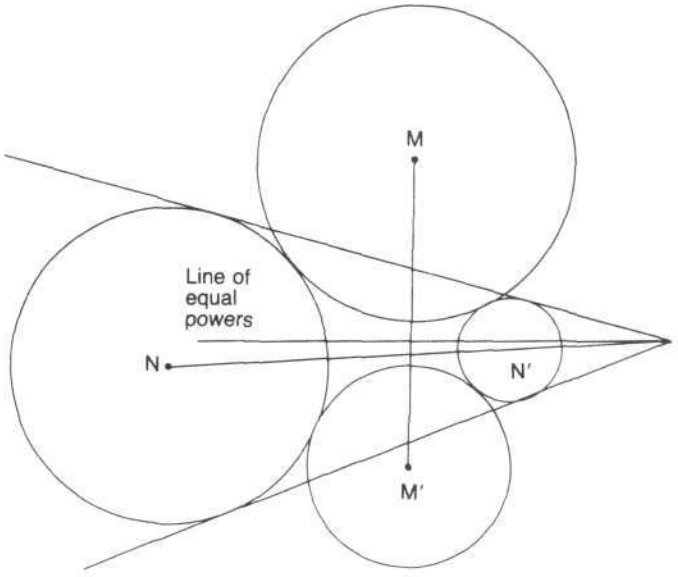
Steiner emphasized that this construction has the following remarkable property: any tangent drawn from the external point of similarity P, to all such tangent circles, will touch their circumferences at points that form a circle with P as its center. External point of similarity P will have the same power with respect to all circles tangent to circles M and M'. This power, $PA \times PA' = PT^2$, is called *the common power* of circles M and M', and assigns a definite numerical magnitude to their projective relationship.

This common power characterizes the mapping of circle M onto circle M'. If given the value of the common power, the external point of similarity, and one of the two circles, we can generate the other circle. If given circle M, point of similarity P, and the common power C, we can generate the locus of all counter-corresponding points A' of circle M' for any point A of M since

$$PA' = C/PA = PT^2/PA.$$

Georg Cantor later credited Steiner and his concept of the common power of projectively related surfaces as having played a key role in the development of his theory of transfinite manifolds. Cantor wrote that two manifolds have the same "power" if they can be mapped onto each other so that there is a one-to-one correspondence of all their points.

FIGURE 19



Projective Properties of 'Power'

The common power of two circles (or spheres) with respect to their external point of similarity, provides a way to measure the degree of wave differentiation in waves generated by a source moving faster than the speed of wave propagation in water, or moving faster than the speed of sound. At any instant, for any two wave-circles generated by a moving source, the location of that source at that instant is always the external point of similarity of the wave-circles.

The common power is zero for waves generated by a source moving at the speed at which waves propagate in water, or the so-called sound barrier. (Therefore, zero is the first "transfinite number.") The common power increases as the source exceeds the speed of sound. Figures 18(a) and 18(b) show that the common power C is related to the Mach angle α, the angle made by the two external tangents that enclose the envelope of spherical waves, as:

$$C = (PH \cos \alpha)^2 = PT^2.$$

As the Mach angle decreases, the intensity of conical action increases; the common power and the Mach number—the multiple of the speed of sound at which the source is traveling—increase. *The value of the common power designates the relative intensity of conical action.* This demonstrates that conical action is the differentiation of spherical action.

The generality of the projective property "power" is also illustrated by the following: The line of equal powers of any two circles M and M' that similarly touch circles N and N', pass through the external point of similarity of N and N' (see Figure 19); and for any two such circles M and M', their external point of similarity lies on the line of equal powers of N and N'. In yet another way, the notions "power" and projective correspondence prove to be complementary. Relationships, not objects, rule geometry.

Steiner wrote in the introductory remarks to his *Systematic Development*:

> The present work has attempted to uncover the organism through which the heterogeneous phenomena of the world of space are bound to each other. It yields a handful of entirely simple fundamental relationships, by which the schema is expressed, after which the remaining mass of theorems follows and develops without difficulty. By the proper assimilation of these few fundamental relationships, one masters the host of the entire subject; it introduces order into seeming chaos and one sees how all parts grasp each other in accordance with nature, arrange themselves in a most beautiful order in sequence, and are transformed to be unified in a well-defined body. In this way, one arrives at possession of the elements from which Nature proceeds, in order to be able—in the simplest way with the maximum economy—to teach the countlessly many characteristics of figures . . . the interdependence of forms on each other and the types and methods are discovered, as their characteristics propagate from the simpler figures to the compound ones. This connection and blending is the proper origin of all isolated statements of geometry.

This curriculum gives the reader a taste of Jacob Steiner's synthetic geometry. Even the slightest effort applied to the material listed in the bibliography will show that this opens a whole new vista of conceptual development—as intended by Steiner and his fellow reformers of Prussian drill-and-grill education.

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NASA

Payload specialist Reinhard Furrer after a blood sample was taken aboard a Shuttle flight in 1985.

Space Medicine—Getting Man Ready to Live on Mars

Space medical research not only will benefit future space colonists but also will help make every Earthling 'as healthy as an astronaut.'

by Wolfgang Lillge, MD

Space medicine can best be compared with medical care in a large hospital, the difference being that the patients who are in the intensive care unit are perfectly healthy people. Space medicine involves using every available tool needed to find out if people suffer from any observable or hidden ailments, to *prevent* them from becoming sick under the extreme conditions of space flight, and to find a fast and effective cure if they are found to be sick.

The most important task of space medicine is to explore those sources of danger to the life and well-being of astronauts that derive from conditions of outer space. This is the type of frontier medical and scientific research that will necessarily lead to new insights into the functioning of the human body and produce novel ways of treatment for diseases that are now deemed incurable.

Before mankind can venture out to live in space, important questions on the effects of zero gravity and gravities smaller than the Earth's one-gravity (1 g) must be answered. Preliminary research has shown that there are deleterious effects from microgravity, and it is not yet known if these effects are irreversible. The answers will be provided by accelerated research, both aboard the planned international space station and in variable-g laboratories orbiting the Earth that can simulate the one-seventh gravity of the Moon and the one-third gravity of Mars. These answers will help determine when and how we colonize the Moon and Mars.

Space medicine has established clearly defined standards for what a healthy individual is and how his health can be maintained and improved, because an astronaut in space cannot afford to be sick. This approach, using the most advanced technologies to keep people healthy, gives us hope that in the future everybody will enjoy the medical achievements that are today available only to a small part of humanity. Our goal as a nation should be to soon ensure that we are all *as healthy as an astronaut!*

Solving the Mysteries of Microgravity

After more than three decades of manned space travel, the National Aeronautics and Space Administration has an accumulation of knowledge that leads to an informed guess as to which problems may pose a real threat for astronauts during long-term flights in space, and which physical changes will be tolerated after a period of adaptation or will even normalize in zero gravity (Figure 1).

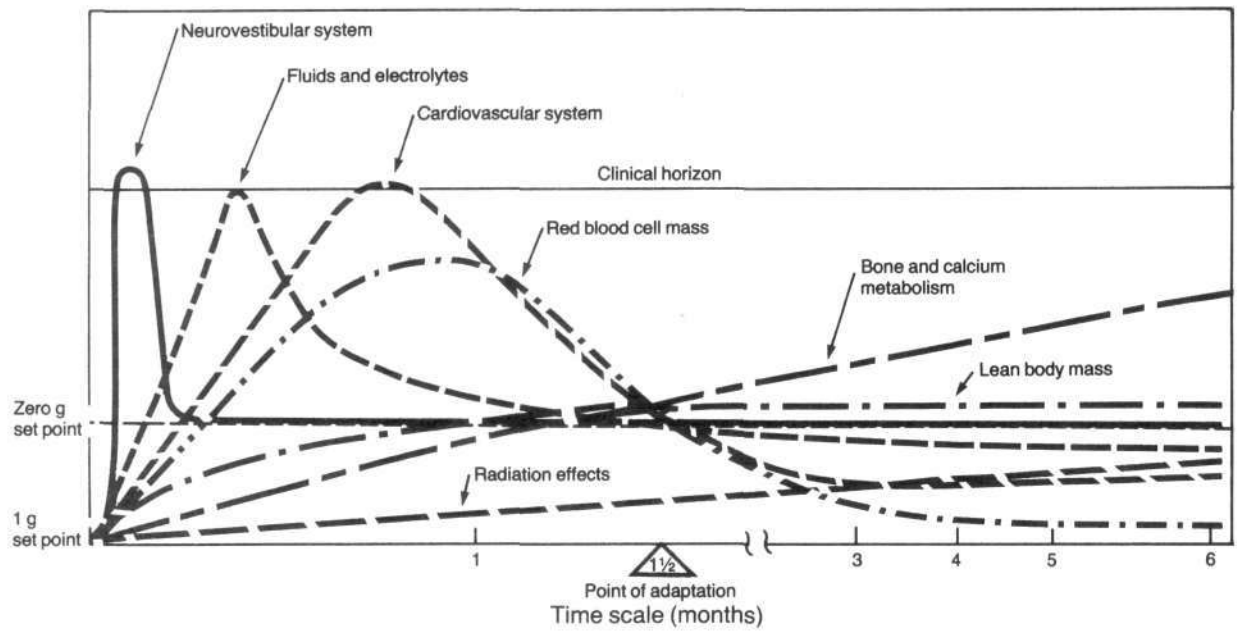


Figure 1

PHYSIOLOGICAL CHANGES ASSOCIATED WITH PROLONGED WEIGHTLESSNESS

Data from three decades of space travel have given scientists a picture of what happens to man in the zero gravity of space. Calcium loss, loss of lean body mass, and possible effects from cumulative radiation appear to increase continually. Other physiological processes undergo changes early during flight—not necessarily simultaneously—but stabilize about six weeks into the flight at levels different from those of preflight conditions on Earth.

Source: A.E. Nicogossian and J.F. Parker, *Space Physiology and Medicine*, NASA, 1982, p. 134.

However, NASA scientists and other researchers involved in these projects worldwide are still in the dark on many questions. For example, what causes space motion sickness, what causes the continuous decalcification of the bones in zero gravity, what causes changes in the immune system and the significant loss of red blood cell mass?

NASA's Life Sciences Division, which coordinates the research and the medical care for the astronauts, has identified several areas that must be researched more intensively if people are to survive in space for prolonged periods of time. These include the effects of zero gravity on the vestibular system; the effects on the immune system, blood regeneration, and fluid balance; on the heart and the circulatory system; and on bones, tendons, and muscles. New ideas and conceptions of how exactly the different conditions in space affect the human body—especially the causal relations involved—must be encouraged and developed.

The centerpiece of NASA's space medical efforts is a system of health tests and supervision for astronauts designed to monitor and evaluate all critical physiological processes. Before an astronaut candidate is accepted into the small circle of active astronauts, he is channeled through a comprehensive physical examination program developed by NASA physicians, based on the experience of training air force pilots and the proven principles of preventive medicine.

In 1958, when the first U.S. astronauts were selected to be launched into space during Project Mercury, a special task force of experts was convened to develop general guidelines and mission tasks for the age of manned spaceflight. The panel defined three basic conditions that had to be fulfilled to make manned space exploration a feasible undertaking: First, man in space has to be able simply to survive. It had to be demonstrated that astronauts could live in space and return safely to Earth. Second, it had to be demonstrated that man could perform useful work under conditions of zero gravity. And last, astronauts must be able to gather more scientific information than can be transmitted by unmanned satellites.

Later, during the Apollo and Skylab projects, it became necessary to define several other standards of qualifications as other specialists and scientists were to be launched into space in addition to the pilot.

As soon as a candidate was found competent for the job of astronaut, he was the subject of strict and continuous medical supervision, which included supervision of his family in order to minimize the possibility of close relatives transmitting infectious diseases. In all U.S. space missions to date, a strict medical program began 30 days before launch, along with the other preparations. Medical checkups were conducted during the countdown before launch on days 30, 15, 5, and 4-0, to establish the immediate flight

competency of the astronauts and, if necessary, to begin emergency treatment.

The data from these tests then served as the basis of comparison for all inflight and postflight follow-up exams. Only in this way could minor but significant changes in organ functions of astronauts be detected. Despite this intensive supervision, in almost all flights of the Apollo series (including the first Moon mission of Apollo 11) there were occurrences of illness in crew members, either shortly before launch or in flight. According to NASA, 57 percent of the astronauts suffered from such illnesses, although in most cases the astronauts had only minor flu-type symptoms.

Just before the launch of Apollo 13, however, one of the reserve astronauts came down with rubella (German measles) and came into contact with the flight commander, who was not immune. The Apollo 13 commander then had to be replaced on very short notice. As a result, NASA instituted a Health Stabilization Program, beginning with Apollo 14, whose basic feature was to isolate crew members from any possible infectious agent during the critical phase before takeoff.

The Astronauts' Health Stabilization Program

This layered quarantine program involved basic inoculations for the astronauts and their families, a comprehensive protection program against infectious diseases, and a system of rapid medical diagnosis and treatment. During the last three weeks before launch, the crew was housed in isolated quarters on the premises of the Johnson Space Center, and the following quarantine procedures were established:

- Throw-away utensils and separate headsets, microphones, and so on were used.
- The air supply was controlled using ultrasensitive filters in the air conditioning systems of the living quarters, and a slight excess pressure was generated so that used air was directed outward and only fresh air could enter.
- The food for the astronauts was purchased in special shops under the supervision of a hygiene expert. Random microbiological tests of all the goods purchased were done routinely, as well as daily inspections of the kitchen areas for cleanliness.
- Separate water supply systems were established for the work and living areas of the astronauts, and water samples were taken daily from all water fountains for microbiological tests.
- Personal contacts were limited during the critical period before launch, especially in the area where the crew was permitted to stay. Only approximately 100 persons involved in immediate launch preparations were allowed to be in contact with the astronauts. These primary contact persons were under tight medical supervision to make sure that they would not inadvertently bring in infectious diseases. No visitors were allowed to come close to the astronauts, and during the last three weeks before launch, even the astronauts' children were not permitted to see their fathers, because experience had shown that children are frequent carriers and transmitters of upper respiratory and intestinal tract diseases.

EFFECT OF HEALTH STABILIZATION PROGRAM ON INCIDENCE OF ILLNESS IN PRIME APOLLO CREWMEN

Mission	Illness	Number of crewmen involved	Mission phase
Before Implementation of Stabilization Program			
Apollo 7	Upper respiratory infection	3	Preflight, inflight
8	Viral gastroenteritis	3	Preflight, inflight
9	Upper respiratory infection	3	Preflight
10	Upper respiratory infection	2	Preflight
11	None	—	—
12	Skin infection	2	Inflight
13	Rubella infection	1	Preflight
After Implementation of Stabilization Program			
Apollo 14	—	—	—
15	—	—	—
16	—	—	—
17	Skin infection	1	Preflight

Source: Johnston, Dietlein, and Berry, *Biomedical Results of Apollo*, NASA, 1975, p. 53.

NASA

Mission specialists Dr. William E. Thornton (right) and Guion S. Bluford test a treadmill exercise device at the Johnson Space Center.

Epidemiological control also included the families of primary contact persons. The schools attended by astronauts' children provided daily reports about sickness, and the local health commissioners were asked to analyze any conspicuous case of sickness that erupted in the neighborhoods of primary contact persons.

The Health Stabilization Program was highly successful, and Apollo flights 14-17 showed a dramatic reduction in the outbreak of diseases in astronauts, both preflight and in flight (see table).

For a journey to Mars, medical precautions will assume an even greater role because the space travelers will be on their own once they have been launched on the trajectory toward Mars, and a serious illness could potentially doom the whole enterprise.

The Immune System and Zero Gravity

The effects of zero gravity on the human immune system may be the most significant problem for the long-term survival of man in space. For example, it has been observed by U.S. and Soviet researchers that microflora in isolation in the spacecraft undergo pathological changes that favor the development of potentially dangerous organisms. We must be sure that such a process will not get out of control and overwhelm the immune defenses of space travelers at a point where they already suffer from immunosuppression for other reasons.

Man will always carry his peculiar microflora into space, since complete sterilization from all microorganisms is not possible and, in fact, not even desirable. We must therefore know more about the interchanges between the human immune system and the conditions of an artificially created environment. Several important observations about how the immune system reacts to zero-gravity conditions have been made during the Space Shuttle and Skylab missions:

- The sensitivity of peripheral lymphocytes has been significantly depressed (39 percent to 82 percent) postflight in almost all Skylab crew members; this group of immune cells showed a diminished ability to react appropriately to invading microorganisms. This decreased blastogenic sensitivity of lymphocytes was detected after stimulation of these immune cells by mutagenic substances.
- Increased levels of neutrophils (another group of white blood cells) observed in many astronauts were maintained up to seven days postflight.
- Gum inflammation (gingivitis) developed in several Skylab astronauts.
- There were decreased counts postflight of lymphocytes, eosinophils, and monocytes—all immune system cells.
- Sporadic bacterial contamination of air and drinking water occurred.

All of the measurements were made on astronauts *after* they returned to Earth, because the equipment needed to do the blood analysis was not carried on board.

Soviet investigations during the Salyut 6 program of 1977-1981 confirmed the U.S. findings concerning the reduced sensitivity of lymphocytes. Soviet researchers also reported other immunological changes in cosmonauts postflight, including decreased counts of T-lymphocytes and diminished reactivity and proliferating capability of these cells. At the end of a 185-day spaceflight, blood tests of cosmonauts showed decreased values for T-helper and killer cells. Again, the reactivity of lymphocytes after blastogenic stimulation was depressed. Additionally, lymphocytes showed a decreased production of alpha-interferon, a key substance in the coordination of the human immune system.

NASA

Before man went into space, monkeys tested the effects of spaceflight. Here, monkeynaut Sam, in a protective suit, is lifted out of his flight container after a 1959 flight. He was in perfect health.

It should be noted that blood analysis of AIDS patients shows similar patterns of change, in part. As a consequence, infections that are rare or almost nonexistent in healthy humans become deadly killers for AIDS-infected people. Whatever the biological-immunological dynamic that leads to an AIDS-like syndrome in space, it is obvious that no HIV virus as currently conceived is necessary to effect the changes that are closely associated with the HIV-caused AIDS syndrome. Although it would be absurd to say that space travelers may die of AIDS, space medical research should concentrate further efforts to uncover the biological process that leads to an apparent immune incompetency in space.

Many experts tend to explain changes in blood cell counts as caused by astronauts' increased stress during critical phases of flight. Increased levels of cortico-steroids and "stress hormones" like epinephrine are mooted to be the

main cause of decreased counts of monocytes and macrophages or the increase of neutrophils postflight. Although these substances are shown to account for changes in immune system responses and there is also evidence for direct interaction between the nervous system and immune system, this theory falls short of explaining the fact (among others) that several parameters of blood analysis remain altered for a significant period of time postflight. It seems that such theories are presented because of a lack of a more convincing approach and the difficulty, at present, of conducting the many onboard experiments needed to clarify the findings.

Even if there have been no serious health problems on U.S. space missions so far, the findings concerning immune system changes are of major significance and must be followed up closely. The question might arise, can astronauts who have been in a zero-gravity environment such as the space station safely return to Earth? In July 1985, an ad hoc working group convened by the NASA Life Sciences Research Office expressed a similar view: "The good health of space crews may be deceptive because patients with severe neutrophil dysfunction can go months or even years without a major infection, only to die of an overwhelming microbial infection at a later date."

The panel of scientists from the fields of biology, medicine, and immunology referred also to the cases of gingivitis observed in several Skylab astronauts, which could reflect a neutrophil dysfunction, such as an impairment of cell-surface adhesion reactions. Patients with recurrent, severe bacterial infections associated with functional deficiencies of their neutrophils have severe gingivitis. "It is important to determine whether abnormal neutrophil function occurs in spaceflight, for, in long-term missions, impaired neutrophil function could be disastrous," the panel said.

Other findings of microbiological studies after long-term spaceflights were published by Soviet researchers in 1979. The observations included: changes in the number of representatives of normal microflora and increased number of foci of pathogenic microflora on the skin of carriers; the appearance on upper respiratory tract mucous membranes of organisms not normally present; the temporary colonization by pathogenic staphylococci on mucous membranes of previous noncarriers by intracrew microbial exchange; a tendency toward increased virulence of pathogenic autoflora; increased concentration of microorganisms including certain pathogens in cabin air and on internal surfaces; and an apparent development of microbiological and immunological conditions favoring increased susceptibility to postflight infections. Although there had not been such dramatic changes during spaceflights in the past, Soviet researchers in 1980 reported that a certain hypersensitivity to microallergens of the normal flora of the body had developed in cosmonauts during a 175-day space flight.

The Soviet findings, similar to those in U.S. spacecraft, indicate the dynamic adaptability that bacteria, viruses, fungi, and other microorganisms have when brought into a new environment. Microorganisms potentially dangerous for man, but checked by the immune system under normal conditions, may suddenly find a more favorable environment that could improve even more when there is an additional impairment of the human immune system. Since man cannot survive in an absolutely sterile condition, the question is, how can man control the microflora he brings into space in a way that is beneficial?

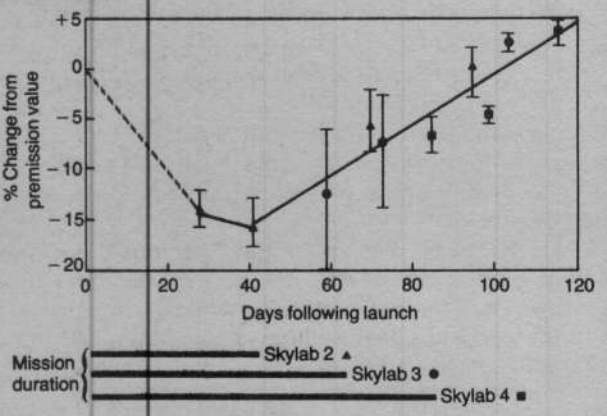


Figure 2
RED BLOOD CELL MASS IN CREWMEN OF 3 SKYLAB MISSIONS

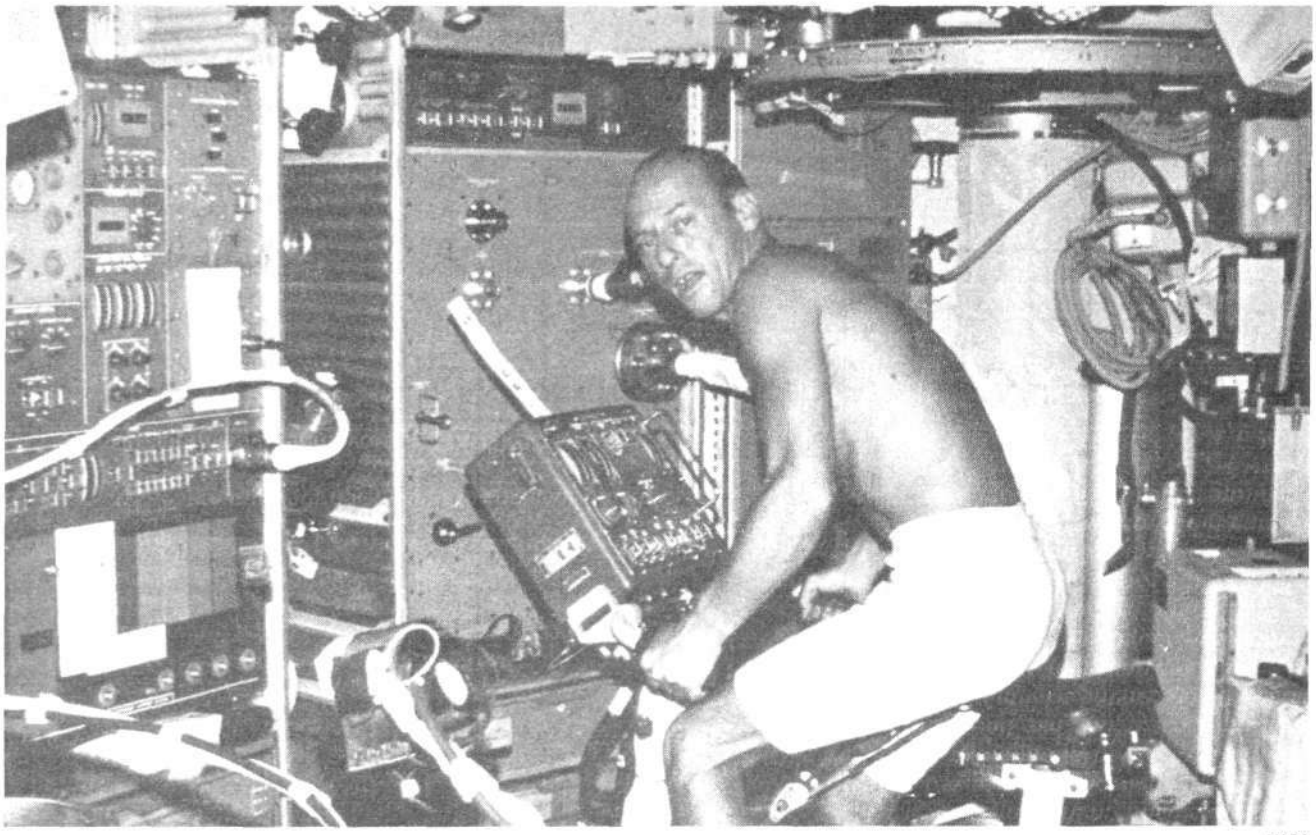
All astronauts and cosmonauts showed a significant decrease in red blood cells. Production of red blood cells begins to slow down after 30 days in space. Shown here are the recovery curves for red blood cell mass, based on both inflight and postflight measurements.

Source: A.E. Nicogossian and J.F. Parker, *Space Physiology and Medicine*, NASA, 1982, p. 213.

Interesting research about life in total isolation from normal microflora (sterile air, water, and food) concluded that such conditions lead to a significant simplification of intestinal microflora where some species disappear altogether. At the same time, the remaining intestinal flora are increasingly less able to suppress the proliferation of pathogenic strains.

In a hypothetically extreme case of simplification of the intestinal flora, space travelers returning to Earth could suffer a microbial shock that was described by a researcher as "the precipitous and harmful action of microorganisms and/or their products on the host." Maintenance of a normal, diversified intestinal microflora is considered essential as a host defense mechanism, and apparently this requires periodic reexposure to microorganisms in order to stimulate the immune system.

Two well-researched situations paralleling conditions in a spacecraft are the crews of nuclear submarines during typical 60-day patrols and personnel of South Pole stations who live in total isolation for several months. In one such station, outbreaks of common colds occurred 17 weeks after complete isolation, that is, long after the accepted incubation periods of human respiratory viruses and at a time when the introduction of new viruses was apparently impossible. There are also two reports of mid-patrol outbreaks of respiratory infections in nuclear submarine crews.



NASA

Astronaut Charles Conrad, Jr., commander of Skylab 11, exercising on a bicycle ergometer in crew quarters. Inset: This "Exer-Genie" is a physical conditioning aid used by astronauts in spaceflight. Within the cylinder, the nylon cords rotate around a shaft, developing controlled resistance for more effective body-building.

These observations raise important questions about the possible persistence and reactivation of respiratory (and other) viruses in spaceflights of long duration, especially if immunosuppression reduces the resistance of crew members. A minor malfunction of the garbage disposal system or the toilet could lead then to an explosive proliferation of microorganisms.

Changes in Blood and Bodily Fluids

A general finding in all astronauts and cosmonauts is a significant decrease of red blood cells (Figure 2). It is unclear so far whether the decrease in red cell mass is a result of intravascular hemolysis (destruction of red blood cells in the blood vessels) or of an increased decomposition in the spleen and liver.

There are also indications that the reproduction of erythrocytes in the bone marrow may be depressed under conditions of zero gravity. Several physiological feedback mechanisms seem to result in a deficient stimulation of blood cell reproduction. Only after approximately 60 days in space does the decrease in red cell counts slow down and an equilibrium on a lower level set in.

There is a close correlation between these changes in red blood cell mass and the observation that under zero gravity the whole fluid volume of the human body decreases and is redistributed toward the upper body. This is combined with a shift in the electrolyte composition of cells.

At the same time, the heart, because of lack of gravity, has to perform less work in order to maintain adequate blood circulation and pressure. This process, including the shrinkage of heart muscle, has been termed cardiovascular deconditioning. Immediately after entering weightlessness, a shift of up to 2 liters of blood and interstitial fluid from the lower to the upper half of the body occurs because of the absence of orthostatic pressure.

In this early phase, the heart and the pulmonary vessels experience a major increase of blood circulation. Pressure in the jugular vein increases, while venous pressure in the legs decreases. As a reaction to this fluid shift, the body loses up to 10 percent of its volume of fluids within the first 10 to 11 days in flight. Astronauts report head "fullness," nasal stuffiness, nasal voices, and slender legs, a syndrome astronauts have termed "puffy faces and birdlegs."

The major concern here is not so much that coronary complications may arise in space—although there was an incident of arrhythmia in one Skylab 2 crewmember—but that such complications may arise after return to the 1-gravity conditions on Earth.

All astronauts and cosmonauts have exhibited some degree of cardiovascular deconditioning upon their return to Earth, regardless of their mission length. Characteristic features are inappropriate heart rate and blood pressure responses when standing upright, when negative pressure is applied to the lower half of the body, and when other stress

experiments are carried out.

The responses include tachycardia (increased heart beat), a drop in systolic blood pressure, and narrowing of pulse pressure. Also fatigue, presyncopal signs and symptoms, reduced exercise tolerance, and impaired locomotion have been documented. Echocardiographic measurements of Soviet cosmonauts after long space missions showed a mean 25 percent decrease in left ventricular volume.

It is unclear up to which point these symptoms of cardiovascular deconditioning can be regarded as physiological adaptation and when there will be a risk that crews will suffer major complications returning abruptly to a gravity environment after spending an extended period of time in space.

Another concern is whether the cardiac muscle itself suffers irreversible damage after a long time of deconditioning in weightlessness. The basis of such concerns is animal experiments showing that the hearts of monkeys and rabbits that were immobilized horizontally for a long time to simulate weightlessness had certain histopathological changes. Even more alarming have been unconfirmed reports from the Soviet Union about atrophic changes in the hearts of the three cosmonauts who were subsequently killed in their spacecraft in June 1971 because of a sudden pressure decrease.

Space Motion Sickness

Almost half of all the astronauts suffer from "space motion sickness" in varying degrees during their stay in space. Although space motion sickness has similar symptoms to seasickness, its cause is apparently more complex. Usually, space motion sickness begins shortly after entering weightlessness, lasts for three or four days, and has a multiplicity of symptoms, including dizziness, headache, apathy, and anorexia, with pallor, cold sweating, nausea and vomiting being the cardinal symptoms. On short Space Shuttle missions, the sickness of astronauts for the first one or two days has a serious effect. In the space station, the loss of one or two days is not a disaster, for astronauts will be spending three months aboard and can have a light schedule on arrival until they adapt to the zero-gravity environment.

Space motion sickness was observed for the first time during the lunar flights. Compared to the Mercury and Gemini astronauts who were buckled to their seats, the Apollo astronauts had a large habitable volume in their spacecraft and could move around freely. The prevailing theory explaining motion sickness is that the increased mobility of the astronauts involves the flooding of eye, vestibular organ (ear), and proprioceptive (sensory) receptors with sensory input that the brain is not able to process so rapidly. After a couple of days, once the vestibular system has adapted to the new environment, all the symptoms of space motion sickness disappear.

This "flooding theory" is the most accepted explanation for the development of space motion sickness to date. However, research about the underlying mechanism is still in its beginning phase, and other explanations are possible. One such theory is that of the West German researcher, Professor R. von Baumgarten, who thinks that small innate differences in the weights of right and left statoliths (the organs of equilibrium), which are normally compensated for by the brain, may become important in zero gravity. In space, the usual compensatory mechanisms are ineffective, because the weight differential is nullified. The result is an imbalance, producing rotary vertigo, eye movements, and posture changes until the central "compensating centers" adjust to the new situation. Individuals with a greater degree of asymmetry in otolith morphology would thus be more susceptible to space motion sickness. (It was von Baumgarten's experiment in 1984, during the first West German Spacelab mission, that overthrew one of the oldest dogmas of vestibular physiology, the mechanism of the so-called caloric nystagm, which holds that there are involuntary, rapid eye movements during cooling or warming of the ear canal.)

The difficulty for researchers of space motion sickness is the fact that the vestibular organ is not directly accessible to investigation; it is part of the inner ear deep inside the cranium. The human vestibular system consists of two types of sensory receptors: the semicircular canals, which are structured to respond primarily to angular accelerations of the head; and the otolith organs, closely related to the canals both anatomically and functionally, which are highly sensitive to linear accelerations and to changes in the direction of gravity acting on the head.

These two receptor mechanisms together provide sensory information essential to the perception of body position and movement. Through several neuronal pathways in the brain, the vestibular system is connected to the visual center, to tactile and proprioceptive input, to the autonomic nervous system, and to certain voluntary skeletal muscles. These interactions have to be reorganized in weightlessness when gravitational forces suddenly disappear, and this dissociation apparently causes all the clinical symptoms astronauts suffer at the beginning of their mission.

Many scientists currently are working to develop a reliable test to determine in advance whether and to what extent an astronaut will show symptoms of space motion sickness. This could lead to finding countermeasures to adapt the vestibular system slowly to the unusual conditions in space. Current techniques have not been successful in predicting space motion susceptibility, which varies not only individually, but also within the same person over time. Astronauts with space experience appear to be less susceptible to space motion sickness than those flying their first mission.

Symptoms of space motion sickness are intensified by head and body movements, particularly when the eyes are open. In most cases, after the symptoms disappear they do not reappear for the rest of the flight. However, after their return to Earth, many Apollo and Skylab crewmen reported vestibular disturbances like vertigo and dizziness after rapid head movements and had difficulty in walking around corners.

More pronounced postflight vestibular disturbances have been experienced by Soviet cosmonauts. These include lasting postural instability, sweating while walking, dizziness, nausea, and vomiting, particularly during head movements. One of the crewmembers of the 175-day Salyut mis-

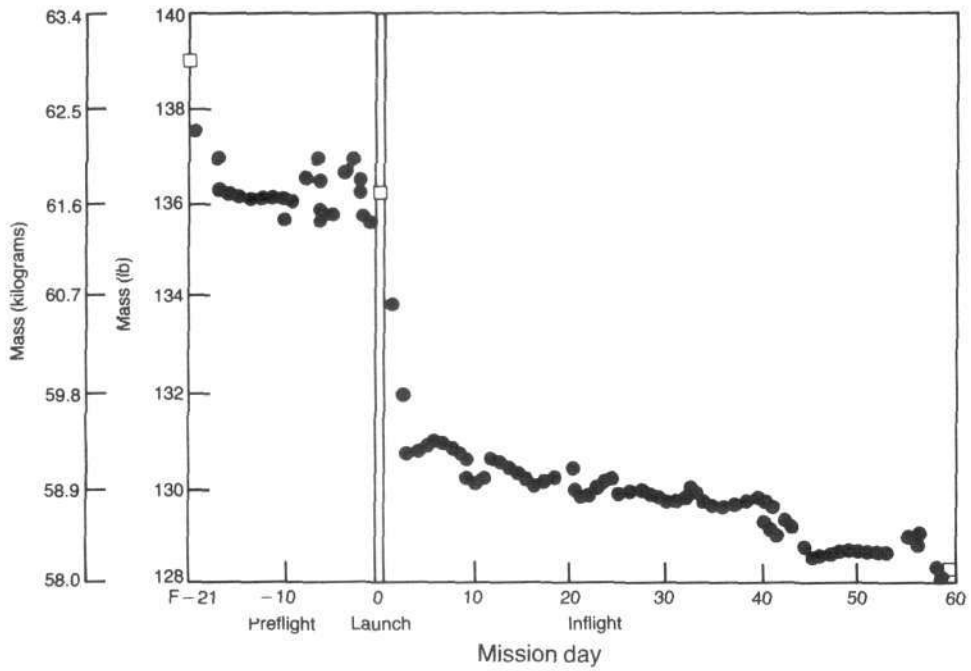


Figure 3
GRADUAL LOSS OF WEIGHT IN FLIGHT

The continuous loss of bone and muscle atrophy, in addition to fluid losses, lead to a gradual long-term loss of body mass in flight. Measured here is the weight of the scientist-pilot on the Skylab 3 mission.

Source: A.E. Nicogossian and J.F. Parker, *Space Physiology and Medicine*, NASA, 1982, p. 205.

sion experienced pronounced illusory reactions postflight. Several Soviet researchers have concluded that the degree and duration of these postflight symptoms are proportional to mission length.

A variety of approaches attempting to prevent or control space motion sickness has been introduced, but only limited success has been achieved so far. Four techniques are in different phases of experimentation: training, by increasing the level of stress to the vestibular system leading to a heightened level of adaptation; pharmacological countermeasures, using a variety of anti-motion-sickness drugs whose effectiveness varies individually and with the amount administered; biofeedback procedures that interrupt symptoms by voluntary control of the autonomic nervous system; and mechanical devices, such as head restraints to reduce movements of the head and neck (these were used mainly by the Soviets).

Bone and Muscle Atrophy

One of the most striking biomedical changes during spaceflight includes the continuous, progressive loss of bone substance and muscle atrophy that cannot be prevented even by very intensive physical training. This loss and additional fluid losses amount to a gradual long-term loss of weight in flight (Figure 3). Those bones and muscle groups affected are the ones that carry the most weight under gravity conditions—the spinal column, and lower extremities. Large amounts of calcium, but also nitrogen, potassium, and phosphorus are mobilized in the body and excreted through the kidneys and intestines (Figure 4).

Changes in the bone structure and mineral metabolism are thought to be the most threatening biomedical risks during long stays in space. Countermeasures used during space travel—intensive exercises on the treadmill, ergometer, and other equipment—are designed to simulate gravity conditions for bones and muscles.

The calcium content in urine samples starts to rise rapidly immediately after launch and reaches a plateau after approximately 30 days. But the calcium content in fecal samples increases throughout the whole mission continuously, without reaching a plateau or decreasing in any way (Figure 5). After returning to Earth, urine calcium was back to normal after approximately 10 days, while fecal calcium, in several cases, did not come down before 20 days postflight.

Metabolic balance studies based on calcium loss during the first 30 days in flight of three Skylab 4 crewmen resulted in a projection of a loss of 300 grams, or 25 percent of the initial body pool of calcium during one year of space travel. Others project that man in space will lose almost 1 percent of his bone substance every month, even with very intensive exercising. It is not clear if these mineral losses will continue unchecked during very long spaceflights or if the bone will regenerate.

From animal experiments it is known that bones become fragile when they have lost 20 to 25 percent of their mineral content. Especially in the travecular areas of the bone (the interior fine structure), the individual traveculae become thinner and thinner with time and ultimately disappear. Once they reach this point, they cannot regenerate, and it may well turn out that much of the loss of travecular bone

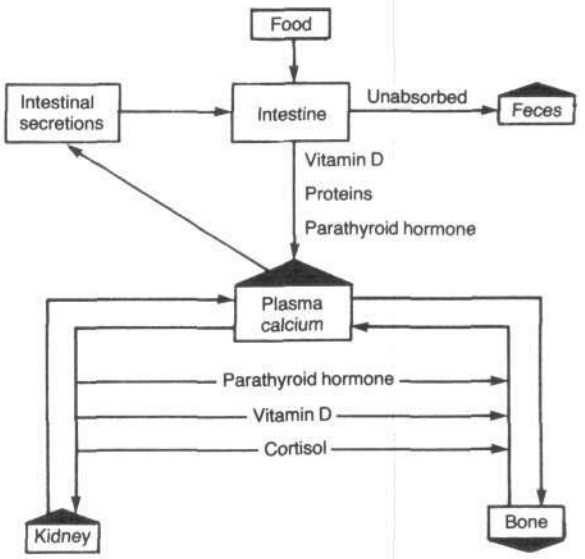


Figure 4
CHANGES IN CALCIUM METABOLISM INDUCED BY SPACEFLIGHT

Skylab metabolic studies showed increased fecal and urinary calcium associated with constant calcium intake. Most of the increased excretion is due to actual bone mineral loss. The heavy arrows indicate measured changes associated with space flight. Serum calcium is tightly controlled by regulating the calcium absorbed through the intestine and excreted in feces and urine. Bone, as the fourth important site for calcium, is in equilibrium with plasma calcium.

Source: C.S. Leach, *Acta Astronautica*, 1981.

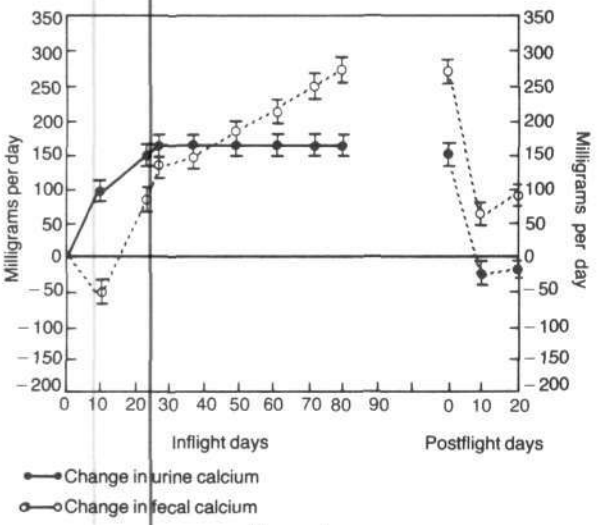


Figure 5
CHANGE IN CALCIUM AS A FUNCTION OF SKYLAB FLIGHT DURATION

The urine calcium content increased rapidly but reached a plateau after 30 days in flight. In contrast, fecal calcium content continued to increase for the duration of the flight. It is not yet clear whether calcium loss will continue unabated during long space flights.

Source: A.E. Nicogossian and J.F. Parker, *Space Physiology and Medicine*, NASA, 1982, p. 205.

is irreversible.

Thus the question becomes, if a bone fracture occurs during spaceflight, will the fragments grow together in weightlessness?

Apart from the consequences of continuous calcium loss in the bones, another complication seems to arise from the risk that kidney stones are formed in the calcium-overloaded urine. As soon as the concentration of mineral salts in the kidney tubuli becomes too high, these salts form crystals and grow into stonelike formations. Besides the danger that the flow of urine may be interrupted, there is the possibility that extremely painful kidney colics might occur, which could disable the astronaut.

The Effects of Natural Radiation

In addition to all the possible deleterious effects noted above, another reason for getting space crews to Mars as quickly as possible (in days or weeks, rather than years) using fusion-powered flight, is the level of potentially deadly natural radiation in space.

U.S. and Soviet space missions to date have demonstrated that there is not a major radiation risk for the crew on relatively short flights, when there is no occurrence of solar flares and the trajectory is carefully planned. However, with considerably longer missions or with repeated longer stays of the same crewmen in space, the problem of protection from ionizing radiation will have increasing significance.

The main sources of radiation in space are high-energy cosmic rays (composed of protons, alpha particles, and heavy ions) and solar flares, which emit high-energy particles. The most immediate target of this radiation is that human tissue that undergoes rapid mitosis, such as bone marrow, intestinal mucous membranes, and the reproductive organs, as well as the eye lens.

NASA Life Sciences Director, Dr. Arnaud Nicogossian, is studying the radiation hazards during a possible two-year round trip to Mars. He expects that at 2.5 grams per square centimeter of shielding, the radiation dose to the blood-forming organs would be about 140 rem. (Rem is roentgen equivalent man, or that dose of radiation that will cause the same biological effect as 1 roentgen of X-ray or gamma-ray radiation.) Although substantial, this amount is still below the officially acknowledged lifetime allowable limit.

The simplest solution would be to equip spacecraft and extraterrestrial habitats with a storm shelter where the crew could take refuge in case of solar flares and other short-term radiation hazards. Such storm shelters could be made more efficient by using as shielding the water carried onboard for the trip. A more imaginative—and probably more effective—proposal was made by the space scientist Wernher von Braun years ago: Provide the spacecraft with

electromagnetic shielding against energetic charged particles from the Sun.

Surviving a Round Trip to Mars?

The Apollo missions demonstrated that man can fly to the Moon, perform work there, and return safely to Earth. The next major goal of manned space exploration must be to go to Mars to establish permanent colonies. With current technology, a round trip to Mars would be a three-year mission. Today's planners proceed from the assumption that such a trip is, in fact, feasible for man; the question is, how great a risk are we willing to incur concerning the health and well-being of the crew?

We must be bold in planning to reach such new frontiers, but we must never do this carelessly. The most advanced knowledge must be applied to prevent disease during spaceflight, including any problems that may arise because of detrimental changes under conditions of zero gravity and the intense radiation environment.

The endurance record in space, held by a Soviet cosmonaut, is 326 days, and it has been assumed that flights up to one-year duration will be of no life-threatening consequence for crews in terms of bone demineralization, muscle atrophy, and cardiovascular deconditioning. However, it would seem more sensible to avoid the problems already known to exist under extended periods of zero gravity and use the most advanced future technologies to get colonists to Mars as quickly as possible.

Without any doubt, the Soviets have accumulated vastly more knowledge in space medicine than the West because of their space station efforts. However, despite Glasnost, detente, and official U.S.-Soviet cooperation, the information we have from the Soviets concerning key areas of scientific investigation is little more than scarce. Even NASA officials have only a cursory overview of Soviet flights, and published reports and studies released to the West are contradictory, censored, and incomplete. Those findings that would allow a realistic assessment of risks and dangers, and thus lay the basis for strategic decisions, are kept top-secret.

How grave are readaptation problems when crews return to gravity conditions after prolonged stays in weightlessness? What was the actual reason for the abortion of the Soviet Salyut 7 mission on Nov. 21, 1985, when cosmonaut Vasyutin became ill and needed urgent hospitalization? Is it true that another cosmonaut suffered a bone fracture after return to Earth, and what were the exact circumstances of this incident? Many more such questions are unanswered from the Soviet side, although sharing such knowledge with the West might save the lives of future astronauts and cosmonauts as well.

Despite these questions, there have long been concrete plans for sending human beings to Mars. A recent document by Nicogossian and his collaborator, Victoria Garshnek, is positive about such a possibility. They write:

> The problem at hand is not that humans are too fragile to pursue a mission to Mars or colonize the planet at some point in the future, but that we should direct our efforts and ingenuity toward providing the necessary conditions and protection that will enable humans to survive the voyage, work effectively on the Martian surface, return safely to Earth, and readjust to terrestrial conditions.

One approach for generating artificial gravity to counteract the problems of cardiovascular deconditioning and muscle and bone problems would be to rotate the spacecraft during its trip. This has been proposed, for example, by the National Commission on Space. However, providing artificial gravity in this manner may have some undesirable effects on the human vestibular system, due to complex Coriolis forces when head movements occur against the main axis of the spacecraft's rotation. Much more severe symptoms than those of today's space motion sickness could develop and the mobility of the crew could have to be curtailed significantly.

The most promising alternative for creating artificial gravity is to develop a rocket engine that would accelerate the spacecraft at 1 g or a fraction of 1 g and thereby prevent the development of major physiological problems. In addition to generating a constant gravitational force, this approach would have the added advantage of reducing the duration of the trip to Mars to only a couple of days! Such a rocket propulsion system could be realized with a fusion power reactor.

There is no doubt that mankind will return to the Moon, and then go on to colonize Mars. Space medicine will make the adventure possible, and will provide new medical science and technology that all of mankind will need, in the 21st century.

Wolfgang Lillge, a physician, is on the staff of the European Fusion Energy Foundation, based in Wiesbaden, West Germany.

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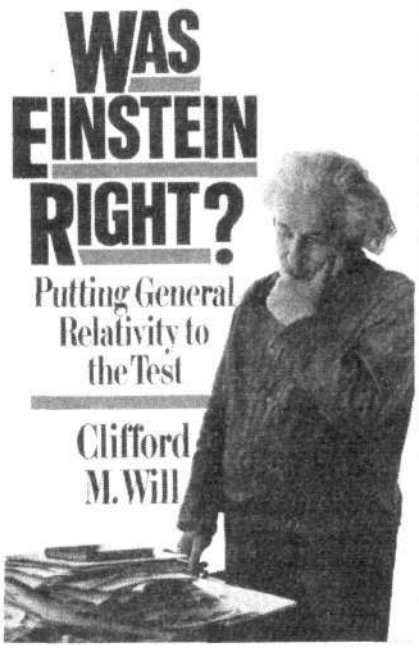
Cheerleading for General Relativity

by B.A. Soldano



Was Einstein Right?
Putting General Relativity to the Test
by Clifford M. Will
New York: Basic Books, 1986
$18.95, 274 pp., hardbound

Professor Will, a physicist who enjoys the reputation of a leading expert on the theory of general relativity, has written an extremely lucid and masterful exposition of the nature of the experiments designed to test this theory. Further, he clearly demonstrates throughout the book that he has the ability to translate the complex mathematical equations of this theory into clear prose. In that regard he has made the best case possible for the validity of general relativity.

However, Will does at times overstate his case; for example, when he claims that Einstein was confused by his unnecessary requirement that the equivalence principle and the concept of space-time curvature be inextricably interrelated. Will claims that the sole function of general relativity is to provide physics with a method of quantifying the curvature of space-time. It should be noted, however, that only because inertial and gravitational mass are equal to each other, can the fundamental undefinables of dynamics, such as mass, length, and time be reduced to geometry. Otherwise, one would have to separately account for the inertial and gravitational dynamic properties of mass.

Will presents details of the classic tests of general relativity, such as "light" bending, gravitational redshift, the time delay of speed of light, and so on, in an extremely informative and illuminating fashion. It follows, therefore, that this work is must reading for anyone interested in obtaining a de-

EDITOR'S NOTE

Reviewer Ben Soldano is the proponent of the only theory today that can account for the empirical evidence that Newton's gravitational constant is in fact a variable *quantity. Readers may be familiar with the subject matter through the popular press accounts of the so-called Fifth Force, a concept recently invented to evade the basic problem with Newton's "constant." Soldano, however, has elaborated his own theory of the nonequivalence of gravitational and inertial mass over many years. His work has received a good deal of covert attention in top scientific circles, but has been studiously ignored in the scientific press.*

Soldano, the president of Grenridge Corporation, taught university physics for 20 years and has also been a NASA Fellow at the Goddard Space Flight Center. He is writing a major article explaining his theory, which will appear in a future issue of 21st Century.

Stuart Lewis

B.A. Soldano speaking at a 1986 scientific conference.

tailed conceptual knowledge of general relativity and the challenges encountered when physicists go about testing the theory. The author also provides interesting historical vignettes of the life and philosophy of many of the scientists engaged in this effort.

Without challenging Will's knowledgeability or competence on the subject of general relativity, I must question his objectivity as implied in the book's subtitle, "putting general relativity to the test." In point of fact, his book is written from the viewpoint of a "cheerleader." That was his own expression in a recent one-hour address on the testing of general relativity before the Southeastern Section of the American Physical Society in Memphis, Tennessee.

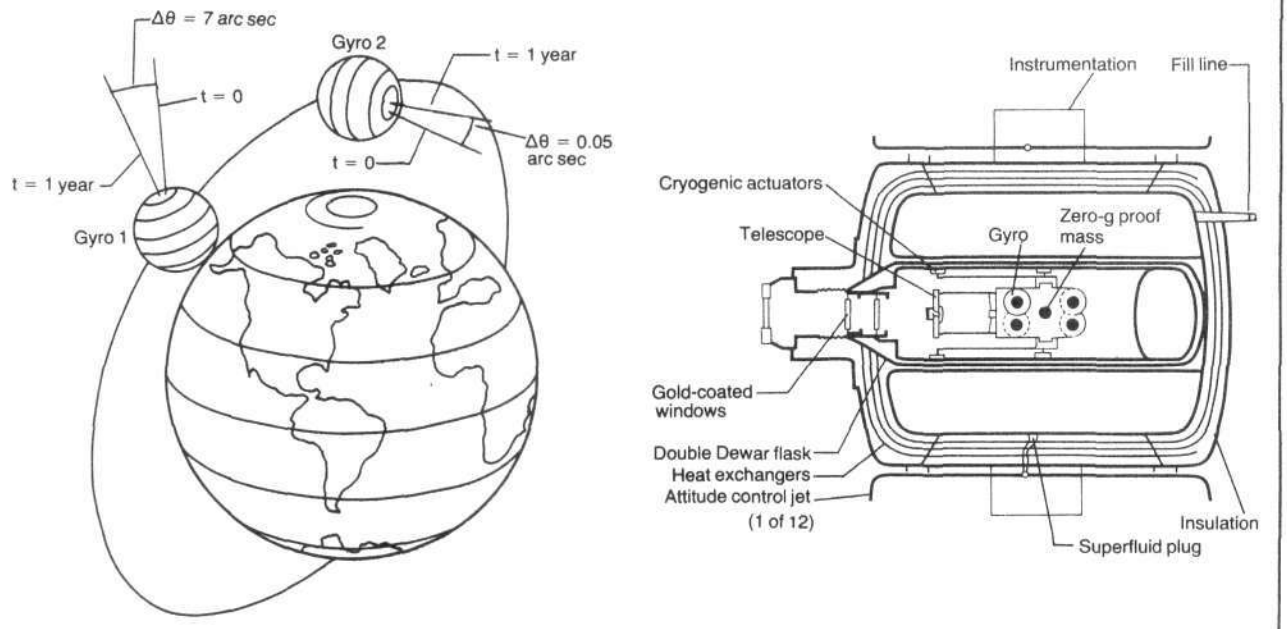
A 'True Believer'

His selection of material to be considered in the book, and the glaring omission of a successful—albeit unpopular—counterinterpretation presented to him at that same meeting (see table for an example of the information presented there) bears out his cited admission of serving as a cheerleader for general relativity. I shall show that it was a true believer and not an objective scientist who collated the testing information included in Will's book. I shall follow, for the most part, Will's chapter order.

On the subject of light-bending tests of general relativity, Will clearly details the experimental problems encountered in improving upon the original eclipse studies of Arthur Eddington. He shows that both the "visible light" bending tests and those "light" bending tests based upon radio waves, have validated general relativity to an accuracy of 1 percent. He then attributes the 1 percent limit to experimentally uncontrollable properties of the Sun, such as its violent gas emissions.

The fact that visible light and radio waves exploit two different portions of the electromagnetic spectrum and yet give the same validity limit never leads Will to wonder whether or not this 1 percent may be a real "light" bending limit to the validity of general relativity. Moreover, as a visiting expert or "judge" in the aforementioned Memphis talk, Will is well aware of the existence of a theory based on nonequivalence between inertial and gravitational binding mass, that requires that the limit of validity of general relativity relative to the bending of light be precisely 0.955 percent.

In addition, the *same* spin-dependent nonequivalence term that sets a 0.955 percent validity limit on general relativity's light bending validity, leads to the prediction that about two-thirds of the number of solar neutrinos otherwise expected to be emitted during fusion should be missing, since, to the extent that nonequivalence exists, neutrino emission is not required for



EARTH 'DRAGS' THE METRICAL FRAME OF A SATELLITE

General relativity predicts that the metrical frame of a satellite orbiting the Earth is "dragged" by the Earth's moment of inertia and spin. An elaborate, two-satellite gyroscope experiment has been designed by a Stanford University team to test the prediction. Reviewer Soldano has no doubt that the prediction will be confirmed.

A fused-quartz gyro the size of a ping-pong ball and spherical to within 0.4 millionths of an inch will be coated with superconducting niobium. In a superconducting state, a field of 0.5 volts will suspend it in weightless space (right). The telescope locks onto a guide star to keep the axis constant.

For the gyro whose axis is parallel to Earth's, general relativity predicts a rotation of 7 seconds of arc per year (left). For the gyro whose axis is perpendicular to Earth's, a rotation of 0.05 arc seconds per year is predicted.

the purpose of conserving energy and spin.

Further, the identical nonequivalence term used in setting the light bending general relativity validity limit requires that the real portion of CP invariance (charge and parity invariance) be violated to about 2.3×10^{-3}. At present, each of the above problems is being treated as one of three, apparently independent, major theoretical difficulties facing the physics community.

Throughout, the book Will makes much of Occam's razor, the minimization principle, as a justification for his strong partiality for general relativity. It appears that this principle applies only when it reinforces the scientifically and politically popular point of view in favor of general relativity.

Redshift Experiments

Will clearly points out that gravitational redshift experiments in relativity are a test of the equivalence principle. They are the gravitational analogue of the well-known Doppler principle.

He discusses in detail the Vessot rocket test of the gravitational redshift, and he lucidly describes the clever computer-controlled electronic techniques that were employed to null out the much larger Doppler electromagnetic effects encountered when a clock in an accelerating rocket must be compared with its ground-based equivalent. Will concludes that the Vessot upper limit of $\leq 2.5 \pm 70 \times 10^{-6}$ constitutes one of the most sensitive confirmations of the validity of general relativity. Will also describes in detail the other famous gravitational redshift test conducted by Rebka and Pound in their "dropping" tower located on the Harvard campus. In essence, Rebka and Pound were able to weigh a "falling" photon, thereby setting a 1 percent upper validity limit to general relativity. This Rebka-Pound experiment is clearly normalized to the Earth. Will, however, remains mute concerning the gravitational redshift results of Turneaure et al., that are normalized relative to the Sun.

In the Turneaure tests, an upper validity limit of *2 percent* was established. From a general relativity standpoint, there should exist no difference in the validity limit in any reference frame. In a theory based on nonequivalence in gravitational binding, however, it is profoundly important what reference frame is used for normalization of the gravitational redshift results. This follows from the fact that the packing fraction that quantifies the gravitational binding energy on each planet, and therefore the limit of validity, can vary widely. It follows, therefore, that the limits of validity set by nonequivalence in gravitational binding should vary widely depending upon the normalization frame used.

Specifically, the nonequivalence in gravitational binding for the Sun requires a validity limit to general relativity of 2.045 percent, a value in close agreement with the Turneaure experimental result. On the other hand, gravitational redshift experiments normalized to the Earth should encounter a nonequivalence validity limit to general relativity of 1.2×10^{-11}, a value far smaller than those found by both Rebka-Pound and Vessot.

In fact, if one makes the reasonable assumption that the Vessot rocket test at the rocket's apogee was in reality normalized to both the Sun and the Earth, then the geometric average of the two nonequivalence validity limits (that is, for the Sun 2.04 percent and for the Earth 1.2×10^{-11}) should constitute the true general relativity validity limit for the Vessot test. This calculated nonequivalence validity limit of 0.49×10^{-6} compares very favorably with the experiment upper limit of $2.5 \pm 70 \times 10^{-6}$ set by Vessot.

In point of fact, the Vessot experiment, because of its high degree of accuracy, might well constitute a strong confirmation of the fact that nonequivalence in gravitational binding is limiting the validity of general relativity in these gravitational redshift experiments.

Planetary Gravitational Binding Energy

Will is well aware of the importance of testing the applicability of the equivalence principle to the gravitational binding energy of the planets. In his book he devotes considerable attention to Professor Nordtvedt's examination of this question. He describes how Nordtvedt, a member of the California Institute of Technology group that dominated the testing of general relativity, evolved in the early 1970s a phenomenological mathemat-

PRESENT EXPERIMENTAL LIMITS OF VALIDITY OF GENERAL RELATIVITY AND THOSE REQUIRED BY NONEQUALITY BETWEEN INERTIAL AND GRAVITATIONAL SELF-BINDING MASS

(a)	(b)	(c)	(c′)	(d)		(e)
1	SE/GRM	0	$\sim 7 \times 10^{-12}$‡	5.05×10^{-12}	=	$[(m_i - m_G)/m_G]$
2	WE	0	$\sim 1 \times 10^{-12}$‡	4.21×10^{-15}	≥	$f_{gk}[m_i - m_G)/m_G]$
3	WE	0	~0.02§	0.02045	=	$\Delta\Theta_\odot/(41.^\circ 84)_\oplus$
4	WE	0	~0.01‡	1.2×10^{-11}	=	$\Delta\Theta_\oplus/(41.^\circ 84)_\oplus$
5	WE	0	$(2.5 \pm 70) \times 10^{-6}$‡	0.49×10^{-6}	=	$\sqrt{(\Delta\Theta_\odot \Delta\Theta_\oplus)/(41.^\circ 84)^2_\oplus}$
6	WE &	0	$\sim 1 \times 10^{-3}$‡	0.74×10^{-3}	=	$(\Delta T/T)_\odot$
6′	TRI	0	$\sim 10^{-4}$	4.2×10^{-13}	=	$(\Delta T/T)_\oplus$
7	SE/GRM	0	~0.01‡	0.009549	=	$[1 - (\Delta\Theta_\odot)/(\pi/2)]$
8	SE/GRM	0		0.02045	=	$\Delta\Theta_\odot/(41.^\circ 84)_\oplus$

Table columns are:
(a) experiments 1-8, described below;
(b) principle tested [strong or weak equivalence (SE or WE), metric of general relativity (GRM), time reversal invariance (TRI)];
(c) fractional theoretical and (c′) experimental deviations from values predicted by general relativity;
(d) fractional derivation from general relativity result required by nonequivalence theory;*
(e) description of the nonequivalence corrections in column (d).

Rows give the experiments:
(1) Nordtvedt test of lunar motion relative to Sun and Earth;
(2) Dicke-Braginski-Eötvös type;
(3) solar redshift (location dependence);‡§
(4) Rebka-Pound terrestrial gravitational redshift;
(5) Vessot rocket, gravitational redshift (normalized to both Sun and Earth because of altitude);
(6) Shapiro time delay test, in reality a solar normalized test of time reversal invariance $(\Delta T/T)_\odot$;
(7) quasar "light" deflection by Sun;
(8) advance of Earth's perihelion.

Some terms in (e) are related by

$$\Delta\Theta_k = M_k[f_{gk}(m_G - m_i)/m_G](\hat{u}_n \cdot \vec{\omega}_{k,\text{surface}})/(\Delta m/\Delta t)_\odot,$$

where $(\Delta m/\Delta t)_\odot c^2$ is the luminosity of the Sun, k is for $\text{Sun}_\odot$ or $\text{Earth}_\oplus$, f_{gk} is the appropriate gravitational packing fraction, and $\hat{u}_n$ is a unit vector normal to the ecliptic plane. For $(41.^\circ 84)_\oplus$, see B.A. Soldano, *International Journal of Fusion Energy* **3** (3):16.

Notes

*B.A. Soldano, *Bull. Am Phys. Soc.***29** (4):683 (1984).
‡C. Will, *Sky & Telescope* **66** (4):294 (1983).
§J. Turneaure, et al., *Phys. Rev. D.* **27** (8):1705 (1983).

The existence of a universal fractional nonequivalence between inertial and gravitational self-binding explains the deviations in experimental results testing the general relativity theory.

ical technique of testing the various forms of general relativity.

According to Will, Nordtvedt "proved" that the behavior of the gravitational binding energy of the planets was also consistent with general relativity. In this regard it is significant that Will makes only a one-line mention of the 1976 Viking Lander experiment conducted by Shapiro et al., that tested the gravitational binding energy of the Sun, Earth, and Moon. Shapiro claimed that his three-body test of the equivalence principle as applied to their gravitational binding energies was null to an upper validity limit of $\leq 7 \times 10^{-12}$. He did acknowledge, however, that his results actually deviated from null by two standard deviations.

The theory of nonequivalence in gravitational binding originally posited in 1969, and to which I have been continually referring, requires the existence of a universal fractional nonequivalence between inertial and gravitational self-binding mass equal to 5.05×10^{-12}, a value comparable to Shapiro's "null" 7×10^{-12}.

The overall magnitude of this effect, therefore, in any experiment is the product of the gravitational packing fraction f_{gi} and the universal $[(m_i - m_C)/m_C] = 5.05 \times 10^{-12}$. The quantity f_{gi} can vary from about -10^{-72} for two nucleons to about -8×10^{-4} for a highly collapsed, massive star.

Time Variation

Will's selectivity continues in his examination of the question of a possible time variation in Newton's gravitational constant G. He not only brilliantly outlines the theoretical consequences of a time variation in G, that is, dG/dt, but he is one of the few general relativists willing to admit the truth; namely, that general relativity is incompatible with dG/dt. In attempting to find any manifestation of dG/dt, he searches for effects such as a decrease in the Earth's spin that would obtain if the relatively large effect,

$$(dG/dt)/G = (1/20 \text{ billion})(1/\text{year}),$$

posited by van Flandern, did exist.

Will shows that the experimentally measured fractional decrease in the spin of the Earth, $(\Delta\omega/\omega)_\oplus \cong 1.5 \times 10^{-3}$ sec/century, and a related decrease in the orbital motion of the Moon are both too small to be compatible with the magnitude of $(dG/dt)/G$ posited by van Flandern. He further concludes that any remaining doubt about a constant G lies in the well-known difficulty of defining the proper mix of body and oceanic tidal effects that are required to quantify the decrease in the spin of the Earth.

Will's position is extremely interesting because he is well aware of the upper fractional limit for $(dG/dt)/G$ set in 1983 by Heiling et al. at $\leq$ (1/ 500 billion)(1/year). Why does he ignore this far more stringent upper limit? I will

posit a possible explanation.

The cited theory of nonequivalence in gravitational binding requires the existence of a local fractional terrestrial time variation in G of $(dG/dt)/G_\infty$ = (1/ 458.7 billion)(1/year) that accounts in part for the ~0.7 percent range dependence of G. This theory also requires that the fractional time dependence of G be planetary dependent.

Significantly, the terrestrial variation in G required by nonequivalence leads via Equation (1) to a fractional terrestrial spin decrease, $(\Delta\omega/\omega)_\oplus = 1.61 \times 10^{-3}$ sec/century, a value that is comparable to the best estimates of $(\Delta\omega/\omega)_\oplus$ based on long-term astronomical evidence. The 173 days in Equation (1) is the well-known oscillation period of the Moon's orbital plane arising from its interaction with the Sun and Earth.

$$\Delta\omega_\oplus = \tfrac{1}{2}(\omega_\oplus - 0)[(dG/dt)/G_\infty] \times (P = 173 \text{ days}) \quad (1)$$

The use of this sharply defined period describing a three-body interaction enables one to avoid the body-oceanic tidal fractional difficulty encountered in the conventional tidal three-body description.

Further, the related product,

$$2\pi\,(dG/dt)/G_\infty = 2''.825 \times 10^{-4}/\text{century}$$

precisely agrees with the astronomically measured drift in the orbital mean motion of the Moon that should accompany the slowing down of the Earth's spin. We therefore can conclude that the fractional time dependency of G required by nonequivalence not only fits the astronomical observations, but also is the only value that has been independently confirmed by Heiling et al.

The Two-Satellite Experiment

In one of the final chapters, Will outlines future experiments designed to test general relativity. He discusses in great detail the Lense-Thirring two-satellite gyroscope experiment. This extremely expensive, albeit ingenious test, whose preparation has occupied the better part of the last two decades, is designed to search for a general relativity prediction that the metrical frame of any satellite orbiting the Earth is "dragged" by the Earth's moment of inertia and spin.

Since the nonequivalence in gravitational binding term depends upon both the spin of the Earth and its orbital motion about the Sun, it should constitute a perturbation of the general relativity Lense-Thirring term and its related solar geodetic effect. In fact, I can firmly predict the results of the proposed experiment. They will confirm the existence of both the Lense-Thirring and the geodetic solar term.

Because this nonequivalence spin orbital term is time-like and represents a perturbation of the time-like Lense-Thirring metric drag term, I predict that the resultant product will be found to be quantitatively linked to the *square* of its space-like Schiff metric drag analogue, through the intervention of a space-like, terrestrial nonequivalence antigravity effect $(\Delta g/g)_\oplus = 0.68 \times 10^{-10}$. This anti-acceleration term will be found to be common to all objects falling to the Earth's surface.

In closing, I suggest that Will has already presented us (pp. 120-121) with an explanation of his general philosophical approach to "the scientific search for truth." Muhleman and Reichley discovered the existence of a speed-of-light time delay prediction within the mathematics of general relativity prior to its independent identification by I. Shapiro in an article in *Physical Review Letters*. Will claims that priority for discovery clearly must go to Shapiro, since his work was refereed by another expert and therefore bears the imprimatur of those who at present control the American Physical Society.

This standard for discovery of truth is comparable to that employed by the Roman church in the case of Galileo. Since Galileo's work did not possess the papal imprimatur, it could not possibly represent truth.

A Man Who Loved Both the Stars and Great Music

by Warren J. Hamerman

A Man Who Loved the Stars: The Autobiography of John A. Brashear
John A. Brashear
Pittsburgh: Univ. of Pittsburgh Press, 1988
190 pages, $19.95 cloth, $9.95 paperbound

This is the inspiring autobiography of John Brashear, an extraordinary millwright of Pittsburgh during the late 19th century, who, after full days in the iron mills, worked late into the night in his home workshop building telescopes, grinding astronomical lenses, and studying the heavens. Brashear so revolutionized the technology and precision in astrophysical instrumentation, that he became the world's foremost builder of astronomical instruments of his day. As his fame grew, he collaborated directly with most of the leading astronomers of America and Europe.

Brashear lived from 1840 until 1920, and by the end of his career, his precision telescopes, stellar spectroscopes, mirrors, and scientific optical instrumentation were the prized possessions of observatories, colleges, and other learning institutions throughout Europe and the United States.

Before his astronomical avocation became his day's work as well, he typically rose at about 5:30 in the morning to get to the mill on time. He would arrive back home at 6:00 in the evening, and then, after supper, he would work with his devoted wife well past midnight, grinding lenses or observing the stars. Despite becoming a friend to all the leading astronomers of his time, he nonetheless always delighted in patiently giving ordinary laborers, children, and common people their first look at the beauties of the skies through one of his telescopes.

Brashear wrote, "For not only did I desire the privilege of seeing the beauties of the heavens myself; I dreamed of a day when all mankind, every boy and girl, might have that privilege, too."

Besides his passion for astronomy, Brashear was an enthusiastic devotee of classical music. He was the choir leader of his church chorus and the organizer of a citywide cantata society,

and he composed several musical pieces. He was a tenor and his wife a soprano who sought out musical friends all their lives.

Brashear's autobiography is a work in the tradition of Benjamin Franklin's classic autobiography because of the way in which it unifies the pursuit of scientific truth with a broad vision of morality that is based upon the joy of uplifting one's fellow men to a higher state of knowledge about the beauty of our universe. Were our nation to rededicate itself to a mission of space exploration again, men and women in this mold will not seem such a rarity.

Brashear wrote: "Perhaps some of the good people will read these reminiscences who have been fellow workers in the domain of our beautiful science of astronomy and astrophysics and who have helped me to 'push forward the frontiers of human knowledge.'. . . But, after all, my one big hope is that my humble effort in jotting down these items from life's memorandum book may help some struggling soul to master some of the problems of life and of the beautiful in science, which will contribute new chapters of discovery to the now unknown and help to make this old oblate spheroid move smoother on its axis."

Brashear's autobiography first appeared in 1924, four years after his death. Readers of this work will be richly rewarded by a man who makes your vision swell and your hopes soar.

BOOKS RECEIVED

Superconductors—Conquering Technology's New Frontier, by Randy Simon and Andrew Smith. Plenum Press, 1988. Hardcover, 326 pp., $23.95.

Space 2000—Meeting the Challenge of a New Era, by Harry L. Shipman. Plenum Press, 1987. Hardcover, 431 pp., $19.95.

Darkness At Night—A Riddle of the Universe, by Edward Harrison. Harvard University Press, 1987. Hardcover, 293 pp., $25.

Gravity's Lens—Views of the New Cosmology, by Nathan Cohen. John Wiley & Sons, 1988. Hardcover, 237 pp., $19.95.

The Star Guide—A Unique System for Identifying the Brightest Stars in the Night Sky, by Steven L. Beyer. Little, Brown, 1986. Paperback, 404 pp., $11.95.

Astrophysics of the Sun, by Harold Zirin. Cambridge University Press, 1988. Hardcover, 433 pp., $49.50; paperback, $22.50.

Global Change in the Geosphere-Biosphere—Initial Priorities, by the U.S. Committee for an International Geosphere-Biosphere Program, et al. Washington, D.C.: National Academy Press, 1986. Paperback, 91 pp. Available without charge from the Board on Atmospheric Sciences and Climate, 2101 Constitution Ave. NW, Washington, D.C. 20418.

Shock Tubes and Waves—Proceedings of the 16th International Symposium on Shock Tubes and Waves, Aachen 1987, edited by H. Grönig. VCH Publishers, 1988. Hardcover, 952 pp., $125.

Archaeometry—An Introduction to Physical Methods in Archaeology and the History of Art, by Ulrich Leute. VCH Publishers, 1988. Hardcover, 176 pp., $25.

The Molecular Biology of Receptors—Techniques and Applications of Receptor Research, edited by A.D. Strosberg. VCH Publishers, 1988. Hardcover, 235 pp., $57.

In This Issue

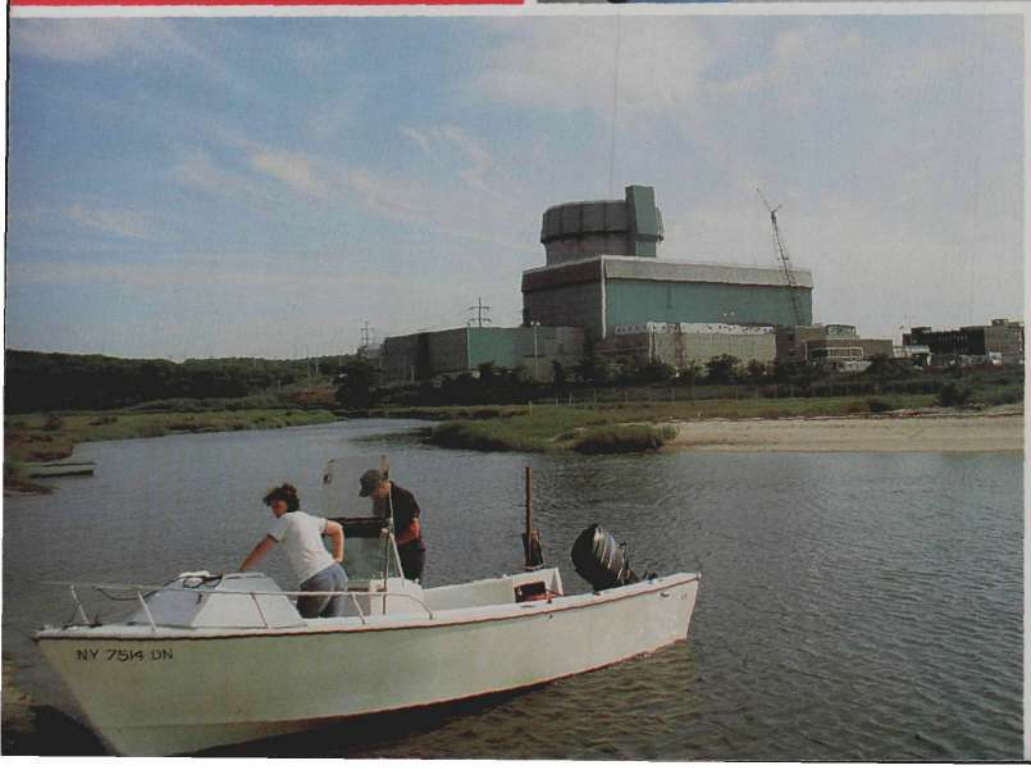
'AS HEALTHY AS AN ASTRONAUT'

The mission of space medicine is to study the effects of factors like weightlessness, to prevent and treat diseases, and to create the conditions that will enhance the functioning of man in space. However, as Wolfgang Lillge explains, one spinoff of this intensive medical study is that everyone on Earth could be made "as healthy as an astronaut": Resolving the problems identified by U.S. and Soviet space scientists will require breakthroughs that touch on every aspect of the body's functioning.

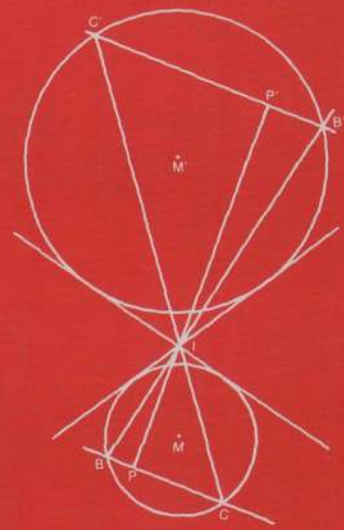
Senator Jake Garn, aboard a 1985 Shuttle flight, conducts a medical experiment on himself for gastric motility.

NASA

Carlos de Hoyos



Steiner showed how to construct parallel lines using a compass, ruler, and no axioms.



STEINER'S SYNTHETIC GEOMETRY AND CREATIVE THINKING

Education reformers in 19th-century Prussia designed a curriculum to produce thinking citizens, in which the synthetic geometry of Jacob Steiner was a central feature. The reformers threw out "drill and grill" memorization of axioms and substituted Steiner's curriculum of constructions with a compass and straightedge, taught using the Socratic method. Robert Gallagher presents a synthetic geometry curriculum based on Steiner's work that is suitable for beginners of all ages.

WHEN WILL THE LIGHTS GO OUT?

Electricity availability may soon have to be rationed in the United States, as it is now in Third World countries. Marsha Freeman reports that the grim state of the U.S. power grid is the predictable outcome of 10 years of attacks on the electricity system by antinuclear extremists and austerity-minded regulators and financial interests. Electricity demand is projected to increase at double the rate of the planned increase in capacity over the next decade. For the first time in history, the United States is headed for unpredictable power outages.

If the beleaguered Shoreham nuclear plant in New York is demolished as the antinukes plan, Long Island residents will pay more for electricity and suffer guaranteed brownouts.