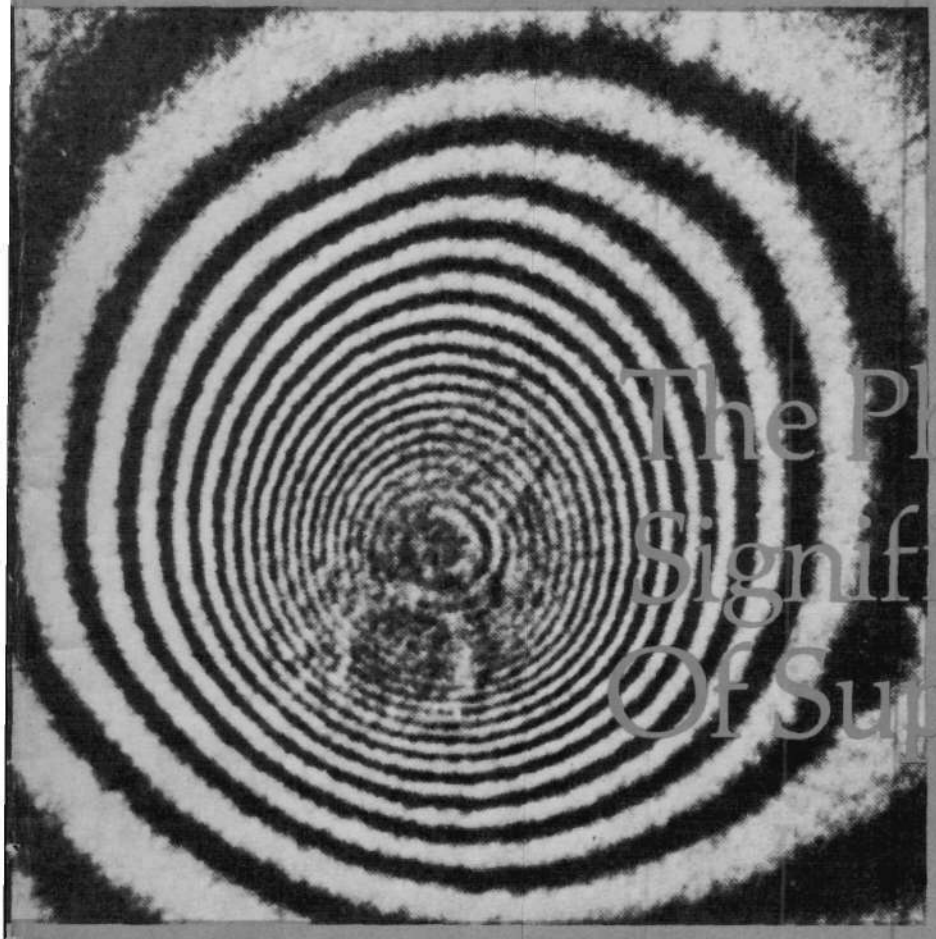
FUSION

MAGAZINE OF THE FUSION ENERGY FOUNDATION



The Physical Significance Of Superfluidity

- *Who's Really Sabotaging Fusion Power?*
- *Technological Cooperation and SALT*
- *Report on the FEF Mideast Conference*

March 1978

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FUSION

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Fusion Power: The Strategic Core

Fusion research and development, which has figured prominently in strategic calculations since the Manhattan Project, is now at the very center of the world strategic configuration. United States fusion policy will be the basis either for the greatest period of prosperity the world has ever known or for the opposite possibility, a thermonuclear conflict the U.S. will not survive. We do not exaggerate in the least the seriousness of the present conjuncture, nor the significance of fusion policy within this reality, as a review of the following features of the current global situation makes clear.

(1) The world economy as a whole, including that of the U.S., is now operating below the breakeven point of real profitability. Real profitability is measured by the ability to produce a net productive surplus that can be applied to new productive technologies which, in turn, cheapen the relative cost of social production. Instead, plant and equipment are being run down and the economy is operating far below even its present capacity.

(2) This has led to an exponentially increasing ratio of debt — largely unpayable — to equity and has cut the vital trade relationship between the high technology exports of the advanced sector and the developing markets of the Third World. In short, the world is in a self-feeding downward spiral of underproduction, inflation driven by speculation, and a lack of capital investment in new production technologies and in development projects.

(3) The only nation in the world for whom this is a natural state of affairs is industrially moribund England. This nation, particularly the City of London merchant banking center and its related thinktanks, is also the source of the ideologies that rationalize the world crisis with euphemisms like labor-intensive production, culturally appropriate and soft technologies, and environmentalism based on zero growth.

(4) The American System, in contrast, is for the technologically driven ex-

pansion of net surplus. If, under the above conditions, the U.S. turns to the British System rationalization of industry and agriculture accompanied by a buildup-in-width of scientifically stagnant military production, conflict with the Soviet Union is ensured.

(5) The current strategic balance tips marginally in favor of the Soviet Union. This results from the Soviets' psychological commitment to a total nuclear war-fighting strategic doctrine and civil defense, combined with a capability to deploy ABM and communications-jamming that is based on their qualitative advances in plasma and fusion research.

(6) The solutions to the strategic crisis and to the crisis of political economy for the U.S. in large part overlap. Precisely those areas of research and development and production that most quickly can reverse the U.S. balance of payments and catalyze the economy as a whole — the nuclear and aerospace sectors — also are the basis for 99 percent of military research and development. If the U.S. increases its financing of the Export-Import Bank to the $200 billion a year level to make possible nuclear fission exports of $50 billion annually, and if the U.S. simultaneously offers the Soviets vastly increased collaboration under the 1973 joint U.S.-Soviet scientific agreement, both crises could be resolved.

Fusion plays a twofold strategic role. First, it represents the most advanced scientific form, the cutting edge, of collaborative U.S.-Soviet technological efforts that form the basis of entente. Second, the rapid proof of fusion's economic viability and its guaranteed development in this century, are necessary to justify the rates of industrial and energy growth (in the range of 15 percent a year) that will be required to break the depression spiral and get the world economy in shape for the coming transition to technologies based on fusion and plasma. Despite these scientifically known facts about fusion, Energy Secretary James Schlesinger has slated the fusion budget for a $100 million cut and has continued to prohibit direct cooperation with the Soviets because of U.S.-British "antiproliferation" agreements.

The nation's most vital interests demand an end to this sabotage. Before it's too late, we must gear up a new Manhattan and Apollo Project, an international entente, and, most of all, we must restore the American system.

Support the NAACP on Energy !

In the few weeks since the National Association for the Advancement of Colored People began its fight for an energy program based on growth and high technology instead of zero-growth and conservation, the battle lines have been sharply drawn.

On the one side are the environmentalists, the liberals, and the Tories and assorted Neanderthals of the administration whose vision of the future is an America of windmills, cottage industry, and large-scale manual labor projects modeled after those of Hjalmar Schacht, Hitler's finance minister. On the other side is a political coalition of industrialists, labor leaders, Democrats and Republicans, scientists, — and three-quarters or more of the American population who want to continue this country in the tradition in which it was founded: human progress.

The NAACP put the facts plainly: jobs and living standards depend on increased energy consumption, and the key to increased energy is the development of nuclear power. A no-growth energy policy is not is the interest of Black Americans—nor any other Americans.

The backlash from the zero growthers was swift, and in many cases it smacked of a racism not usually seen publicly even in liberal circles. But now, the tide has turned. The nose-diving dollar and the visible collapse of the U.S. economy have pushed to center stage increasing numbers of leaders who represent that three-quarters of the population committed to progress and

Continued on page 4

Calendar

March

1-3
High Temperature Plasma Diagnostics,
American Physical Society,
Los Alamos, N.M.

5-8
Fuel Cycle Conference,
Atomic Industrial Forum, New York City

6-10
Symposium on Export
of Nuclear Power Plants, IAEA, Vienna

13-18
Nuclear and High Energy Physics,
IAEA, Heidelberg

27-29
17th Symposium on Engineering
Aspects of Magnetohydrodynamics,
Stanford University, Stanford, Calif.

April

3-7
3rd International Conference
on Plasma Surface Interactions in
Controlled Fusion Devices,
Abington, U.K.

4-8
Conference on Reactor
Licensing Safety,
Atomic Industrial Forum,
Phoenix, Ariz.

9-13
Gas Turbine Conference and Show,
American Society
of Mechanical Engineers,
London

16-18
5th Annual Conference: Energy,
American Society
of Mechanical Engineers, Tulsa, Okla.

17-19
American Power Conference,
American Society
of Mechanical Engineers,
Chicago

17-20
10th National Atomic
and Molecular Physics Conference,
Atomic and Molecular Physics Group,
Egham, U.K.

The Lightning Rod

My Dear Friends,

The most astounding thing is happening here in North America. Suddenly we are swamped in press accounts of nuclear radiation danger from the most curious sources. It began some weeks ago, with the reentry of the Soviet Cosmos 954 satellite into the Canadian tundra. Four of Her Majesty's Royal Canadian Mounties were sent immediately to guard a six-foot hole 200 miles from the nearest human inhabitant. Stories — later all traced to Secretary Schlesinger's Department of Energy — warned of continentwide contamination, or alternatively, the threat of nuclear "bombs" circling over us, ready to fall day or night. But the worst was yet to come; Rupert Murdoch's *New York Post* warned: "Up to 20 Eskimos and Fur Trading Indians May Be Evacuated."

Living as I do on the Eastern Seaboard, I know the influence of the British Malthusians on the nation's press, and such tales no longer frighten me. Consider: We have tamed Nature's lightning into electricity (and myself gotten a few shocks in the process). Surely nothing man can place into the heavens for his own use need turn into a malevolent, uncontrollable terror. This reasoning may lack the subtlety of our "environmentalists," in whose fitful nightmares demons arise from our every scientific achievement, waiting like Frankenstein's monster to avenge their creation by destroying us. But according to my poor common sense, the following points seem most pertinent:

(1) Nonexistent dangers to tundra and caribou aside (as predictably, no radioactive danger ever materialized), the important news of Cosmos 954 bearing on our future is that Soviet science has achieved breakthroughs in miniaturizing fission reactors and that this has immediate implications for expanding satellite use and space travel (!) through collaborative U.S.-Soviet efforts.

(2) Only Beldame Britain would gain strategic advantage in preventing the development of this technology — because she cannot hope to keep pace with Soviet-American collaborative efforts in this area of advanced technologies.

I ask you: Why did we make our Revolution, if we now bow to every British fop's mode of thinking and deny the generative powers of our science and industry?

There is, of course, a remote possibility that Secretary Schlesinger knows something of which I am ignorant. A recent U.S. Senate report warns of "Regulatory Confusion and Inadequate Federal Law Allowing Millions of Americans to be Exposed to Low Level Radiation from Consumer Products such as Television Sets...." I in my ignorance thought this report to be still another attempt to broaden the scope of the anti-nuclear campaign of the Council on Environmental Quality. But perhaps there is more to it; perhaps the Tory Secretary has secret word of an impending Soviet attack, that the Soviets intend to obliterate us in a hail-fire of 21-inch color TV's. Or perhaps this is the real thinking behind ravings of trade war against the Japanese?

Your Obedient Servant,

Post script: As for Canada, my conviction following the Revolutionary War still holds. Neither they nor we are safe until they break from the British Empire and the Empire is decisively broken.

NAACP on Energy

Continued from page 3

growth. The loud and clear pronuclear statements coming from the National Conference of Governors meeting in Washington and columnists like Joseph Kraft, and the well-deserved drubbing meted out to Schlesinger and his energy plan in Congress in the last few days are a measure of how the energy climate has changed since the NAACP first publicized its energy plan.

The "Big Industry, Big Labor, Big Minorities" coalition called for by the NAACP has not yet kicked Schlesinger and his conservation scheme out of the White House. But the potential is there, and the forces are mobilizing for such a blow.

We urge readers to support the NAACP's call for an energy policy based on growth and high technology, and to make sure that your elected representatives in Washington are on the side of progress and energy.

News Briefs

SCHLESINGER ENERGY BILL FLOUNDERS AS CONGRESS BACKS NUCLEAR ENERGY

The long-stalled National Energy Program is considered a congressional dead letter in its present form, despite the strident optimism voiced by Energy Secretary James Schlesinger. Estimates at this point are that the most the administration will be able to get is a few minor tax credits and concessions to encourage more home insulation.

The Schlesinger no-energy plan is floundering badly against a strong pronuclear current and the realization by many congressmen that Schlesinger is an incompetent and a liar and that the energy question is tied to the sinking dollar. "There has been a drastic drop of the dollar. The only thing that will make sense to our allies is ... the assurance that there will be more domestic production of energy," Republican Senator Clifford Hansen of Wyoming told Schlesinger at a recent meeting of the Senate Energy Committee. "We have to put Americans to work producing energy."

Democrat Bennett Johnston of Louisiana pointedly asked the energy secretary at the same meeting; "Isn't it true that nuclear energy is cheaper, 30 percent cheaper per kilowatt hour, than coal?" Schlesinger had to admit, "Yes, that is true."

In the House, the pronuclear sentiment was dramatically expressed in the budget recommendations of the Fossil and Nuclear Energy Research subcommittee of the Science and Technology Committee. The subcommittee, headed by Alabama Democrat Walter Flowers, voted March 1 to increase the Carter budget for the Clinch River breeder project from $13.4 to $159.1 million, to add $5 million to the inertial confinement fusion research program, and to increase the fusion magnetic confinement program operating expenses from $224 million to $232.9 million and the plant and equipment budget from $135.8 million to $145.8 million. The subcommittee recommendations go to the full committee and then to the House Appropriations Committee.

U.S. GOVERNORS URGE CARTER TO GO NUCLEAR

The annual meeting of the National Conference of Governors, which concluded Feb. 28 in Washington, D.C., issued an unequivocal statement supporting nuclear power and urging the administration to reconsider its policy on nuclear energy. Excerpts from the statement follow.

"The majority of governors feel that the reprocessing and fast breeder technology decisions of the administration must be reconsidered....

"The governors recognize there is a direct correlation between energy and jobs. Without adequate energy there can be no industrial expansion, no new jobs and modern agriculture. Without energy our economy will falter....

"The clear-cut consensus of the governors is that the nuclear energy program should be continued....We need a definite timetable policy adopted at the presidential level to produce answers on the reprocessing and breeder technology issues. The president must take the lead and rally public support....

"The governors understand that the president's policy on the reprocessing and the use of breeder technology is based on foreign policy concerns and the potential for further proliferation of nuclear materials. However, many governors feel that such a viewpoint will seriously damage our world position economically and endanger our national security...."

Nuclear advocate Governor Dixy Lee Ray of Washington

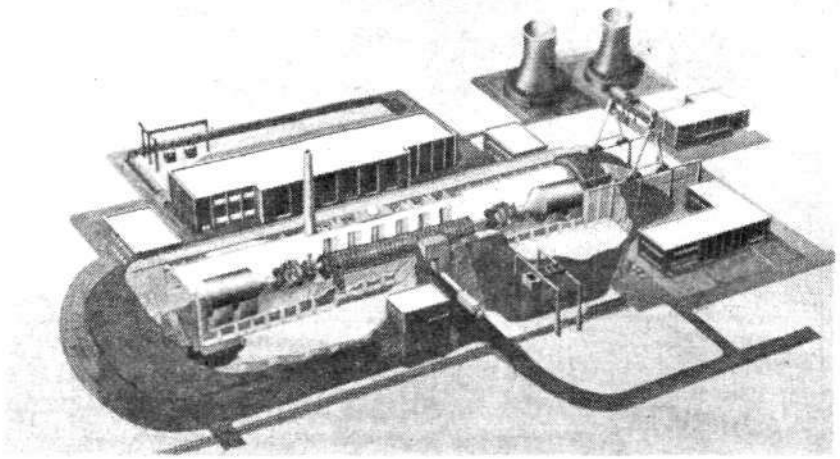
COMMERCIAL FUSION BY 1990

Fusion could be producing commercial energy by 1990, physicist Burton Richter told participants at the Fifth Energy Technology Conference in Washington early this month. Scientists in the fusion program, Richter said, are now asking, "What will it take to reach a commercial reactor, not what does it take for scientific breakeven." Despite this enormous promise, however, Richter

said that "current research is not even being funded at a level where we can make rational decisions about the design of the program."

Richter, who received the Nobel Prize in 1976 for his discovery of the "J particle" in work at the Stanford Linear Accelerator, outlined plans for a new approach to fusion in which high energy ion beams — streams of fast, positively charged particles from an accelerator — are directed at a small pellet of fusion fuel. The energy from the beam is used to heat and compress the fuel to its fusion ignition point.

Stamping a picture of a fusion pellet "TOP SECRET," Richter attacked the classification policy of the Department of Energy that has made all advance fusion pellet fuel designs highly classified.



Artist's drawing of fusion power reactor based on the Lawrence Livermore tandem mirror system.
ERDA

BETHE PROPOSES DEVELOPMENT OF FUSION-FISSION HYBRID

Leading nuclear physicist Hans Bethe of Cornell University has proposed the development of a hybrid fusion-fission reactor that would produce fissile uranium (U-233) much more cheaply than current uranium enrichment techniques. The "hybrid fusion" machine is a power-generating fusion reactor surrounded by a blanket of fertile material that would breed fissile fuel using the high energy fusion-produced neutrons. This will "assure fissile material for millenia," said Nobel Laureate Bethe.

Bethe's proposal, given front-page coverage in the March 2 issue of *Nucleonics Week*, a nuclear trade journal, calls for the parallel development of the fast breeder and for "strong monetary and scientific support to fusion as such," to ensure that all options are kept open. Bethe also noted that the potential high efficiency of the hybrid eliminates the proliferation issue since fuel breeding could be centralized at just a few facilities.

The leading supporters of the Bethe initiative are Dr. Edward Teller and his colleagues at Lawrence Livermore Laboratories, who have suggested the use of the Livermore tandem mirror fusion project for the hybrid experiments.

NEW REPROCESSING TECHNIQUE OFFERS "PROLIFERATION PROOF" FISSION BREEDER

A "proliferation proof" technique for reprocessing and breeding fission fuel was announced at a press conference in Washington, D.C. Feb. 28 by Dr. Chauncy Starr, president of the Electric Power Research Institute, (the research arm of the U.S. utilities), and Dr. Walter Marshall, deputy chairman of the United Kingdom Atomic Energy Authority.

The chemical technique, called CIVEX, produces nuclear fuels in a fast breeder without producing weapons-grade material. With CIVEX, all plutonium from the fast breeder is mixed with uranium and with fission by-products so that the concentration of plutonium never exceeds 20 percent. A concentration of more than 60 percent is needed to produce weapons-grade plutonium.

In the press conference announcing CIVEX, Dr. Starr said: "Most of us in the nuclear industry disagree that proliferation is a serious issue. However, the president does; we have the technology in the CIVEX process which solves any proliferation problems."

NONPROLIFERATION ACT AWAITS CARTER'S SIGNATURE

The Nuclear Nonproliferation Act of 1978, which would destroy this country's nuclear industry, has been on the president's desk awaiting signature since early February, when the so-called Percy-Glenn bill passed the Senate by

a vote of 88 to 3. The bill makes into law the entire panoply of Carter-Schlesinger restrictions on the distribution of U.S. nuclear technology.

Under the guise of preventing the spread of what it terms "sensitive nuclear technology," the bill forbids U.S. aid to foreign nations in developing the fast breeder and related plutonium-based reprocessing facilities. It prohibits "the export of sensitive nuclear technology to non-nuclear weapon states," and it defines U.S. policy as aiding "foreign nations to identify and adapt appropriate technologies for energy production, including solar and unconventional technologies, and in particular, to identify alternative options to nuclear power...to meet their energy needs."

The bill also establishes an incredible morass of red tape and veto powers that could make nuclear export licensing of a U.S. firm virtually impossible.

AUBURN, N.Y. MAYOR ORGANIZES PRONUCLEAR COALITION

Auburn, N.Y. Mayor Paul W. Lattimore announced Feb. 10 that he is organizing a statewide coalition to promote high technology and nuclear development. Lattimore fully endorsed the energy policy of the National Association for the Advancement of Colored People (see news section) and sent a support statement, excerpted below, to the NAACP leaders.

"I am in the process of putting together a coalition in New York state which will consist of industrialists, businessmen, union membership, and, very importantly, the New York state chapter of the NAACP. I expect to call an initial meeting of these leaders in the very near future....

"The creation of new additional energy sources, especially electricity, are absolutely critical to the economic development of our country and the creation of new jobs for our people — especially the youth.

"My deep involvement in the energy crisis dates back to 1968 when I was appointed chairman of the Energy Task Force for the U.S. Conference of Mayors and the National League of Cities. I am unalterably opposed to the hard-core environmentalists whose position is no growth. They do not believe that we should have new additional energy sources and facilities since they avowedly profess that....we do not need any new industry, commerce, or people. Such a position is indeed suicidal for the economy's future and the well-being of our society."

Mayor Paul W. Lattimore

CINCINNATI ENGINEERS ADOPT LABOR PARTY ENERGY PROGRAM

The Cincinnati section of the American Society of Mechanical Engineers has adopted the energy program of the U.S. Labor Party and has circulated the program and a support call to the organization's 181 national chapters. The program, written in collaboration with the Fusion Energy Foundation, demands the immediate development of the full spectrum of fission and fusion-fission power systems and a crash program to develop fusion energy as a long-range solution.

The organization is the largest professional engineering group in the country, with 80,000 members.

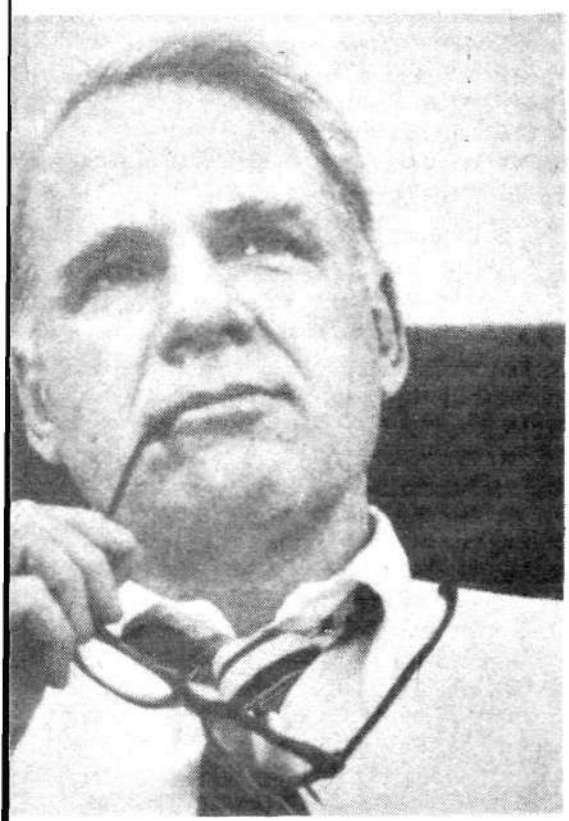
SUN DAY CELEBRANTS ATTACK SUN'S BASIC PROCESS — FUSION

The coalition of environmental and antinuclear organizations sponsoring the May 5 celebration known as Sun Day attacked thermonuclear fusion power in a recent mass mailing. Among the unfounded Sun Day claims are "fusion will produce large amounts of radioactive wastes" and the equally erroneous "no one knows how much it will cost, how it will work, or even if it will work."

In addition to Friends of the Earth, Worldwatch Institute, the Natural Resources Defense Council, and other environmental groups, Sun Day has enjoyed the official support of Energy Secretary James Schlesinger.

Sun Day is promoting the use of soft energy — such as solar power, biomass, garbage burning, and windmills — as alternatives to fossil and nuclear fuels. The particular irony of the Sun Day attack is that fusion is the basic process of the energy production in the core of the sun.

"Our British allies won't let us." Above, U.S. Secretary of Defense Harold Brown; below, U.S. Energy Secretary James Schlesinger



Washington

Who's Really Sabotaging Fusion Development ?

by Dr. Steven Bardwell and Dr. Morris Levitt

The British government was involved in the veto of at least three collaborative research projects between the U.S. and the Soviet Union in the past year, any one of which could have put the U.S. and the Soviets within five years of achieving a prototype nuclear fusion reactor. This extraordinary sabotage operation came to light in the Fusion Energy Foundation's examination of the Department of Energy papers released to the FEF under the Freedom of Information Act on the case of Leonid Rudakov. Rudakov is a top soviet physicist who visited the U.S. in July 1976 and declassified Soviet electron beam research, offering the U.S. a cooperative research project using the Soviet breakthrough.

Further investigations by the FEF staff revealed that the British have a little-known treaty arrangement with the U.S., signed in 1958,* that provides the British with access to top U.S. research that might undermine Britain's so-called nuclear parity by the proliferation of "secrets," particularly in the form of collaboration with the Soviets.

This shocking British intervention to prevent scientific progress and to keep the energy-starved world in poverty was acknowledged on at least one occasion by U.S. Defense Secretary Harold Brown. When a non-British NATO official pointedly asked Brown why the U.S. had not declassified the Rudakov results and had turned down the 1977 offer by leading Soviet physicist Nikolai Basov for cooperative projects to develop fusion power, Brown replied bluntly, "Because our British allies won't let us."

The proposed joint U.S.-Soviet efforts, outlined below, all fall within the rubric of a protocol agreement that is in contradiction to the U.S.-British treaty arrangement. The U.S. and the Soviet Union signed this "Protocol on Joint Projects in Controlled Thermonuclear Fusion and Plasma Physics," in 1973 for the stated purpose of bringing on line operating fusion power plants. The agreement, part of the program for U.S.-Soviet Peaceful Uses of Atomic Energy, states: "The aim of this cooperation is to demonstrate jointly the scientific and technical feasibility of thermonuclear power production through the eventual development of prototype and demonstration-scale thermonuclear reactors."

The British Sabotage

The FEF has compiled documented evidence of British sabotage of the U.S. policy for U.S.-Soviet collaboration for nuclear fusion in four cases over the past two years.

(1) July 1976. The disclosures and offers of collaboration of Soviet physicist Leonid Rudakov in the area of electron beam fusion.

(2) July 1977. The proposal by Soviet Academician Velikhov for joint U.S.-Soviet work on the "imploding liner" approach to fusion.

(3) November 1977. The offer by Nobel Prize winner and Party leader Nikolai Basov of expanded collaboration in laser fusion.

(4) December 1977. The pro-

mulgation of an internal memo by the Division of Classification of the Department of Energy that, if implemented, would classify the whole next generation of magnetic fusion experiments (and so preclude U.S.-Soviet collaboration) under the rubric of nuclear proliferation.

In each of these cases, the combination of military classification and nuclear nonproliferation treaties has been used by U.S. officials closely associated with Energy Secretary James Schlesinger and *under direct British prodding,* to halt U.S.-Soviet collaboration. In several instances this has meant the denial of even domestic U.S. access to the scientific fruits of this potential collaboration.

The intervention to prevent the development of fusion has been carried out by a little-known outpost of British intelligence called the Joint Atomic Information Exchange Group within the U.S. Department of Defense. Set up under the authority of the U.S.-United Kingdom Agreement for Cooperation on the Uses of Atomic Energy for Mutual Defense Purposes, this agency has functioned to provide U.S. military and technical secrets to Great Britain. This information has then been used by the British to block domestic American access to the military and technical material for use in civilian industrial applications and to interfere with the international negotiations regarding these technologies. All the while, Britain has conducted this sabotage from its privileged position as "U.S. ally and collaborator."

There must be no confusion about the actual degree of American responsibility for this obstruction. Schlesinger has been supporting the British interference all the way in violation of the national interest.

The Rudakov Case

Under the authority of the 1973 U.S.-Soviet protocol, several hundred Soviet and American fusion scientists exchange visits each year. During the week of July 4, 1976, one such Soviet scientist, Leonid Rudakov, head of the Soviet electron beam fusion research effort, visited several major U.S. laboratories involved in fusion research. On these visits, Rudakov detailed recent Soviet breakthroughs in the area of electron beam fusion. He also proposed that these new Soviet results be connected with the U.S. capability to rapidly fabricate electron beam sources to build brute force an electron fusion prototype plant by 1981!

The reaction of the U.S. energy bureaucracy was a panicked attempt to keep the whole affair secret, since the information that Rudakov revealed might, they argued, be used for construction of atomic weapons by "nonweapons states" and hence cause proliferation.

The British enter the scene, at the latest, in August 1976, when a meeting is set up between Alfred Starbird, the Energy Resources and Development Administration Deputy Assistant Administrator for National Security, Edward Giller, ERDA Deputy Assistant Administrator for National Security, and a Mr. Macklen from Britain's Ministry of Defense. At their August 31 meeting, the entire Rudakov revelations are discussed, as well as British concern about being involved in decisions regarding the information and its release.

After this meeting, there is a steady stream of memos, letters, and reports sent to the British on the Rudakov presentations and on U.S. reaction to their classification. At the same time, the documents in question were denied to at least two U.S. Senators — Case of New Jersey and Jackson of Washington — but were provided to the British under the terms of the U.S.-United Kingdom Agreement. These documents remain classified today.

The Case of Velikhov

About a year later, in early summer 1977, another high-ranking Soviet fusion scientist, V.I. Velikhov, visited the Los Alamos Scientific Laboratory. Velikhov made a proposal quite similar to Rudakov's in an area of fusion research which the Soviet Union has pioneered — imploding liners. The Soviet Union was at the time (and still is) several years ahead of the U.S. in this very promising line of research. Just prior to Velikhov's arrival, final notice had been given to Los Alamos concerning a funding cutoff for another one of their experiments.

Velikhov made the following proposal: Why not couple the considerably advanced Soviet experimental and theoretical program in liners with the power source from the discontinued U.S. Linus experiment? By fall 1977, a five-man delegation was visiting the Soviet Union to set up details for the collaborative experiment, and proposals for U.S. funding had been submitted to the Department of Energy.

Late in 1977, the policy ruling came down from the Energy Department. The liner experiment would not be funded; funds for Los Alamos were cut severely by the Carter budget, and there were no funds available for this experiment. This meant that the only way the experiment could continue would be through large Soviet input.

The Basov Case

The Soviets then escalated their push for collaboration by sending Nikolai Basov, head of the Soviet fusion effort and a Supreme Soviet member, to the United States in November 1977 with an unofficial plea for expanded U.S.-Soviet collaboration in laser fusion. Basov made a point of documenting his offer with two pieces of scientific information: the Soviets had achieved a new milestone — beyond energy breakeven — in their laser program and they had done so on the basis of the results Rudakov had announced a year and half earlier.

Schlesinger's official response to Basov's offer, during a press conference several weeks ago, was a resounding "No, a flat no." The secretary then claimed that laser fusion is classified in the United States, but in point of fact, Schlesinger's statement is incorrect, since almost all of the laser program is now declassified. More important, however, the source of Schlesinger's total refusal to work with the Soviets

*The 1958 agreement between the U.S. and Great Britain — Atomic Energy Cooperation for Mutual Defense Purposes — was most recently renewed in 1974.

stems not from U.S. security considerations, but, as Secretary Brown admits, from British pressure brought to bear on U.S. officials in the Department of Energy and the Department of Defense.

New Classification for Tritium

Perhaps the most far-reaching of the British-instigated attacks on the U.S. fusion program is found in a Dec. 1, 1977 memo from the Energy Department's Division of Classification, "Tritium Production and Processing Technology Classification Guide." This memo would, for the first time in 20 years, establish classification procedures for magnetic fusion. According to sources inside both the Department of Energy and the State Department, this policy was inspired by British and NATO concern over proliferation hazards associated with tritium, the heavy, radioactive form of hydrogen used as fusion fuel.

To quote the cover letter to the classification guide: "In view of the intense interest in programs and studies concerned with the proliferation of nuclear material and nuclear weapons information to nonweapons states and subnational groups, and because of the requirements of the Magnetic Fusion Energy program, it is important that each facility involved with tritium production or research and development on tritium technology have a local classification guide."

Once research on magnetic fusion becomes classified because of the involvement of tritium, then this research, which is now the main focus of international fusion research efforts, cannot be exchanged under the joint U.S.-Soviet agreement.

The FEF is continuing its investigations of the British violation of U.S. sovereignty described here and has called upon Congress to enforce the intent of the U.S.-Soviet fusion protocol and secure a renewed national commitment to full international nuclear power development.

Steven Bardwell is director of plasma physics research for the FEF and Morris Levitt is the organization's executive director.

Tass from Sovfoto

The signing of documents at the close of the November 1973 meeting of the Soviet American Commission on Scientific-Technical Collaboration in Moscow. Seated [right] is Academician V.A. Kirillin, deputy chairman of the Soviet Council of Ministers and G. Stever, science advisor to the U.S. president.

Schlesinger's 1979 Makes Fusion

By the Department of Energy's own admission in its published planning documents, the budget handed to Congress by Energy Secretary James Schlesinger for operating his department during fiscal year 1979 would ensure that "a practical fusion power system might never be built."

To date the only part of the fusion budget cuts made public are those for the laser fusion research program, which has been cut from $129 million in fiscal year 1978 to $126 million for 1979.

For magnetic fusion research, the $334 million 1979 budget represents a $9 million increase over funding for 1978, but actually will not even compensate for the effects of inflation.

Most damning of all is the fact that the development and technology portion of the fusion research effort is completely gutted. In particular, Schlesinger has decreed that the intense neutron source and the lithium deuteride accelerators, facilities crucial for developing the materials needed for practical fusion power applications, cannot be built under any circumstances. This funding cut alone will retard any future fusion effort, no matter how great, by at least four to five years. It will make the construction of experimental reactors almost impossible.

As for the rest of the fusion projects, informed Washington sources have reported the main U.S. fusion program at Lawrence Livermore Laboratory will receive token funding increases while other national labs, including those involved in the electron beam research program, are being cut back. These sources further report that there will not be enough funds available for the Livermore Laboratory to fully operate the Shiva laser. This is the largest, most

Energy Budget Impossible

powerful laser in the world, and if operating fully it could demonstrate the feasibility of laser approaches to fusion.

A "Soft" Approach

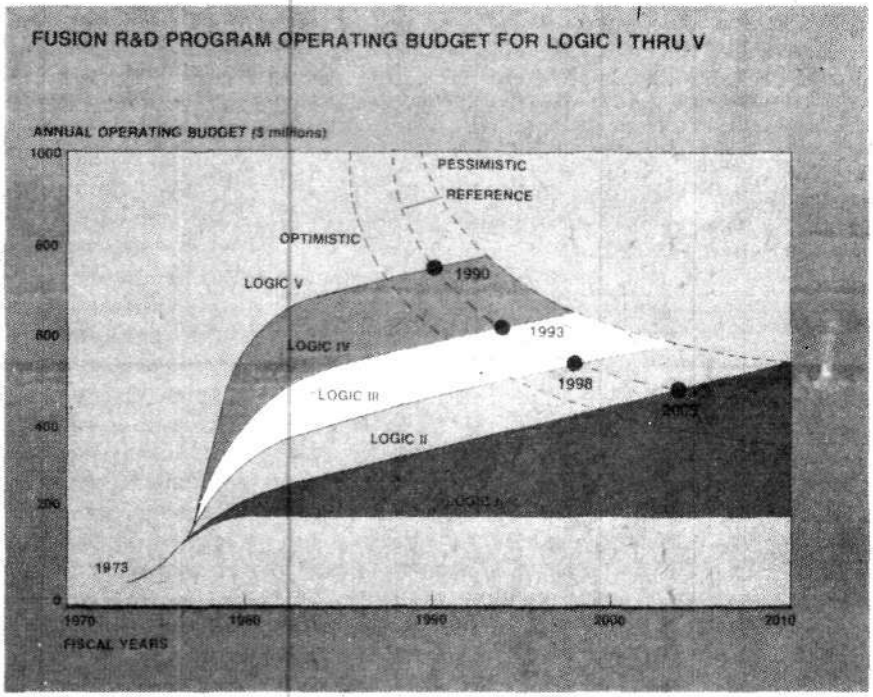
The basic thrust of the 1979 energy budget overall is to halt high-technology, long-range solutions to the energy crisis and substitute the so-called soft technologies associated with our ancestors — windmills, wood burning, and of course the old familiar method of belt-tightening.

The Schlesinger-prompted campaign against all advanced energy methods has been brazenly publicized by his right-hand man James O'Leary. "The energy problem is not one that is going to be solved by research and development," O'Leary informed a Hispanic business meeting Feb. 1. "No technology spawned by government has resulted in significant new energy supplies," he added. O'Leary then bragged that after spending decades and billions, nuclear power provided only 1 percent of the nation's energy.

The special target of the Department of Energy's Dark Ages campaign is fusion power, the safest, almost limitless energy source whose actual experimental results here and in the Soviet Union prove scientifically that everything Schlesinger says about energy scaricity is a lie. To quote madman O'Leary again, we "have misread the potential of fusion...."

Fusion-Wrecking

Aside from death by starvation, there is other evidence of the Schlesinger campaign to do away with fusion. The imposition of security classification on any research involving the basic fusion fuel, tritium, (see "Who's Really Sabotaging Fusion?" this section) will greatly inhibit the progress of magnetic confinement research.



In its 1976 study, "Fusion Power by Magnetic Confinement," the Energy Research and Development Administration outlined timetables for achieving commercial fusion reactors based on different levels of funding allocated to magnetic confinement fusion research. The various funding paths in the study are labeled Logic I to Logic V in the figure above, with Logic I as the lowest level research budget. The horizontal axis gives time, and the vertical axis the budget dollars. The dots labeled with years indicate conservatively when fusion reactors would be achieved for each logic; the dashed curves at the point of intersection with each Logic represent "optimistic" [left] and "pessimistic" projections for the necessary scientific and technological progress required.

The current level of funding for magnetic fusion falls within Logic I, funding so low that no projected dates fall within this figure, but out in the indefinite future.

In addition, the Department of Energy has announced another fusion-wrecking operation under the guise of a "review" premised on the sinister question: "Does a budget of $300-$400 make sense for something 30 to 40 years away?" What the department has in mind, according to one inside source, is the elimination of so-called expensive, large-scale programs, going instead for "technological breakthroughs."

The threatened budget reduction may be turned around, however, by the selection of a distinguished group of scientists and industrial executives to a department fusion planning group.

The review is being carried out by the Fusion Energy Review Committee under the department's research director John Deutch and it will be coordinated with assistant secretary for defense Donald Kerr and assistant secretary for energy technology Robert Thorne.

Fire the Liar

The Schlesinger campaign against high technology has not proceeded unscathed. Members of the House Science and Technology Committee put the energy secretary and his department spokesmen through the wringer in hearings, and there have been various public attacks on Schlesinger and on the figures he has mustered to make his argument for conservation.

A former U.S. deputy secretary of defense, who had worked directly

under then-defense secretary Schlesinger, called him "the most devious character I have known in all my life." "Mr. Schlesinger is an absolute disaster," William P. Clements told a meeting in Dallas Jan. 16.

At least one senator has called for the energy secretary's resignation for "lying." Senator Howard Metzenbaum, an Ohio Democrat, asked for Schlesinger's resignation this month on the grounds that the secretary had lost credibility because of his incompetence and his fabrication of figures.

Similar sentiments were expressed by the proindustry press. A lead *Wall Street Journal* editorial Feb. 10 chastised Schlesinger's department for "doing its share to impede energy development" and concluded by comparing Schlesinger to the moron who "shoots his mother and father because he wants to go the orphans' picnic."

Government Denies Scientists Fusion Information

Government documents released under the Freedom of Information Act to the Fusion Energy Foundation Feb. 13 by the Naval Research Laboratory in Washington show that the Department of Energy denied U.S. researchers critical information on Soviet electron beam fusion research. As discussed in previous issues of this magazine, research information presented by Leonid I Rudakov, section chief of the I.V. Kurchatov Laboratory in Moscow, was immediately classified after Rudakov's first trip to U.S. laboratories in July 1976. During Rudakov's second and third trips in April 1977 and in February 1978, as the documents from the Naval Research Laboratory show, the Department of Energy prevented Rudakov from presenting the latest Soviet breakthroughs in electron beam research.

Nuclear Power Is Key

NAACP Demands Policy for Energy

The National Association for the Advancement of Colored People released an energy policy statement Jan. 8 that is at an opposite pole to the "no-energy" National Energy Plan of the Carter administration. The organization submitted the statement for energy expansion and nuclear power to the White House before its general release, only to have it forwarded to Energy Secretary James Schlesinger and then officially ignored. However, the contents of the statement, summarized below, have dramatically changed the line-up in the national energy debate and formed the basis for a progrowth coalition of "Big Industry, Big Labor, and Big Minorities."

The NAACP Policy

—There is a direct correlation between energy consumption and economic activity, which means jobs and living standards. The Carter plan calls for cutbacks in energy consumption growth rates, and is therefore against the interest of Black Americans.

—Although the organization fully agrees with the administration's concept of cutting wasteful energy consumption, this is not an end in itself. There must be an overall policy of rapid energy growth.

—Key to energy growth is nuclear power. Both the use of conventional nuclear fission reactors and the development of the fast breeder reactor are necessary to sustain an expanding economy.

— The protection of the environment is extremely important and with dedicated effort the government and the scientific community can make sure that there is no compromise between the health and safety of the population and economic social objectives.

—The administration's energy policy does not do enough to encourage the development of new supplies of oil and natural gas, as well as new technologies.

—The administration proposes sharp increases in energy taxes that would hit directly at low income families. If the price of energy is to be raised artificially, these revenues should be used to develop new energy supplies rather than for tax rebates.

—The NAACP urges Congress and the president to evolve a national energy plan that reflects an accommodation of differing views, including those of minorities.

The Press Reaction

Much of the press, like the administration, chose to ignore the NAACP statement, and those who did not ignore it were strongly on one side or the other of the energy question. The hostile press not only criticized the NAACP policy but distorted it, concentrating on the issue of deregulation, which the NAACP had not specifically addressed. (The NAACP had called for planned energy growth and economic expansion, which subsume the question of deregulation and conservation.)

The liberal-environmentalist press outlets were particularly vicious. The *Washington Post*, the *New York Times*, and the *Los Angeles Times* attacked the NAACP for stepping out of place and sticking its nose into things other than civil rights, for not having the support of its membership, and for being in the pocket of the oil industry on the question of deregulation. The *New York Times* insinuated that the NAACP was incapable of writing such a policy, while the *Village Voice* claimed that the organization actually had been taken over by the big oil companies and utilities.

By the end of January, the distorted accounts of the NAACP and deregulation prompted the NAACP to

Growth

clarify its statement on deregulation. The clarification — "The NAACP... does not endorse regulation or deregulation; it raises questions about the best approach for meeting the energy crisis" — was greeted with press statements heralding what was erroneously called a reversal of the NAACP position!

On the other side, the statement was hailed by papers like the *Wall Street Journal*, the *Dallas Times*, the *Seattle Times*, and *New Solidarity* reflecting their proindustry constituencies, and statements of support were issued by industrial and political leaders like John Connally, Ronald Reagan, Chamber of Commerce head Richard Leshler, and national Farm Bureau president Allen Grant.

The Energy Shake-Up

The bold NAACP statement and the organization's continuing fight to win the battle for energy expansion turned the usual Democratic Party alignments topsy-turvy and threw the labor movement into a quandary. The AFL-CIO, the Black Congressional Caucus, and many congressmen have traditional positions on the side of Carter-Schlesinger zero-growth program and its concomitant labor-intensive work projects like the Humphrey-Hawkins bill. Yet the rank and file to whom these politicians and labor leaders report are increasingly siding with the NAACP and energy growth. Even the United Auto Workers union leadership, staunchly in the official Schlesinger camp, is internally dicided in whether to support the NAACP.

As for the black community, Margaret Bush Wilson and Benjamin Hooks, NAACP chairman and exectutive director respectively, characterized the changes their energy policy has wrought: "free at last — from the liberals."

—D. Goldberg

Photos NAACP

Increased energy consumption is in the interest of black Americans and the rest of America. Margaret Bush Wilson, NAACP chairman; Benjamin Hooks, NAACP executive director.

The NAACP Energy Line-Up

Ronald Reagan:
"The Black leaders understand as energy gurus don't seem to, that increased economic activity means more jobs, and more jobs means denting the stubborn 14 percent unemployment rate among Blacks."

The Village Voice:
"The largest black organization in the country has placed itself beneath the boot of the most merciless defenders of corporate privilege both in the United States and abroad...."

Benjamin Hooks, executive director of the NAACP, speaking at a Chicago press conference in answer to a question of the lone CBS Radion reporter present:
"When Blacks start talking about energy, liberals begin to freak out....The liberal press has made a conscious effort to black out the NAACP....They have a contempt for what we stand for....The press has pursued a form of overt rascism. If we supported deregulation, we would have said that....We can spell deregulation. The liberals will support us as long we walk in step with them...they'll pat us on the head....You don't see the media attacking Jewish groups who supported a similar energy policy."

An aide to *Rep. Charles Rangel,* a New York Democrat:
"Rangel and most Black congressmen are against nuclear power. We don't need it."

International

The Satellite Hoax and the SALT Talks

Cosmos 954: Schlesinger's Horror Show

The routine reentry and disintegration of the Soviet nuclear-powered satellite, Cosmos 954, over the Canadian tundra in January turned into an international campaign by U.S. Energy Secretary James Schlesinger to stop nuclear power and start world war.

Despite the fact that there is not now and never was any radioactive debris from the satellite, the U.S. and other international press had banner headlines for days warning of the radioactive dangers in the subpolar Canadian region and running scare scenarios that would make the editor of the *National Enquirer* blush.

Several U.S. reporters told Fusion Energy Foundation staff members that their information about the alleged radioactivity came not from official Canadian spokesmen but from Schlesinger's Department of Energy. Intelligence sources in Washington then corroborated that as of Jan. 27, the secretary had taken over the Cosmos incident as his special "black propaganda" operation.

At the same time that Schlesinger hoped to add the Cosmos scare to his bag of tricks for implementing an antinuclear, no-energy program nationwide, the chicken-little propaganda was intended to exacerbate U.S.-Soviet relations and to force the Soviets into accepting a ban on technological development in the ongoing Strategic Arms Limitation Talks. The official Soviet daily, *Pravda*, quite rightly denounced the miserable affair as a "cold war operation," Jan. 28.

What Really Happened

The Cosmos 954, launched in September, is designed to jettison its small nuclear reactor into space before reentry into the earth's atmosphere. This time the procedure failed, bringing the reactor into the atmosphere. However, the satellite is constructed to disintegrate during reentry in such a way that even if the reactor returns with the satellite, there will be no danger of radioactive contamination.

As the Canadian Defense Information Service stressed, there is a "98 percent probability" that the satellite totally disintegrated in the atmosphere, leaving no debris to fall to the ground.

Satellites lose altitude and reenter the atmosphere on a regular basis. Two previous Soviet satellites had similar difficulties ejecting their reactors in the 1960s, subsequently falling over the ocean, and two U.S. satellites have fallen in a similar manner.

From the very beginning, the official Canadian spokesman on the matter, Major Hasswell, assured FEF staff that the Canadian government had issued no estimates of radioactive danger from alleged pieces of the fallen satellite, nor had the government ever said that the situation was "extremely dangerous," as the Schlesinger press conduits blared around the world. According to Hasswell, the press reports about the

"extreme danger" were filed by two Canadian reporters who were not even present at the press conference where such remarks were supposedly made.

A Real Danger

Any real danger to the U.S. is that the Schlesinger provocation will bring the country closer to war with the Soviets. Equally real is the fact that the U.S. is 10 to 15 years behind the Soviets in the technology that built Cosmos 954, a fact that affects not only defense but also the space and energy programs. The Soviets have had seven or eight miniature nuclear-powered satellites in orbit since 1964, reported one source at *Aviation Week* magazine. The U.S. has nothing this sophisticated, just two satellites that use nuclear materials as the heat source for batteries.

Technological Cooperation— The Only Acceptable Basis for SALT

The Fusion Energy Foundation collaborated with the U.S. Labor Party in December 1977 to draft a policy statement expressing the true interests of both the United States and the Soviet Union at the Strategic Arms Limitations Talks. The statement "From Detente to Entente," spells out how the sole acceptable basis for SALT negotiations is collaborative arrangements in the two fields of technology that comprise 99 percent of the basis for advanced weapons systems — fusion energy and aerospace technology.

We reprint excerpts from this statement here because it is clear that the satellite hoax and renegotiation of a Test Ban Treaty are being used to run the ongoing SALT talks into a replay of the 1920s and 1930s League of Nations disarmament talkathon. We stress that initially the strategic arms negotiations must be a matter conducted exclusively between the United States and the Soviet Union on the above basis, with issues relating to satellites, incidental weapons systems, and other secondary matters as subsumed features of an overall settlement.

In particular, the U.S. and the Soviet Union must rein in the most backward nation in the advanced sector, England, which has been sabotaging scientific cooperation between the U.S. and the Soviets. [*See "Who's Really Sabotaging Fusion?"*]

A U.S. Policy for the SALT Talks

...The international nuclear energy development strategy proposed here in analogy to Eisenhower's "atoms for peace" proceeds from two interrelated assumptions:

First, that the most likely cause for the outbreak of open conflict between the United States and the Soviet Union is not tension among the nations or military blocs of Central Europe nor any irreconcilable ideological conflict between the two powers themselves. The most likely flash-points which could spark rapid escalation to thermonuclear confrontation between the "superpowers" are located in Third World regions such as the Middle East, South Africa, etc. In these regions, a combination of growing economic impoverishment and deeply entrenched ideological positions has created a highly explosive mix that could blow up (or, for that matter, be wilfully detonated) at virtually any time.

Our second assumption is that such dangerous developing sector conditions will necessarily be exacerbated by the domestic U.S. policies of economic retrenchment promoted by Vice President Mondale and Senator Humphrey, including not only "energy conservation" but the entire range of Malthusian and neo-Malthusian principles from conversion to more labor-intensive production methods to zero and even negative population growth....

Our contemporary equivalent of "atoms for peace" is designed to confront the problem of dwindling world resources head on. The Labor Party has proposed that the United States, the European Economic Community and Comecon sector countries, and Japan immediately begin to gear up their national economies to reach a common production goal of 250 nuclear power plants with a combined power output of 250 GW (gigawatts) annually by the year 1985. These plants are intended about two-thirds for domestic installation and one-third for export into Third World nations. Such a construction program, which reflects roughly a tripling of existing advanced sector production capacity over a seven-year period, would be based on low-cost national and international development credits extended (in the U.S. through the Export-Import Bank) exclusively for the construction program outlined. This credit flow would bypass the enormous internal and external indebtedness problems of most of the developing sector countries and several advanced sector nations. The program must be supplemented by a significant expansion in present research and development efforts in fast breeder technology and controlled thermonuclear fusion, as well as in the international space program. In all of these R and D areas, we can build on already existing bilateral exchange programs between the Soviet Union and the United States, France, and Japan. The U.S.-Soviet Apollo-Soyuz joint space flights are a prototype for cooperation in space exploration.

Spinoffs of Nuclear Development

International nuclear energy development is uniquely capable of permanently redressing the shortages problem defined above — not only in the energy field as such, but also in agricultural production, where productivity depends largely on the availability of abundant and reasonably priced energy for

Tass from Sovfoto

American physicists in Moscow inspect the superconductive windings of the Soviet Tokamak-7 fusion reactor in July 1976.

At left is Soviet Academician B.B. Kadomstev and E. Kintner, head of the U.S. magnetic confinement program.

irrigation and the production of chemical fertilizers. Through the development of breeder reactors (including fusion-fission hybrid reactors) we could increasingly close the nuclear fuel cycle and incur no new raw materials problems before the onset of commercialization of nuclear fusion reactors and thus the availability of virtually limitless energy supplies in the 1990s.

Finally, it is a highly desirable by-product of in-depth nuclear energy development that it results in a secular tendency for *decreasing* energy prices (i.e., social costs) through increasing energy flux density and reactor temperature. Thus, the mere commitment to nuclear development will immediately create highly desirable pressures for increased fossil fuel production at lower prices. An added advantage lies in the fact that as a high-technology industry the nuclear power industry operates near the borderline between technological innovation and more fundamental scientific advances. As such, it represents the spearhead of an array of technological and scientific breakthroughs centered on the fusion torch which will once and for all lay to rest the ignorant or fraudulent arguments for zero or negative economic growth based on alleged absolute limits to natural resources.

In answer to the argument that broad-scale international nuclear development will lead to unacceptable levels of nuclear weapons proliferation, the following observation must here suffice: the pressure to obtain nuclear weapons as well as the temptation to use them will rise in direct proportion to the increase of political tensions among Third World nations, which must inevitably occur if the economic development problems of these nations remain unsolved. There is no question that there is a vastly greater likelihood for an actual use of nuclear weapons as the result of the failure to enact an adequate nuclear energy development program than as a consequence of the possibility of weapons proliferation.

Implications for SALT

The initial targets of an international nuclear energy development policy will be those Third World regions which can be characterized as "hot spots" of friction between the U.S. and the USSR, but simultaneously satisfy the minimal infrastructural and population-base requirements to make implementation of such a policy feasible. On both these counts, the Middle East region, including Iran and the Sudan, and South Africa (roughly the entire region south of the Congo River) would provide plausible starting points. A Geneva Middle East peace conference, which limited itself to the redrawing of boundaries in the area without at least beginning to address the more fundamental problems of the economic development of the region, would necessarily result in the early resumption of the present conflict.

...Stability in international relations actually depends on progressive economic and technological development. To prevent a "spill-over" of technological breakthroughs into areas where it would destroy the military strategic balance, the U.S. should not embark on the futile course of attempting to banish innovation from arms development. Instead, an international agreement (or a sequence of such agreements) for nuclear energy development should prominently contain a clause providing for far-reaching scientific collaboration, exchange of information, and actual joint research and development efforts especially in the various areas of fusion research.

Scientific advances in the fusion and aerospace fields are the most relevant to potential revolutionary developments in nuclear weapons as well as antiballistic missile defense systems, and close scientific collaboration in these fields would not just assure the early practical development of a virtually unlimited energy source, but would also make all but entirely impossible the secret achievement of a major unilateral advantage in military applications.

The Mideast Problem Can Be Solved

The FEF Mideast Development Conference

In an extraordinarily successful conference on Mideast Peace and Economic Development Jan. 24, the Fusion Energy Foundation pulled together major political forces concerned with the Mideast to discuss the interdependence of peace and industrial development and the critical role of fusion power in this process. The purpose of the conference was to begin to circulate here and abroad the information and ideas necessary for putting a Mideast economic development project into operation. As one conference participant summed it up at the close of the conference, "The proceedings here today should be seen as crucial experimental evidence that the Mideast problem *can* be solved."

More than 250 persons attended the conference, which was addressed by representatives of the Arab and Jewish communities as well as by leading U.S. scientists, political leaders, and strategic thinkers.

The diverse audience included eight or more representatives of Middle East diplomatic missions or government agencies, and three from Africa.

From the U.S. there were representatives of military, intelligence, and energy research and development agencies, as well as of state and local governments. There were three international trade union representatives, and representatives from private industry including the world's largest manufacturer of electrical technology, the nuclear industry, international shipping, and the world's largest construction engineering consulting firm. From the academic world there were specialists on Jewish and Arabic history, international policy, and science from Georgetown University, Columbia, Stanford, and others, and a host of students.

On the basis of the conference's success, the FEF plans a similar conference on South Africa to be held in Washington, D.C. May 4.

The Highlights

The highlights of the historic conference were the announcement of a major advance in the U.S. fusion energy research program by Dr. Stephen O. Dean, Assistant Director for Confinement Systems of the Department of Energy's Division of Magnetic Fusion Energy (see research news) and a call by Iqbal A. Akhund, Pakistan's ambassador to the United Nations, for a new international economic order to make possible the industrialization of the Third World.

In addition to Dr. Dean and Ambassador Akhund, the conference attendees heard presentations on diverse aspects of the Middle East development and peace problem from experts including Palestinian economist and consultant Dr. Mohammed Rabie, a permanent delegate to the Euro-Arab dialogue; Hoover Institute senior fellow and noted U.S. strategic analyst Stefan Possony; Mayor Paul J. Lattimore of Auburn, New York; FEF Director of Research Uwe Parpart; Dr. Clovis Maksoud of the Center for Contemporary Arab Studies, Georgetown University; Criton Zoakos, author of "Ibn Sina and the Dawn of the Humanist Heritage"; Dr. Ellis Rivkin, Adolph Ochs Professor of Jewish History at Hebrew Union College in Cincinnati, a last-minute addition to the day's final panel; and John C. Currey, a former syndicated columnist and U.S. military intelligence officer who is now senior editor of the *Oklahoma Times*.

The tone of the conference was set by Mayor Paul J. Lattimore of Auburn, New York, who also serves as chairman of the National Joint Task Force on Energy Strategy of the League of Cities and U.S. Conference of Mayors. The energy shortage, Lattimore charged, is "one of the biggest scandals in the country." U.S. policy should be "developing energy in whatever manner it might be." Assailing "professional environmentalists, who are no-growth people," Mayor Lattimore declared that "the most sensible way to generate electricity is with nuclear power." The mayor also welcomed the recent NAACP statement on energy policy (see Washington news).

Ambassador Akhund followed, declaring himself "heartened to hear Mayor Lattimore...say things with which I find myself in considerable agreement." Motivating his endorsement of nuclear power to meet Third World energy needs, Akhund cited former U.S. president Eisenhower's historic Atoms for Peace program, stating that he was confident that all environmentalist objections to nuclear power could be easily met. The ambassador emphasized that even oil-rich developing nations, such as Saudi Arabia and Iran, required nuclear power to meet their energy needs, pointing out that this would free their vast oil reserves for such far more efficient applications as petrochemicals.

In conjunction with his call for a new world monetary system, Akhund emphasized that development of the Third World through technical transfers would provide the outlet for industrial expansion needed by the stagnating economies of the industrial West.

The Export-Import Bank

U.S. Labor Party executive committee member Warren Hamerman then presented the party's proposal for expansion of the U.S. Export-Import Bank, in the context of European moves toward a gold-based

Photo by Armando Vergara

FEF Mideast Conference participants: Dr. Clovis Maksoud [l] and Muhammed Rabie [r].

international monetary system centered in Luxembourg.

Raising the bank's lending capacity from a ceiling of $9 billion, Hamerman declared, will intersect three critical problems facing world economic development: (1) the lack of low-cost credit for the advanced sector; (2) the need in the developing sector for commitments and political and economic contracts for capital, energy, and technology-intensive programs; and (3) the need to provide concrete avenues for the Comecon nations into international cooperation around fission and especially fusion development. Such a plan could be ready within two weeks, Hamerman declared, launching a massive revival of basic U.S. industry such as steel, and beginning unparalleled industrial development in the Third World. He called on the audience to push such expansion of the Exim bank at upcoming hearings by Sen. Adlai Stevenson III.

Potential of Nuclear Energy

In a joint presentation, FEF research director Uwe Parpart and FEF director of physics Eric Lerner concluded the first portion of the panel on Mideast economic development by outlining a $700 billion program for economic development of the Middle East. "The raw materials approach is historically an economic transfer approach," Parpart declared, which will inevitably result in the economic exhaustion of the region if pursued to its conclusion. Proceeding from a basic infrastructure of nuclear development, he declared, and concentrating on Egypt, which has the largest and most highly skilled population of the Arab nations, the region should proceed with development of a petrochemicals and related textile industry, steel and concrete, and basic infrastructure such as housing — a prerequisite to development of a skilled labor force. Parpart also outlined an agricultural development program relying on nuclear energy to provide vastly expanded irrigation.

The FEF research director stressed that it was only in conjunction with such a development program that a Palestinian state — considered a prerequisite to a workable peace solution — could hope to exist as a viable nation.

Speaking at the afternoon session, titled "U.S. and International Energy Policy: Fossil, Fission, Fusion," Department of Energy official Dean coupled his fusion research bombshell with a presentation showing the rapid progress in the U.S. fusion program in recent years. As recently as 1974, projected fusion reactor designs were feared to be too large to be economical, Dean said, but subsequent research breakthroughs have greatly reduced reactor size. He reported that a fusion device designed to achieve energy breakeven levels, the General Atomic Doublet III Tokamak, would be in operation next month.

Noted strategic analyst Stefan Possony then presented a wide-ranging discussion of the prospects and requirements for development in the Middle East and the relationship between peace and economic development.

"Development of the Middle East is a mandatory matter. The penalty for not doing it...is catastrophic," Possony declared.

The objective of development in the Middle East, he continued, must be the immediate introduction of 21st century technology. "You have to leapfrog....You need new technologies."

"You cannot really plan this as a regional thing," he said. "You are involved in a worldwide project. I think India belongs in this region, and a place like Japan."

Islamic Humanism and Peace

The conference's evening session, on the Cultural Heritage of Islamic Science, featured presentations by Parvis Morewedge, secretary-treasurer of the Society of Islamic Philosophy and Science and translator of the *Metaphysics* of the Islamic philosopher Ibn Sina; Criton Zoakos, U.S. Labor Party director of intelligence; Dr. Clovis Maksoud; and Dr. Ellis Rivkin.

Following Morewedge's presentation, in which the noted Islamic scholar presented the thesis that the philosophy of Ibn Sina was based on process-and development-conceptions in contrast to the fixed categories adopted by such

nominalist thinkers as Aristotle, Locke, and Hume, Zoakos developed the contribution of Medieval Islamic science and philosophy to the European Renaissance and later the American Revolution. It was Islam that first systematically developed the voluntarist principles that are the basis of Western humanism today, Zoakos said, noting that "at a time when no European king or queen and very few monks could read," mass literacy was the basis of the Islamic faith.

Applying that Islamic voluntarist principle to what he termed the "paradoxes" confronting the parties to the Middle East problem, and reflected in a number of the day's presentations, Zoakos pointed out that the framing of such "paradoxes" — presenting a fixed range of solutions, no one of them expressing the actual interests of the parties involved — was the essence of the method used by Britain to manipulate and control the region. The voluntarist solution, he said, is summed up in the Talmud: "When presented with two choices, always take the third." The same problem was addressed by Dr. Maksoud, who declared that Arabs had historically been torn between the two poles of "consistency" — full recovery of Palestinian lands occupied by Israel — and "relevancy" — complete abandonment of any rights of Palestinian sovereignty.

Destroy Britain

Both Zoakos and Rivkin addressed the problem of British presence in the Middle East. Rivkin, citing the Manhattan Project as the key breakthrough which demonstrated that the nature of U.S. capitalism was developmental, contrasted this impulse in U.S. capitalism to the capitalism of underdevelopment, centered, he said, primarily in London. It is London's effort to assert hegemony in the Middle East, he asserted, which has been the main obstacle to industrial development in the region.

Zoakos noted that the works of the great Islamic philosophers, Ibn Sina, Averroes, and al-Farrabi, had been in the libraries of every major leader of the American Revolution. No solution to the Middle East can be found without combating the influence and activities of British intelligence in the region, and the key to that problem, he said, is the solution adopted by the Islam-influenced leaders of the American Revolution: "Destroy Britain!"

News of the conference traveled over Italian, French, Pakistani, and Japanese wires the following day from reports filed by correspondents for those countries' wire services. In addition, reporters were at the conference from the Jordanian press, the U.S. business press, Mideast and energy newsletters, the U.S. Black press, and various campus press.

Full and excerpted transcripts of the conference are available (see advertisement).

— Paul Arnest

Toward a Coherent Theory Of Fundamental Processes

THE FEATURED ARTICLE in this issue of *Fusion*, "The Physical Significance of Superfluidity" by Dr. Morris Levitt, is the first in a series of major scientific studies that *Fusion* will publish in the coming months. Accompanied by the simultaneous publication of crucial historical studies, this series will demonstrate conclusively that (1) fundamental physical processes cannot be comprehended by any type of Newtonian or Maxwellian derived physics; and (2) the way forward theoretically — in close conjunction with basic experimentation — is to be found in a radically relativistic approach based on the relationship between geometry and physics as conceived by Bernhard Riemann and reevaluated in the light of Georg Cantor's concept of the *transfinite*.

It is important to make explicit the FEF scientific program that underlies this *Fusion* series. We stand for the necessary connectedness of coherence in theory and human progress. The issue is this: The ultimate measure of the relative degree of truth in any physical theory is its realized effect on human productive capacities when applied as new forms of technology. Conversely, the real or threatened breakdown of the material basis of human society and the loss of the ability of creative individuals to contribute to cultural and material progress is a clear sign that there are inadequate rates of the introduction of new productive technologies and of the generation of new scientific knowledge. Whenever inappropriate and insufficient theoretical knowledge informs or controls human activity, so-called economic or resource crises result.

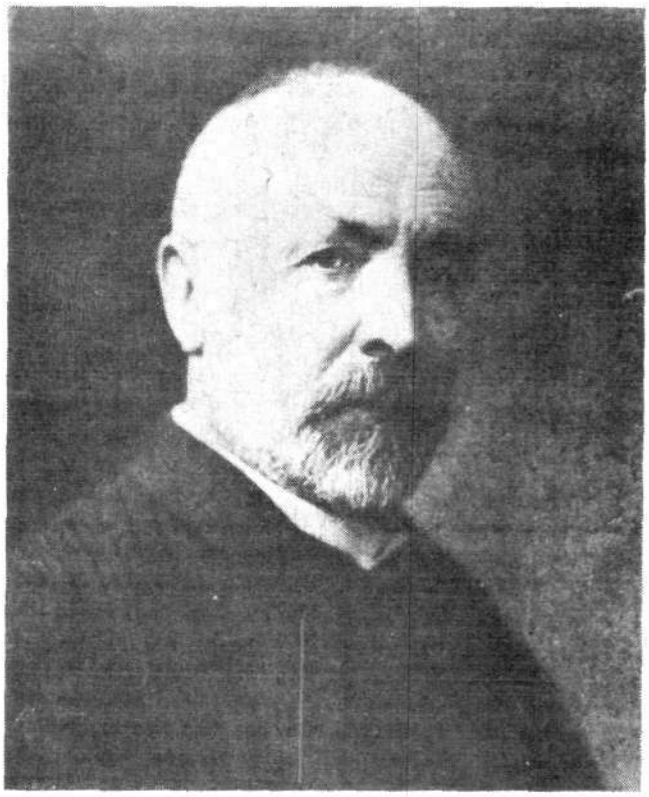
The demonstrable progress of the human species to date, as indicated by general parameters like per capita production of energy and productivity and the rate and intensity of energy throughput in industry and agriculture, is a history of progress in scientific conceptions and the social forms of application of these conceptions. This history depends on several fundamental developments that occur in parallel. The ability of the human mind to generate new scientific conceptions of a higher order that are appropriate to increased thermodynamic potentials of per capita energy production and associated increases in energy flux-density is conclusive proof of the coherence between the potentiation of mental and physical processes. That is, two related forms of psychophysical parallelism demonstrate the necessity and practicality of advances in scientific-theoretical knowledge for human species development. We will summarize these in abstract form and then address the specifics of the scientific issues in this new series.

First, the succession of epochs of exponential increase of energy throughput in new, more flux-dense forms demonstrates the increasing higher-orderness of the general line of development of scientific conceptions. Second, such purposive and effective qualities of the human mind simultaneously demonstrate fundamental nonlinear qualities of physical interaction and self-ordering of the physical substrate of mind.

The only coherent conclusion to be drawn from these basic empirical data is that the lawful evolution of higher orderings and associated laws from their predecessors is what characterizes the physical universe, not any particular ordering or set of fixed laws. This, in turn, demands an appropriate process conception of the increasing potentiation of nonlinear field-particle interaction and of the particle as something other than a simple singularity. The function of science is to generate conceptions of physical processes that are ever more appropriate for human intervention into the succession of orderings of the human-dominated biosphere.

This formulation is not original. In somewhat different form, the same epistemological outlook was expressed explicitly by the seminal figures of the Islamic and European humanist-scientific traditions, Ibn Sina and Leibniz. More recently, two current publications have systematically investigated the field-particle problem in its historical and epistemological dimensions: Uwe Parpart's "Concept of the Transfinite" and translation of Cantor's Grundlagen,* and Carol White's forthcoming *Energy Potential: Toward a New Electromagnetic Field Theory*, which includes James Cleary's translation of Riemann's "Lectures on Electromagnetic Field Theory."† These studies both derive from the discovery of political economist Lyndon H. LaRouche, Jr. that human social negentropy could be represented formally in the language of Riemann and Cantor as a series of nested manifolds of higher and higher transfinite order. In a recent article LaRouche summarized the appropriate heurism for physics as follows:

> The essential problem of mathematical thinking, as we presently know mathematics, is that the geometric notions underlying both geometry and all algebraic constructions are premised either upon Euclidian axiomatic systems or upon non-Euclidian geometries that intrinsically have the same fundamental "hereditary" flaws as Euclidian systems. They presume abstract space and time, in which extension is *scalar*....



Georg Cantor
[1845-1918]

Georg Friedrich Bernhard Riemann
[1826-1866]

Riemannian geometry poses the question of physical universes in which extension of the process generates a succession of geometries each axiomatically distinct from one another. That is, no axiomatic geometry can account for the causal relationships of transition from one geometry to the next. However, each successive state of the universe can be approximately described in terms of some axiomatic geometry, different from the axiomatic geometries appropriate to describe preceding and subsequent states....

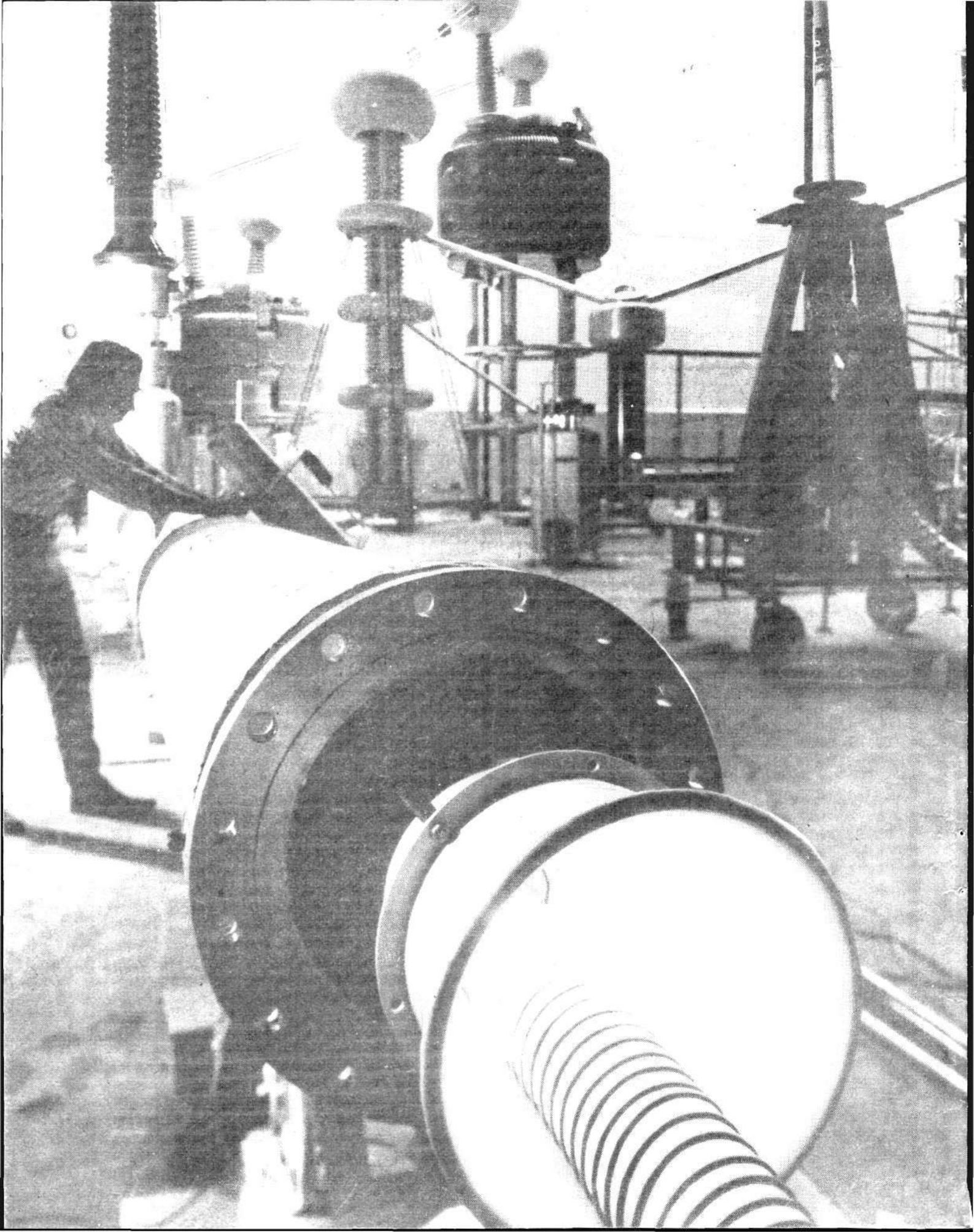
The experienced fact that a "unified field theory" presently cannot be developed is itself conclusive proof of one or both of the following facts: (1) that the universe is not characterized by any one invariance, and hence no one geometry; (2) that our mathematical physics is somehow inherently defective. This problem would be solved if (1) the universe is actually Riemannian, and not as Einstein, Weyl, and others imagined it to be; (2) We redefine the empirical evidence in such new conceptual terms that we find in any state of the universe a "marginal" developmental element which causes that universe to evolve into one of higher order. In the latter case, if the universe is in fact Riemannian, the unified field problem can be *conditionally* solved for any state of the universe, by taking into account the developmental causal element which governs the passing-over into a higher-order universality.‡

The absence of this outlook in contemporary scientific practice (for example, look at *Science* magazine, if you have the stomach) is not only an unfortunate case of historical amnesia and prejudice but a practical danger to humanity. At the same time it opens the door to zero-growth ideology and policies and dangerously narrows the scope of scientific inquiry in precisely those research areas like fusion that are critical to continued human progress.

The basic issues are the nature of the "connectedness" of the physical universe and the relationship between quantization of energy — the particle — and the time-evolution of the geometry of the physical continuum — the field — in the large and in the small. To deal competently with this problem, one must take on the original sources mentioned here as well as recent studies by the FEF and its intellectual collaborators. The scientific series initiated here and the parallel historical studies will continue this line of development. Scheduled for publication after Levitt's article are "Toward Understanding the Nature of Fusion Energy" by Winston Bostick of the Stevens Institute of Technology, a study of the geometrical basis of mechanics and the many-body problem by Dr. Steven Bardwell, and studies of the scientific thought and contributions of Leibniz, Riemann, Cantor, and Schrödinger by Uwe Parpart.

—The Editors

*"The Concept of the Transfinite." *The Campaigner* Jan.-Feb. 1976.
† *Energy Potential: Toward a New Electromagnetic Field Theory*. New York: Campaigner Publications, University Editions, 1978.
‡ Unpublished manuscript, 1977.



The Physical Significance Of Superfluidity

by Dr. Morris Levitt

Part I

An Epistemological History

Helium 4, the Simplest Superfluid

In 1971 researchers at Cornell reached a historic scientific milestone with the "accidental" experimental discovery and investigation of the long-sought superfluid state of the rare isotope helium 3. This discovery at Cornell, and soon afterwards at other laboratories, capped the preceding 60 years of investigation of the critical effect known as superfluidity.

Superfluidity is exciting to study not only because it directly counters the foolish common sense notion that *dissipation* of energy dominates the universe, but also because it provides direct insight into how entropic processes coexist with, yet are dominated by, primary *negentropic* processes in the physical universe.

Superfluidity is the essentially frictionless (in liquid parlance, *inviscid;* in electric current terms, *resistanceless*) flow at low temperatures of certain fluids, even in the absence of any apparent driving force. The term superfluidity is used here to include these two basic phenomena: first, the case of superconductivity where the "fluid" is composed of the mobile electrons in various metals and alloys; and second, the unique liquid states of the common element helium 4 and the artificially produced, rare isotope helium 3. As one might expect for substances with such peculiar hydrodynamic properties, they also defy the normal laws of energy transfer and degradation as described by thermodynamics.

For example, in the phase of helium 4 below temperatures of 2.2 K,° a phase known as He II, the liquid exhibits the following extraordinary properties:

Thermal superconductivity. The amount of energy flow in the form of heat current does not depend in the same way as in normal fluids on the temperature gradient (the rate of change from point to point), and the energy flow is much larger than in the normal case for a given temperature difference between flow points.

Superfluidity. He II can pass with ease through capillaries that are so small (10 millionths of a centimeter) that even gaseous helium is stopped. In this superfluid flow, the apparent viscosity (internal friction) of the liquid passing through capillaries on the order of a micron diameter is many orders of magnitude less than that of the other liquid phase of helium, He I, and also is not dependent on the pressure head.

The fountain or mechanocaloric effect. Heat and matter transfer in He II, and thus thermodynamic and hydrodynamic properties are inseparable. Although such transfer can take spectacular forms of fountainlike vertical flow up through a capillary immersed in He II, the basic effect is the flow in *opposite* directions of strong but completely reversible currents of heat and helium. Most striking is the substantial flow of matter from colder to hotter regions — totally contrary to the normal effects of bulk heat convection.

Supersurface film flow. Extremely rapid flow of heat and liquid between connected vessels was found to take place in a film several millionths of a centimeter thick, at a rate largely independent of the level difference but strongly dependent on liquid temperature. The linear flow velocity was about 30 cm per second at 1.5°K, and cannot be accounted for simply by the usual interatomic forces.

At a temperature hundreds of degrees below that at which most substances are frozen solid, helium flows more easily than any liquid known!

The usual theories of heat flow and hydrodynamics cannot describe these phenomena. As the pioneer superfluid scientist Fritz London noted, "...a description by the customary differential equations, even with in-

The Uses of Superconductivity

This supercooled aluminum power cable, 320°F below zero, successfully withstood up to 435,000 volts of electricity during tests by engineers from the General Electric Research and Development Center in Schenectady, N.Y. Based on these results, power transmitted by such supercooled cables could exceed 3,500 million-volt-amperes; now a 500 million-volt-amperes rating is considered high for transmission cables serving metropolitan areas. ERDA

finitely large or infinitely small values of the common specific coefficients (heat conductivity or viscosity), seems entirely inadequate."

Although these and many other highly unusual features of superfluidity have been widely recognized to demonstrate "right before your eyes" some of the most profound implications of quantum theory,* there also has been a tendency either to reduce these implications to overly simple pictures or models of quantum behavior or to overemphasize the special set of conditions under which superfluidity occurs (even though there is reason to believe superconductivity does or can occur at room temperature). Both tendencies miss the point that superfluidity suggests about the general nature of the relationship between particles and the fields through which they exist and interact and the structures both form. This article, therefore, will focus on the basic physics of superfluidity and will minimize discussion of the many important potential technological applications, especially in the case of superconductivity.

The superconductivity effect was first seen in 1908 in conjunction with liquefaction of helium at 5.2° K, and new behavior of liquid helium below 2.2° K was observed in 1911. This was just before the earliest primitive quantum-wave theories of atomic structure were constructed by de Broglie and others to account for the observed discrete spectrum of atomic radiation. During the following three decades, wave mechanics was perfected in the form it was to take until new developments after World War II (for example, quantum electrodynamics); P. Debye formulated the basic thermodynamic relationships for solids based on the quantum nature of their basic energy levels (that is, the

A Note on Physics and Definitions

Symbols frequently used in this article:

α means "is proportional to."

v or V, particle or fluid *velocity*.

p, *momentum*, which for particles with mass is the product of mass times velocity.

k, *Boltzmann's constant*, which connects energy and temperature for thermodynamic systems.

h, *Planck's constant*, the quantum of action which connects energy and frequency of wave-mechanical systems. ($\hbar = h/2\pi$)

ϱ (Greek rho), *density*, or mass per unit volume of fluid.

m or M, *mass* of fluid.

Ω or ω (Greek omega), *angular velocity*, i.e. rate of fluid rotation.

∇, the *gradient* of a function, its directional rate of charge.

∂, *partial derivative* of a function with respect to one of its variables.

$\oint$, *integral* of a function along a closed line path.

$\sum$, *summation* sign.

e, E, $\mathcal{E}$, *energy* in various forms.

Δ, the *energy gap* between the two types of microscopic excitations in He II.

P, pressure; T, temperature; S, entropy; V, volume.

The two isotopes of helium are *He 4* and *He 3*. The first has a nucleus with mass approximately equal to two protons and two neutrons; the second has only one neutron. The liquid phases of the isotope He 4 are designated with roman numerals.

The higher temperature "normal" liquid state of He 4 is *He I*, found between 5.2 and 2.2°K. The low temperature, superfluid state of He 4 is *He II*. These are distinct phases, separated by the critical temperature of 2.2°K. However, the "normal component" of He II, its dissipative singularity-excitations, cannot be physically separated from He II.

He 4 nuclei follow *Bose-Einstein* statistics. These differ from classical Maxwell-Boltzmann statistics in that particles of the same type, *bosons*, are taken to be indistinguishable. The prototype of a Bose system is the distribution of energy among the photons of different frequency in *black body radiation*, (see below), which is different from the distribution of energy among the velocities of atoms in a simple gas.

He 3 nuclei and electrons obey *Fermi-Dirac statistics*, that reflect much more strongly the collective nature of field-particle interactions, since no two of the so-called *fermions* can be in the same state. This Pauli Exclusion Principle is the basis for the building up of the electron shells in the elements of the periodic table and underlies the physics of electrons in materials.

An *angstrom* is the unit of convenience for measuring dimensions in atoms and wavelengths of X-rays and visible light. One angstrom equals 10^{-8} cm or 10^{-10} meters.

Black body radiation is the idealized distribution of energy among the various frequencies emitted by a body at a given temperature in thermal equilibrium with its radiation field. That field transmits its energy in discrete packets or photons, which travel at the speed of light and have energy proportional to the frequency (inverse of wavelength) associated with the photon.

The Kelvin unit of measurement is equal to the centigrade degree; absolute zero is 0°K, the equivalent of -273.16°C.

A *mole* of any material is simply the amount comprised by a standard chemical sample containing Avagadro's number of atoms (about 6×10^{23}) of the material.

Superfluidity is any form of nondissipative energy propagation. The He II state of He 4 and the ultra-low-temperature state of He 3 exhibit superfluidity in the form of bulk liquid and heat flow.

Superconductivity is the resistanceless flow of electric current in metals and alloys when cooled to temperatures generally in the range of 5 to 15°K.

spectrum of simple "collective excitations); and researchers discovered that the unique "quantum fluid," liquid helium, entered a totally new phase at temperatures below 2.2° K and exhibited superfluid behavior strikingly similar to the electronic superconductivity with which "normal" liquid helium had been so closely associated.

Helium I

We will first look at "normal" liquid helium to clarify what is meant by a quantum fluid and why under certain conditions it should exhibit such astounding behavior. It is important to keep in mind that only with relatively recent developments in mathematical physics have the most interesting aspects of *any* liquid behavior just begun to be systematically comprehended. The major conceptual advance in this field, which has permitted the first detailed quantitative solutions to the nonlinear equations of motion † known for over a century, was summarized recently by a leader in the field, Professor N. Zabusky of the University of Pittsburgh:

> In the last decade, we have experienced a conceptual shift in our view of turbulence.For flowswith strong velocity shears, near boundaries, density gradients, magnetic fields, or other organizing characteristics, many now feel that the spectral or wave-number space · description has inhibited fundamental progress.
>
> The next "El Dorado" lies in the mathematical understanding of coherent structures in weakly dissipative fluids: the formation, evolution, and interaction of metastable, vortexlike solutions of nonlinear, partial differential equations....

The point to be stressed here is that exactly *under* conditions where the usual geometric-dynamic notions and reality of the types of basic collective microscopic excitation in the fluid break down, the most striking ordered structures dominate the macroscopic dynamics. There clearly is something very important about the transitional configuration in a highly turbulent fluid, where no description of the fluid as either a set of interacting particles or as an elastic continuum can be found, and yet there is a global coherence manifested by the onset of large-scale vortices, and so forth. "Something else" must be there.

The same essential point is exemplified by liquid helium in a somewhat different form. The liquid phase called helium I, which is found at temperatures between 5.2° and 2.2° K, has a structure that cannot be accounted for by any force law! Its volume per mole of material, 27.6 cm^3, is about three times larger than what would be expected on the basis of the balancing between attractive (Van der Waals type) and repulsive forces of the helium atoms as measured by atomic scattering experiments. Further, the viscosity of the liquid varies with temperature much more like a gas than like a liquid. That is, the temperature dependence varies linearly with $T^{1/2}$ rather than as an exponential ("energy activation") function of T^{-1}.

To say that liquid helium is a quantum liquid means not simply that microscopic interactions obey the principles of quantum mechanics (that's true for any liquid) nor even that quantum-type behavior obtains on the macroscopic scale. In a quantum liquid, the liquid as a whole has properties determined by some higher ordering principle than that given by *any* mechanics, quantum or classical. The apparent explanation for why this quality, which is *universal*, should be manifested more directly in helium of all the liquid species exemplifies the contradictions physics constructs for itself by not comprehending that universality.

Because of their tightly bound and closed electronic structure (two paired electrons in the lowest possible orbital), helium atoms interact with each other very weakly, except at close proximity (interatomic dimensions on the order of Angstroms). But it is just this property that supposedly accounts for why in the liquid phase helium atoms are forced so far apart! If one pictures the energy content of helium at low temperatures as proportional to the kinetic energy of helium atoms, then the thermodynamic relationship ($E_{kin} \cong kT = \frac{1}{2} mv^2$) indicates that the atomic velocities will become very small until two related quantum mechanical effects come into play. The first is that if there is any interaction between the helium atoms, say of the form of a harmonic oscillator, then the minimum energy of excitation cannot be zero but must be at least $\frac{1}{2} h\omega$, where ω is a measure of the interaction strength. N such excitations must then have total minimum energy ,called the zero point energy,of at least $\frac{1}{2} Nh\omega$.

But another general result of quantum mechanics is that if the Hamiltonian form of physics (that is, the energy-conserving formulation that linearly separates intrinsic and extrinsic forms — motion plus interaction — of energy content and transfer) is extended down to dimensions of the order of interaction lengths (the radius of the hydrogen atom electron-proton separation is 10^{-8} cm) then position and momentum are no longer mutually independent variables as in Newtonian physics. Instead they are coupled together in a way summarized by the unfortunately named Heisenberg Uncertainty Principle.

This principle summarizes the result in the form $\Delta x \cdot \Delta p_x \cong \hbar$, indicating that the smaller the distribution of momentum values, the larger the geometric volume over which a physical system must be distributed. Therefore, liquid helium in this context expands in volume until there is a balance between the fall-off of the zero-point energy and the gain in average potential energy — even though neither quantity can be defined or calculated exactly from "first principles." This effect is so pronounced

*See the author's article "Certainty and Uncertainty, the Incoherence of the Physicists," *The Campaigner*, Jan.-Feb. 1975.

† Nonlinear here indicates that motions in the fluid interact with the local gradient (that is, the spatial rate of variation of the local motions) in a way that continuously and complexly alters both. The simplest sort of hydrodynamical interaction operator to express this coupling is of the form $\mathbf{v} \cdot \nabla \mathbf{v}$. In a linear system (as for example, a simple harmonic oscillator where restoring force simply varies linearly with displacement from average or equilibrium position), this coupling is negligible.

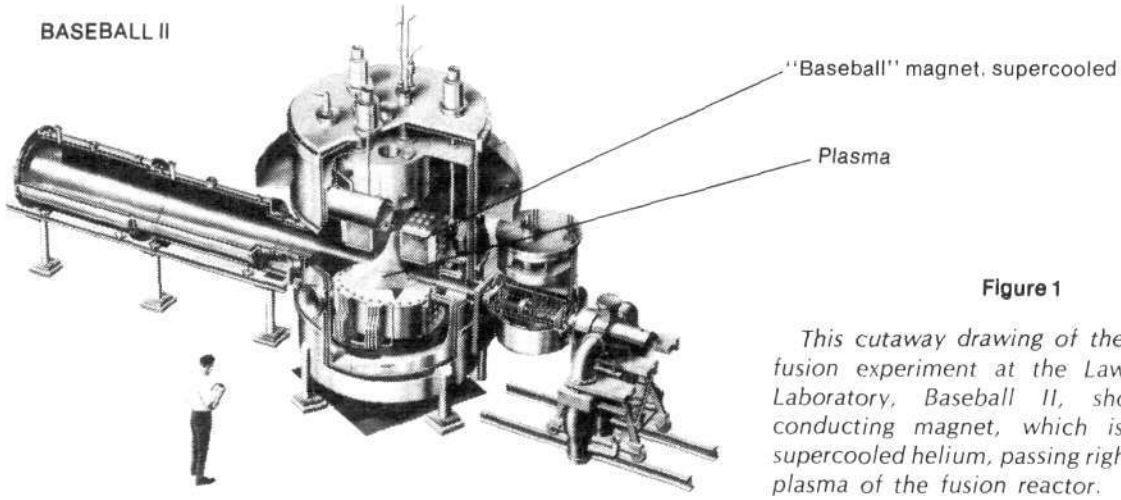


Figure 1

This cutaway drawing of the magnetic bottle fusion experiment at the Lawrence Livermore Laboratory, Baseball II, shows the superconducting magnet, which is surrounded by supercooled helium, passing right through the hot plasma of the fusion reactor. ERDA

in fact, that helium 4 cannot be frozen, no matter how low the temperature at normal pressures.*

To get a sense how abnormal this behavior is, imagine that for a system composed of masses connected by springs to their nearest neighbors the equilibrium state consisted of all the springs being stretched taut instead of being in a state of minimum tension.

The proper conclusion to be drawn from this situation is that quantum behavior is not simply some refinement of the classical Newtonian notion of interaction (whether contact, at-a-distance, or retarded) in exchange for the introduction of a little more incoherence. Instead, it indicates that a more comprehensive conception of the physical continuum is required. This becomes even more imperative when one considers the phenomena of superfluidity and superconductivity.†

At this point, the reader is advised to set the following ground rules for himself or herself before proceeding. As you read any general description or technical elaboration of superfluidity in any of its forms, ask yourself whether there is a fundamental paradox or antinomy involved in superfluidity, and whether the article obscures and intensifies the paradox but does not resolve it.

The paradox itself may be stated as follows: A normal fluid can be pictured as composed of interacting atoms and molecules, linked together under equilibrium with whatever external or self-pressure is applied. When the fluid as a whole moves, or there is significant internal fluid flow, the situation can be thought of as strings of coupled railroad cars on parallel or somewhat divergent adjacent tracks moving in unison or with slippage via the tracks and linkages. But the very linkages, the friction in the system and collisions among the train segments, cause unavoidable losses.

In the superfluid phase, on the other hand, the liquid moves as a whole without dissipation. One way to describe this is by saying that the liquid as a whole is in a single, conserved quantum state that orders all the particle motions (momenta). But if there are no lossy (energy dissipating) collisions, how are the coordinated motions maintained? What is the nature of physical interaction associated with self-sustained motion? Can it be described by an incredible internal balancing of the forces of physics as we know it, or does that physics simply begin to describe what's happening just outside of the fundamental aspects of such self-ordered phenomena?

Thus the paradox: How can a physical system overall be in a *presumed* single mechanical state when that implies that its *presumed* elements are extraordinarily coordinated, even though any *presumed* mechanical basis for their correlation also would imply processes that would destroy the single-valueness of the overall state.

Helium II

The transition from gaseous to liquid helium at 5.2° K is accompanied by a jump, a discontinuity in the specific heat. Thus it is of the usual type of *first order* phase transition.‡ At 2.2° K, however, something quite different happens. There is a sharp peak in the specific heat function in the shape of the Greek letter lambda, indicating that there is a *second order* phase transition associated with a continuous change in the internal geometry of the liquid. While this is a well-known situation in crystals and alloys, how can it be happening in a liquid that apparently has no well-defined internal geometries other than simple homogeneity of helium atom configurations? Again, we must pit the usual explanation against the actual implications of the "freak" phenomenon.

The second order phase change marks the onset of superfluid behavior, the state designated as He II with the spectacular properties indicated earlier.** Although the microscopic basis for electronic superconductivity had practically no theoretical underpinning in the late 1930s, He II was given an explanation and description. This work on He II was done primarily by F. London and L. Tisza, and the essential elements of their work have been accepted as the core of the matter up to the present. Even at that time, however, the leading (then) young Soviet physicist Lev. D. Landau raised sharp objections and posed counter-examples to the London-Tisza model. It is Landau's work that enables us to locate the conceptual — and psychological — blocks of physicists of both the reduc-

tionist particle-interactionist schools and of the relatively more consistent Soviet "Einsteinian" continuum outlook.

London was instrumental in gaining acceptance for the notion that superfluidity was basically a result of the close resemblance of He II to an ideal gas of bosons undergoing "Bose condensation." In this London was relying on one of the more incoherent algebraic features of quantum theory, the postulate that in addition to the energy levels determined by the Hamiltonian interaction of the discrete entities of a physical system, the entities are divided into two basic classes, bosons and fermions, and that these must follow independent axiomatic rules about the allowed arrays of occupation of those levels. Classical thermodynamics then can be extended from its prescription for the level occupation distribution of classical particles to a similar one for quantum entities. The quantum statistics differ from the classical case basically in that the same type of quantum particles are considered *indistinguishable*, and, therefore, exchange of any two of them in different levels is not counted as a new state. The further qualification is that as many bosons as you like can fill any level, while no more than one fermion is permitted per well-defined quantum level. With these rules the basic features of black body radiation and the general ordering of the periodic table of the elements can be delineated, since photons are bosons and electrons are fermions.

More than anything else, however, these statistics indicate that the linear, theoretical separation of discreteness and interaction is a very crude bit of "curve fitting" made to suit any real physical process.

London pointed out that the mathematical behavior of the ideal Bose distribution (for noninteracting bosons) at low temperatures has the same qualitative feature as the lambda point in liquid helium: a discontinuity in the derivative of the specific heat correlated with a discontinuity in the derivative of the statistical occupation function of the ground state. From this London concluded that the superfluid behavior was located in the ground state condensate; that is, the atoms in the heavily occupied ground state.

The issue least satisfactorily answered was how this particle picture connected up to the macroscopic fluid behavior. The inconclusiveness of London's thinking on the subject is summed up in the following reflections excerpted from his final treatise on superfluidity:

> Superfluid flow might be connected especially with the condensed phase which — at least in the ideal gas — consists of molecules of *macroscopic* de Broglie wavelength. . . In superfluid helium, as in superconductivity, a macroscopic quantum current is responsible for a particular transfer of matter which would not require the intermediary of excited states, and hence would show no energy dissipation. This transfer might rather be the result of an *adiabatic transformation* of an isolated ground state. . .
>
> In fact, an understanding of a great number of the most striking peculiarities of liquid helium can be achieved, without entering into any discussion of details of molecular mechanics, merely *on the hypothesis that some of the general features of the degenerating ideal Bose-Einstein gas remain intact, at least qualitatively*. . . pending an ultimate justification by the principles of quantum theory.

Tisza, meanwhile, extended this formulation at the macroscopic level by postulating a "two fluid" model in which the superfluid behavior was located in a supercurrent constituted by the particles in the condensate, and the normal fluid behavior was located in the "excited" particles. Although there has been much research since then on collective motions in superfluids and superconductors, the London-Tisza picture has remained the generic model for conceptualizing superfluid behavior.

As a model this is backward enough, for reasons described below, but it also overlooks the insightful and

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*There is no simple energy-potential-related geometric determinant of the average atomic spacing and liquid quasi structure (in terms of average nearest neighbor lengths and orientations, which can be very crudely made out by X-ray diffraction studies), since the interatomic spacing is much larger than the distance between minima in the simple potential energy function. The absence of a stable, symmetric solid state when there are no large applied pressures is related to the negative slope of the dE/dv line connecting the minima of energy (E) versus volume (v) plots as a function of temperature for solid and liquid helium, so that the solid state is never stabilized.

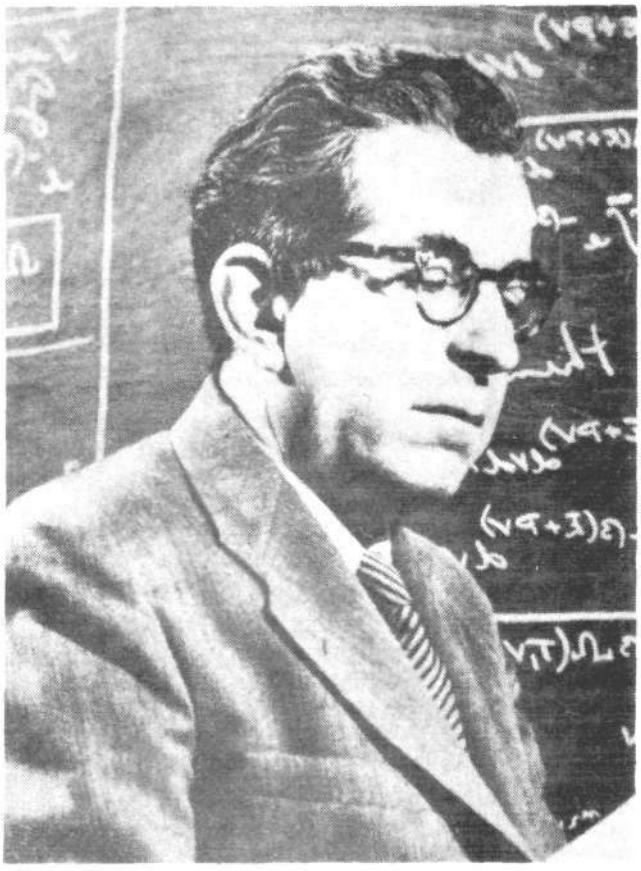
† In ordinary liquid states, a linear field theoretical approach yields reasonably accurate and consistent correlations of local electric field and average global field values. This is because the macroscopic modes of liquid motion are relatively insensitive to the quality of microscopic interaction since they average over a large number of ordered but uncorrelated interactions. In superfluids, as in energy dense plasma (or the high-energy particle collision "fireball"), microorder and macroorder are directly and visibly reconnected in a unified transfinite ordering. He I is apparently an intermediate case.

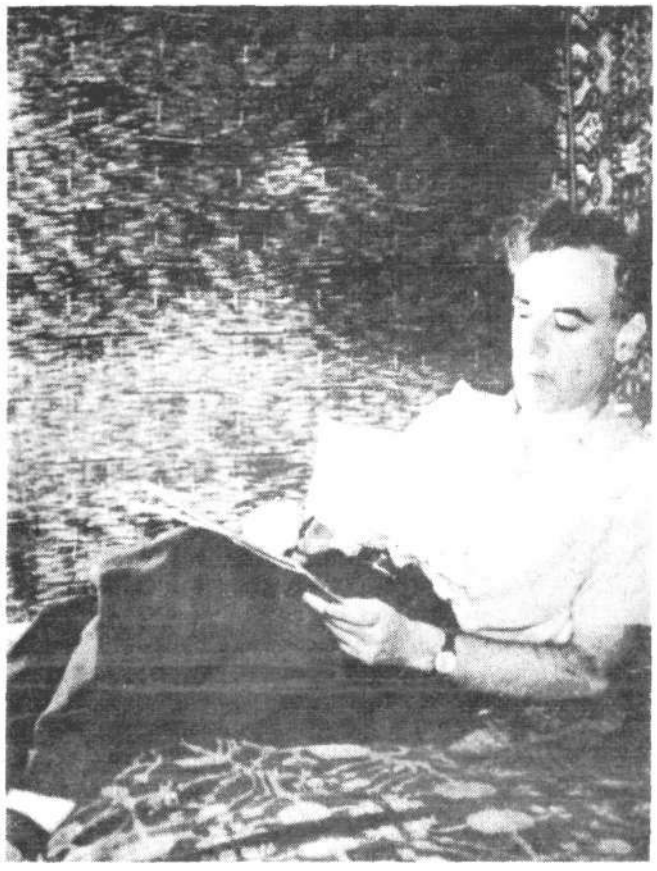
‡ The specific heat is the amount of energy required to change the temperature of some substance by one degree when pressure or volume is kept constant. The functional variation of this parameter indicates that at each value of T the internal energy content is rearranged into a new geometry. At critical points such as phase changes the qualitative nature of the internal geometrical change is most marked.

We normally compare the actually complex reorderings associated with temperature change with the simple scalar changes associated with an ideal gas thermometer. It is also possible to define temperature on the basis of statistical mechanics, even resulting in negative absolute temperatures for a system in an "improbable" distribution of occupied states (as for example Onsager's study of two dimensional vortices.) As stressed in an earlier paper by the author (1976), the consistency of these definitions and the relationship between statistical and thermodynamic properties depend on the linear degeneracy or nonlinearity of physical interactions dominating the system's dynamics.

**Since onset of superfluidity differs from normal second order phase changes in both its lack of well-defined change of Euclidean geometry and its extraordinary coherence, it might be well to distinguish the transition with the nomenclature of a higher-order second order phase transition.

Shenoy and Biswas have also recently theorized that one of the basic features in the transition from He I to He II is that the microscopic zero-point energy of the former is superseded by macroscopic zero-point momentum in the superfluid; that is, that the superfluid as a whole has nonzero total momentum from moment to moment. If true, this would contradict the simplistic notions of homogenous and symmetric continuum on which such mechanical laws as conservation of momentum and energy largely are based.





Fritz London[1] and Lev D. Landau. "Landau's work enables us to locate the conceptual blocks of physicists of both the reductionist particle-interactionist schools and of the relatively more consistent Soviet-"Einsteinian" continuum outlook."

provocative critique and alternative formulation of Landau, which unfortunately now is remembered more for its analytic formalism than its conceptual motivation.

Landau's Approach

Not one to mince words with what he considered to be scientific inanity, Landau opened one of his earliest papers on the subject of He II with a double-barreled attack on the London-Tisza model:

> L. Tisza suggested that helium II should be considered as a degenerate ideal Bose gas. He suggested that the atoms found in the normal state (a state of zero energy) move through the liquid without friction. This point of view, however, cannot be considered as satisfactory. Apart from the fact that liquid helium has nothing to do with an ideal gas, atoms in the ~~normal~~ state would not behave as "superfluid." On the contrary, nothing could prevent atoms in a ~~normal~~ state from colliding with excited atoms, i.e. when moving through the liquid they would experience a friction and there would be no superfluidity at all. In this way the explanation advanced by Tisza not only has no foundation in his suggestions but is in direct contradiction to them.*

There are three things to consider in respect to Landau's outlook: (1) why it represents a relatively more coherent view of some essential aspects of superfluidity; (2) what experimentally verifiable theoretical results it predicts that are different from Tisza's particle thermodynamics; and (3) what questions it leaves unanswered.

The outstanding feature of Landau's viewpoint is that he took as primary the coherent aspect of superfluidity. Landau then posed for elaboration the relationships among internal features of the coherent process and the interaction of the coherent process with its environment. Conceptually this is quite different from assuming a priori modes of particularity and interaction and then trying to construct the subsuming phenomena. This point is closely related to the comment above that the integrality of vortex motions in fluids are not reducible to lower order modes. Landau, in fact, stated explicitly that although the realms of normal thermodynamics and hydrodynamics coincide, they cannot possibly characterize the universe as a whole.

Landau proceeded by formulating an improved superfluid theory and a specification of the most general types of collective internal excitations by hypothesizing results consistent with the basic thermodynamic and hydrodynamic features of observed superfluid behavior. For all its successes, however, Landau's approach also exemplifies

the problem of attempting to fit He II behavior with a patchwork quilt theory.

The major elements of Landau's superfluidity theory include the following:

(1) To account for the failure of superfluid helium to participate in rotation (at low velocities) the most general hydrodynamic relationship to be satisfied is curl $v_s = 0$. † This is also consistent with the failure of superfluid helium to exert any force as it undergoes potential flow ($v_s = \nabla \phi$). Landau also developed a more detailed superfluid mechanics, and then, with limited success, attempted to bring in quantum behavior by quantizing the fluid parameters as field operators in the style of quantum field theories.

(2) Landau postulated that there were two basic types of microscopic excitations in the superfluid. First, the usual longitudinal phonon excitation ‡ with energy $e = cp$, which Landau showed could be excited only at absolute zero temperature if the superfluid flow exceeded a critical velocity, v_c. The phonon spectrum is the critical collective or quasi-particle replacement of Tisza's single particles to account for true two-fluid superfluidity at temperatures near absolute zero.

To account for viscosity and thermal properties at higher superfluid temperatures, Landau also postulated a more mysterious excitation termed a *roton*, which lay above the minimum of the phonon energy levels by an energy gap, Δ, and obeyed a quadratic energy-momentum relationship given by

$$E = \left[\Delta + \frac{(p - p_o)^2}{2\mu}\right].$$

The energy "spectrum," that is, the total energy of excitation in the superfluid as a function of the momenta of the quasi particles in the fluid, therefore, looked like the relationship in Figure 19.

(3) With these hydrodynamic and spectral features basically defining the macroscopic and microscopic ends, Landau proposed an improved two-fluid theory, stressing that the two-fluid components really represented two motions of He II. No physical separation of the two components of He II could be effected, Landau said, any more than one can isolate a phonon from the medium of which it is an internal excitation.

As Roberts and Donnelly note:

> In helium II...it is impossible, in principle or in practice, to visualize any value of ϱ_s or ϱ_n other than that appropriate to the thermodynamic state specified. All attempts to separate components will fail. For example, we might hope to obtain a pure sample of superfluid by utilizing its inviscid properties. With this end in view, we might pierce a reservoir with a hole so fine that the viscosity of the normal fluid could effectively prevent its escape, leaving the superfluid, unimpeded by friction, to be collected in a bucket below. Such a hole is termed a *superleak*. On examination of the contents of the bucket it would be found that it did not, after all, contain a superfluid. Instead, there would be a mixture of components of precisely the percentage appropriate to the temperature and pressure (the vapor pressure) at which the bucket is held.

The physical continuum and its excitations are inseparable. Superfluidity directly demonstrates that particles — energy storing and transmitting entities — cannot and do not exist as things-in-themselves. Altered boundary conditions, therefore, can be expected to produce geometrical changes in the He II state, a subject that runs throughout Landau's researches on superfluidity and superconductivity.

Landau went on to write a number of papers on the technical details of the spectrum and applications to computation of superfluid viscosity and other properties. Perhaps the most physically interesting paper in the series was titled "On the Rotation of He II" (1955), which posed the problem of what happens when a particular type of stress — rotation — is placed on the superfluid. The result provides a neat general picture of how coherent phenomena respond to altered boundary conditions and coexist with domains representing a different order of self-structuring.

Proceeding from his usual principled method of studying reasonably hypothesized dynamical structures, Landau perceived that experimental results on fast rotations of He II indicated modification of his earlier theoretical work. Although the experiments of Andronikashvili involving the *slow* rotation of He II had demonstrated beautifully that only the normal fluid rotated (that is, that curl $v_s = 0$) with the cylindrical container (and measured the ratio ϱ_s/ϱ), the size and shape of jagged meniscus formed upon *fast* rotation indicated that this no longer could be the case. But how could this be squared with the basic consistency relationship for an inviscid fluid; that is, that it undergo potential motion satisfying curl $v_s = 0$?

Landau recognized that a consistent solution demanded that the superfluid motion assume a coordinated, layered geometry (interspersed between layers of normal fluid moving with the rotating cylinder) that would preserve the condition curl $v_s = 0$ for the velocity field but minimize the free energy of the system by the addition and balancing of two new physical terms associated, respectively, with the additional angular momentum contributed by the

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*Landau's use of the normal state here refers to the ground state of zero energy and should not be confused with normal fluid which refers to the dissipative component.

† This condition means that are no circular lines of motion (mass fluid flow) that close back on themselves. This implies the absence of the formation of a structuring "backbone" for the rotational motion, such as that provided for a magnetic field by a line of electronic current according to curl $H = J$.

‡ These are the quantized constituents of sound waves in media such as water or air. The waves that you see radiating out when a stone is dropped in water are composed of coordinated clusters of these packets of energy. The critical importance of this relationship between energy and momentum for superfluids and electromagnetic photons is developed in sections D and E in Part II. Note that while the energy spectrum and its crucial role are recognized and developed by Landau as *algebraic* relationships, nothing is said about their *structure* or *geometry*.

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superfluid and with the surface interaction between the super and normal fluid layers. In this approach superfluidity is maintained as an integral phenomenon and gross motion is excited in a geometry circumscribed by undergoing phase transition to He I at its appropriate internal boundaries. These conditions are satisfied by a superfluid velocity field following the relationship

$$v_s = b_i / r_i$$

$$\text{where } b_i = \frac{\Omega}{2} \frac{r_i^2 - r_{i+1}^2}{\ln r_i / r_{i+1}}$$

(Ω is angular velocity, $r_0 = R$, and so forth), so that the dominant terms are those near the outer wall where $r = R$ (since the free energy takes the form

$$\sum_i \left[\lambda x_i^3\right]^{1/3}$$

where $x_i = r_i / R$) with typical superfluid layer thickness of about 0.05 cm.*

This result illustrates heuristically not simply a neat solution to a particular case, but a very profound and general epistemological result. The predicates of the coherent structures and processes of physics are determinate aspects of the process-as-a-whole. Under a certain range of conditions, knowledge of the lawful relationships among the predicates permits us to intervene to direct the process by a correlated "tuning" of its parameters; for example, in the temperature and velocity of rotation of a superfluid sample. To the extent that coherent processes determine metastable totalities whose interactions with each other only marginally affect the geometries of each other's "internal spaces," then the overall situation generally will conform to the statistical "laws" of thermodynamics. Such pseudolaws, however, cannot grasp or account for what is fundamental: the self-ordering of coherent existences and that marginal aspect of their interaction that is directly coupled to their internal "energy" content so as to produce negentropic evolutionary development †

Superfluidity not only makes us more sensuously receptive to this point of view, but also provides some highly suggestive conceptions for advancing toward a new continuum mechanics appropriate to the fundamental conception of negentropy. We can now see where the method of Landau and his collaborators and students reaches its conceptual limits, despite their high achievements. They did not have the scientific hubris to assert explicitly any physical principle beyond those sanctioned by mere formal mathematical nonlinearity as it is currently defined. Throughout his entire professional career, Landau was consciously aware that the notions of elementary particles and of the universality of the Second Law were absurd and that the essence of strongly interacting or relativistic systems was their breaking the bounds of the Hamiltonian formulation of physics, their "wholeness." Nonetheless, he could not reproduce as human knowledge the fundamental achievement of Humanism in grasping the common transinvariant shared by the physical universe and creative human mentation.

The Fundamental Issue

Some of the more recent theoretical and experimental results in superfluidity show clearly that one cannot simply elaborate or refine the Landau approach but must confront the fundamental issue posed here.

First, let it be said that the basic experimental results of the 1960s and 1970s strikingly confirm the elementary features of Landau's two-fluid and spectral models. The scattering of neutrons by He II, especially as performed by Cowley and Woods in Canada, has shown beautifully the general type of spectrum postulated by Landau (Fig. 19). On the other hand, the precise shape of the spectrum and its variation with temperature have convinced some of the leading workers in the field that there is no way at present theoretically to account for the results!

As recently as April 1977, Humphrey J. Maris, in his review of phonon-phonon interactions in liquid helium, restated the problem raised earlier by London and Pines: *"At present there is no rigorous first-principles theory of the excitation spectrum of liquid helium"* (emphasis added).

That is, in addition to the problem of reconciling bulk properties with the quasi-particle spectrum is the question of how the spectrum itself arises. Attempts to obtain the

spectrum using any of the formalisms for quantum interaction of helium atoms all have run into basic problems. The situation in 1961, as described by Pines, indicates the mathematical difficulties encountered:

> The dilute boson gas serves as a model for the phenomenon of superfluidity observed in liquid He 4, since the linearity of the quasi-particle spectrum guarantees the superfluid behavior. However, it does not respresent a good model for the actual behavior of He 4, because the density and scattering length of the He atoms...render the series expansion...meaningless....An accurate microscopic calculation of the spectrum does not yet exist (and)...the depletion of the zero momentum state due to particle interaction has not been properly handled.

The lack of progress since then is not, however, a matter of the mathematical formidability of the problem, but of its conceptual basis. The collective excitations constituting the spectrum cannot be built up from single particle interactions, since they themselves are the elementary expressions of discreteness appropriate to the general physical state of He II.

The most compelling evidence of the state of affairs is provided by Donnelly and Roberts in their review article on the thermodynamic properties of He II. They also comment pessimistically that, "The overall success of the quasi-particle method as applied to thermodynamics leaves much to be desired."

The problem is apparently twofold. On one level, when the spectral results at various temperatures are transformed into predicted bulk thermodynamics properties, they fail to fit the independently determined experimental thermodynamic results. No less disturbing to theorists is the fact that the sequence of spectra obtained as one scans through successive temperatures cannot be fit even by a semiphenomenological model based on Landau's spectrum, with variable parameters for the energy gap, and so forth.

Particularly high energy neutron scattering studies show a richness in the dispersion spectrum (the relationship between quasi-particle velocity and momentum or wave number) that indicate that the value of Δ is constantly changing and that not even an empirically adjustable quantitative theory can be determined self-consistently. As Roberts and Donnelly put it, "The implications here of failure to connect the macroscopic and microscopic picture seem profound." Indeed!

Another basic area of experimental research where some general theoretically predicted features have been verified nicely but where the detailed coherence and correctness of the theory is challenged sharply is small-scale vortex formation and dynamics. Although Landau's 1955 paper on nonvortical superfluid rotation seems to have been ignored for the most part (despite the fact that his free energy formulation is widely used), the problem of the quantization of an inviscid fluid stimulated a good deal of research on quantized vortex excitations in He II.

For a classical inviscid fluid, the flow parameter known as the *circulation* must be a constant of the fluid motion. This is expressed mathematically as

$$\oint \mathbf{v}_s \cdot d\mathbf{l} = \text{const.}$$

On the other hand, a quantum-fluid — here defined as being in a single, well-defined quantum state of the form

$$\Psi = e^{i\Phi}\Psi_o$$

(Ψ_o = ground state fluid wave function, and $\mathbf{v}_s \propto \nabla\Phi$) — satisfies the condition (for Ψ to be single-valued, Φ must change by some multiple of 2π around a closed path)

$$\oint \mathbf{p} \cdot d\mathbf{l} = m\oint \mathbf{v}_s \cdot d\mathbf{l} = Nh$$

(h = Planck's constant). Therefore, the circulation must be

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*Interestingly, a similar result was obtained by London, without taking into account surface energies and using the simplistic model of collective motion as the sum of individual particle motions. For angular velocities larger than a critical value

$$\omega = h/4\pi mR^2$$

the layered superfluid velocity distribution is of the form

$$v_k(r_k) = \omega r_k\left(\frac{k}{k-1/2}\right).$$

For a container of radius only 1 cm, the period of rotation would have to be on the order of a day in order to be far from the critical velocity. London points out that this effect may be critical in trying to determine just from rotation experiments whether lack of viscosity is due to the vanishing of dissipative interactions ($\eta = 0$) or to the condition curl $\mathbf{v}_s = 0$; that is, whether the superfluid component is truly irrotational. This, in turn, involves the question of whether curl $\mathbf{v}_s = 0$ is a local average result associated with the hydrodynamics or is a truly independent microscopic field feature connected to the profound quantum nature of liquid helium discussed above with reference to He I.

† Landau's geometric model for a stressed, rotating superfluid also provides an immediate analogue for the interrelationship of structures, flows, and boundaries in biological systems and organisms. The literalness of this analogy in the thinking of Little, in fact (as seen below), first inspired his notion of high temperature superconductivity.

In addition, these geometric considerations underlie two speculations with respect to superfluidity in media other than liquid helium. Ginzburg and Sobyanin have hypothesized the possibility of producing molecular hydrogen (H_2) in the superfluid state. At first sight, this might seem out of the question, since the predicated T_λ (for Bose condensation) is 6° K while freezing occurs at 14° K. However, various mechanisms such as impurities and surface-boundary interactions are thought to have the potentiality to lower the freezing point, T_M, to 6 to 8° K, while raising T_λ to this range in low-density H_2 liquid films on ultra-smooth surfaces.

The most non-commonsensical idea so far advanced is that superfluidity could be exhibited in *solid* He^4 or other crystals! Saslow has recently followed up theoretically the suggestion made by Legget in 1970 that a superfluid density fraction ρ_s/ρ could be defined for solid He 4, but was too small to observe at temperatures above zero. Physically, Saslow defines superfluid rotation for this case as a flow pattern in which matter flows as a total wavelike propagation but the locations of the lattice sites in space (that is, the density profile) do not change. According to his theory, ρ_s/ρ depends critically on how concentrated matter is at the lattice sites compared with the intersite spacings (this is called localization). Higly localized systems (for example, conventional solids) are predicted to have negligible ρ_s/ρ. For some delocalized crystals, however, ρ_s/ρ might be large enough (0.2 to 0.4) to produce observable effects. Saslow also tentatively proposes localization as an important concept in explaining the phase change and attenuation of superfluidity in fluid layers adjacent to a boundary, where possible localization greater than in solid He 4 leads to sharp fall-off of ρ_s/ρ.

Both Saslow and Ginzburg-Sobyanin strongly urge experimentation as the only means of providing definitive answers to their fascinating suggestions.

not only constant but quantized (and thus subject to quantum changes) in units of

$$Nk_o = Nh/m = N \times .997 \times 10^{-3} cm^2 sec^{-1}.$$

At first glance, a rotating superfluid structure satisfying this relationship would appear to conflict with the condition of irrotationality unless it were mathematically represented by a delta function (singularity). However, because nature abhors a point-singularity as much as it does a vacuum, a different physical solution is found. Since He II is a real and not an idealized linear continuum, the change of phase over boundary conditions determined in part by the interatomic spacing — a phenomenon called *healing* — cuts a hole out of the rotating superfluid where there would otherwise be a singularity. This produces a vortex ring, the geometrical structure that satisfies the physical conditions for quantized circulation (under conditions of rapid fluid rotation) in a mathematically and physically self-consistent way. (This process is not altogether different from the means by which a singularity at the center is eliminated from Landau's bulk circulating superfluid referenced above.)

The theory predicts a closely spaced array of quantized vortex lines as the rate of rotation of a cylindrical body of superfluid is increased, but the first experiments to demonstrate the existence and basic features of vortex motions in He II were somewhat less direct.

In the now-classical experiments of Rayfield and Reif in 1964, the experimenters indirectly observed the properties of quantized vortex rings in He II by exciting and tagging the rings with charged alpha particles from the radioactive decay of polonium 210. The charge permitted stabilization against frictional losses and measurement of the self-induced drift velocity of the vortices as a function of their energy of excitation (and, hence, size). The results strikingly confirmed the theoretically expected inverse variation of energy with velocity characteristic of vortex rings, verified that k was about 10^{-3} cm^2 sec^{-1}, and indicated that the inner vortex radius was about an Angstrom while the overall radius was on the order of 10^{-4} to 10^{-6} cm for energies in the range of about 1 to 50 electron volts.

Although these results confirm the simplest theoretical quantum relationships, the overall structure of the quantized vortex ring remains a basic problem in quantum hydrodynamics, particularly the apparently very small inner diameter.

These results are highly suggestive, however, of the possible relationship between the macrostate of the system and its most elementary excitations. Specifically, they suggest that the rotons are the physically smallest possible version of the vortex ring, or what Onsager referred to as a "ghost of a vortex ring." In their recent review of superfluid mechanics Roberts and Donnelly stressed in particular what they thought to be the overlooked significance of Feyman's earlier comments on the subject, in which he said:

> ...In a roton we imagine that the forces tending to contract the ring are already opposed by a kind of stiffness of the ring. It is already as small as possible. No drift motion results. In fact, forward drift would expand it and raise the energy, while reverse drift would try to compress it to a smaller size, again raising the energy. The lowest energy is at zero drift velocity.

This point of view, in fact, is one of the most fruitful insights to come out of the esoteric welter of postwar theoretical physics. Physics has done reasonably well and even elegantly with nonlinear problems where critical interaction relationships remain well defined or can be traced as they change, as in laser and nonlinear optics or solid state physics where analytic or statistical Hamiltonian physics can be used appropriately.* But nuclear and high-energy particle physics have enjoyed no such good fortunes, nor has fluid-plasma research, except for the approaches cited above †. The "freak" He II tells us why.

The View of the Universe from He II

The fact that in He II we get so much interesting phenomenology from apparently so little, is very nice. This is exactly what we want from a physics based on Riemannian — that is, physically determined — geometry.‡ The tricky thing about dealing conceptually with He II is to maintain an inviscid fluidity in thinking (without being slippery) so that conceptions brought to bear from normal physics for modeling aspects of He II are used to locate the precise points where such conceptions empirically reach their limits, and are then reflected back, along with the He II phenomenology, to rethink the problem in terms of new, more general features of the physical continuum and so to creatively modify the original conceptions.

When all the most important experimental results are reviewed — even when described in "first order" using existing quantum and continuum conceptions — the most crucial points are as follows:

(1) The motions of various types and dimensions within or of He II cannot be reduced to any description involving the presumed axiomatic metrical phase or physical space of interacting helium atoms. Every aspect of microscopic and semimicroscopic dynamics appears to be remarkably linked to the global state of the fluid as a whole, with a type of nonlinear feedback approximated only vaguely by prevailing notions of interaction.

(2) At the same time, the fluid as a whole is neither the impenetrable mysterious "whole" of those Copenhagen metaphysicians led by Niels Bohr nor the amorphous continuum of Schelling and his fluid-theoretical successors. There are characteristic scale lengths (for example, interatomic spacings or even smaller dimensions) consistent with the state of the fluid as whole that determine the semimacroscopic boundaries of the distribution of phases and structures within the fluid. The scale lengths and phase distributions, in turn, are related in some way to the intermediate distribution of collective excitations and their interactions within the phases, and to the energy of interaction between the phases.

Granted, when we are handed a box of helium gas and a

cryogenic apparatus, we are given certain initial conditions. The helium nuclei are in a sense *a priori* nodal points (which in fact play an absolutely critical role in the states of liquid and superfluid helium 3). But the dynamic self-ordering of the totality and the conditions under which metastable structures play an important mediating role can be due only to the type of fundamental physical process that is beyond the grasp of any axiomatic mechanics and that is of the quality involved in the formation and transformation of the elementary particles.

The specific results of superfluidity even in their own current descriptive terms provide a most provocative picture. A grainy continuum (the superfluid) that can move as a whole nondissipatively relative to an ensemble of excited quasi particles (the normal component) that interact entropically with each other; mechanisms of marginal interaction after the total continuum is properly excited for the formation of new geometries of the nondissipative component that then opens up a whole new range of processes....

A quantum state, therefore, is a Riemannian geometry. The epistemological blunder of physics is to look for the group-theoretic symmetry that encompasses all known interactions, when any fixed analytic geometry at best can be an approximate non-Euclidean mapping of the moments of any physical state. Interaction is a predicate, of self-subsisting or self-developing, physical geometry and not the other way around.

What's the practical implication of this? A good deal of time and effort can be saved by not barking up the wrong tree, such as doing a detailed calculation from "first principles" when the first principles are not available. In general this suggests making more use of analogue computing of dynamics that employ appropriate intermediate structures and empirically verified rather than dangerously assumed forms of interaction, and keeping a sharp eye out for "phase transitions" to new physical regimes. As long as science remains this side of the development of "Cantorian" techniques for comprehending the self-generation of higher-order Riemannian geometries, it might as well be done as self-consciously and efficiently as possible where practical results, such as those in the FEF's climate modeling project are involved.**

This is not to reduce science to a mere utilitarian activity; politically and intellectually there can be no real progress without creative hypothesizing and a rekindled Neoplatonism. But until we unfrock the "ghost" with the advancing and testing of new hypotheses, we're better off keeping our eye on the folds in his sheet rather than projecting our prejudices about what we think is underneath it.

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*See Bardwell and Levitt 1976.

† The article by Winston Bostick in the next issue of *Fusion* is one of the only efforts to go beyond the too literally fluid vortex model of the elementary particles of Kelvin, and to illuminate possible mechanisms for the energy-momentum (alternatively momentum-wavelength) relationships of elementary particles even more rigorously than the hypothesized roton-vortex ring connection.

‡ See Parpart 1975 and White 1978.

**See Lerner 1977.

Part II

The Crucial Experiments

Part II systematically develops the conceptions presented in Part I and provides a self-contained "course" in the physics of superfluidity. The critical experiments that prove the basic thesis of the transfinite quality of superfluidity are discussed in detail, along with relevant excerpts from the literature reviewed in Part I.

A: The Basic Thermodynamic and Hydrodynamic Properties Of Liquid Helium

This section summarizes the most interesting physical features of helium at low temperature using graphs and excerpts from London's 1955 treatise.

Density of liquid helium as a function of temperature

That something strange happens to liquid helium at about 2.2° K was noticed by Kamerlingh Onnes as early as 1911. He found that when the liquid is cooled below that temperature it starts expanding instead of continuing to contract, thus deviating from the behavior of most substances. Later, in 1924, Kamerlingh Onnes and Boks made more elaborate measurements and found that the density-temperature function has a sharp maximum with a *discontinuity of its slope* (discontinuous thermal expansion coefficient) at that temperature....In 1928 Keesom and Wolfke, comparing the discontinuity with a phase transition, were first to use the terminology "helium I" and "helium II," suggesting the idea of a kind of allotropic modification, helium II being the low temperature form (Figure 2).

Specific heat of liquid helium as a function of temperature

In contrast to ordinary phase transitions, the transition from helium II to helium I is not accompanied by a latent heat. Specific heat measurements by Keesom and Clusius in 1932 showed a singularity of the specific heat curve whose characteristic profile, resembling the shape of the letter λ ....has given rise to the name "λ-point" for this kind of singularity. Lambda points occur in many substances and are characterized by vanishing latent heat and the above-mentioned sort of singularity of the specific heat (Figure 3).

H_2O: latent heat of fusion = 79.7 cal/gm } These are isothermal
" " vaporization = 540 cal/gm } processes

Pressure versus temperature phase diagram of helium 4 before liquefaction

[Figure 4] shows the distribution of the solid, the gaseous, and the two liquid states in the *P-T* plane, as evolved mainly from the investigations of Keesom and coworkers. The most conspicuous peculiarity of this diagram is the absence of a triple point between the solid, liquid, and gaseous states. Instead of one there are actually two triple points — at the ends of the λ-*line* which separates liquid helium I from liquid helium II. Another peculiarity is that the melting curve seems to approach T=0 at a pressure of about 25 atm. Liquid helium presents the unique case of a substance which cannot be solidified under its own vapor pressure merely by cooling.

The melting of helium at absolute zero (and for all practical purposes that means up to 1° K) is a very remarkable process. Solid helium cannot be melted isothermally by supplying heat to the system, since there is no heat of melting. Close to absolute zero, solidification and melting are *purely mechanical processes*. If condensed helium is compressed above 25 atm, it is isothermally solidified. If the pressure is relaxed again, the substance is liquefied. *No entropy change* is involved in this transition. At absolute zero, where the system is in its lowest (single) quantum state, melting must then consist in an *adiabatic transformation of this quantum state.*

Figure 2 33 (2,7)

DENSITY OF LIQUID HELIUM AS A FUNCTION OF TEMPERATURE

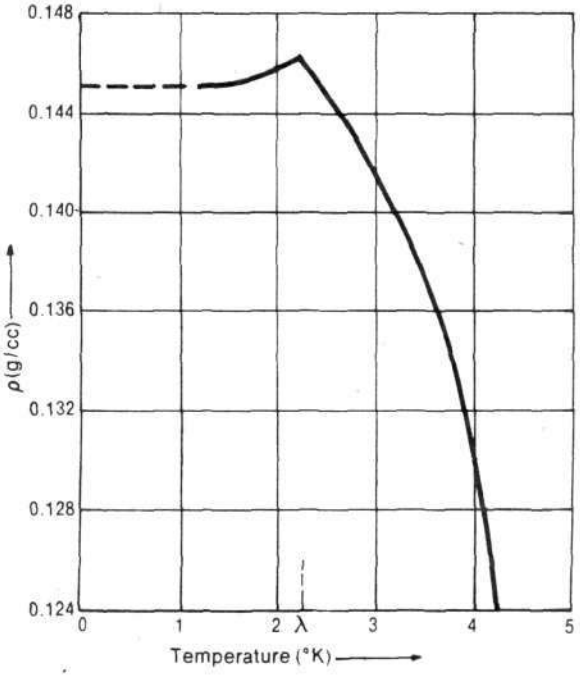
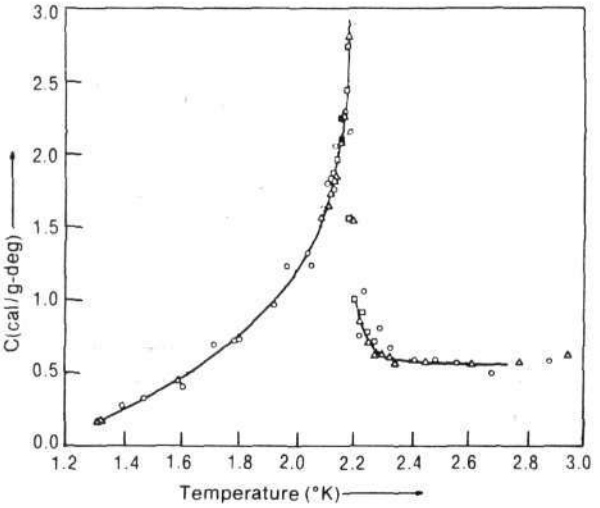


Figure 3 33 (2.10)

SPECIFIC HEAT OF LIQUID HELIUM UNDER ITS OWN VAPOR PRESSURE



Thermal conductivity of the superfluid

Devices with extremely fine slits or capillaries are required to detect any measurable temperature difference in liquid helium II. In 1937 Allen, Peierls, and Uddin first noticed that the heat current in liquid helium II is *not proportional to the temperature gradient*. They observed that the heat conductivity if defined by the ratio (heat current/temperature gradient), depends on the temperature difference and appears to become infinite with decreasing temperature difference. This, of course, indicates that the heat transfer in liquid helium II cannot be characterized simply by a large value of the ordinary heat conductivity coefficient and that accordingly the customary differential equation of heat conduction has to be replaced by something else (Fig. 5).

Viscosity of gaseous and liquid helium and of gaseous and liquid hydrogen as functions of temperature

Figure 6 shows clearly that the viscosity of liquid helium at normal pressures behaves like a gas (as for example, hydrogen) rather than a normal liquid. The value of the viscosity of He II remains at a nonzero value because of the presence of the normal component even at several tenths of a degree Kelvin.

heat current temp. grad. Air: $5.7(10^{-6})$
Thermal Conductivity: (Kcal/sec)/(meter)^2(°C/meter) Silver: $9.9(10^{-2})$

B: Basic Experimental Evidence For the Two-Fluid Model of He II

The earliest experiments to demonstrate that superfluidity apparently is associated with two noninteracting fluid components—one "normal" and one "super"—and to measure the relative amounts of each component as a function of temperature were performed during the latter part of the 1930s and the 1940s. These experiments involved measurements of the rate of rotation and damping of various oscillating devices submerged in He II, and of rotation of samples of He II. The classic experiment in this field, providing direct demonstration of two-fluid-like behavior and measurement of the ratio of normal component to total fluid density was reported by the Soviet scientist Andronikashvili in 1946.

The review article on superfluid mechanics by Roberts and Donnelly provides a compact, simplified summary of the results obtained from this class of experiments.*

Excerpts and illustrations from their discussion appear below:

Superfluidity and the Two-Fluid Model

It has long been known that, even in the complete absence of applied forces or pressure gradients, helium II can flow slowly through narrow channels for as long as the experimenter's patience lasts; during this time there is no detectable abatement in flow speed. This phenomenon is known as *superfluidity* and demonstrations of the effect are called *persistent-current experiments*. We describe one such situation: the liquid gyroscope....Our description will be idealized, as the experimental details are somewhat technical.

An axisymmetric container of helium is set into slow solid-body rotation about its axis of symmetry A at a temperature T_0 above the λ point. The apparatus is cooled while rotating to some preassigned temperature T_1 below the λ point, and the container is clamped. A complicated spin-down process evidently ensues as the liquid adjusts to these new surface conditions. This is not germane to the experiment and can be considerably shortened by making the interior of the container a honeycomb of narrow channels; one experimental procedure is to pack the container with a powder such as jewelers' rouge. At the end of the spin-down period, the fluid reaches a new steady state, but it is not one of rest relative to the container. This is explicitly demonstrated by the application of a small torque perpendicular to A. In response, the container starts to precess about A, showing the presence of an angular momentum L_1, owing to a flow about that axis, which can be assessed from the precession rate.

It is found experimentally that L_1 is constant in time and that, if it is measured hours or even weeks later, it is not diminished. This is the evidence for the existence of persistence of circulation of helium II. It is known that such currents *do* decay (roughly as the inverse logarithm of the elapsed time), but it requires very special experimental arrangements to observe such a slow process.

By repeating the experiment many times for different T_1, always starting with the same initial angular velocity and therefore the same initial angular momentum L_0 of the fluid above the λ point, a

*It should be noted that these experiments differ qualitatively from observations of superflow through tiny capillaries where the flow viscosity is determined almost completely by the superfluid component alone.

Figure 4

ALLOCATION OF THE FOUR STATES OF HELIUM IN THE PRESSURE-TEMPERATURE PLANE

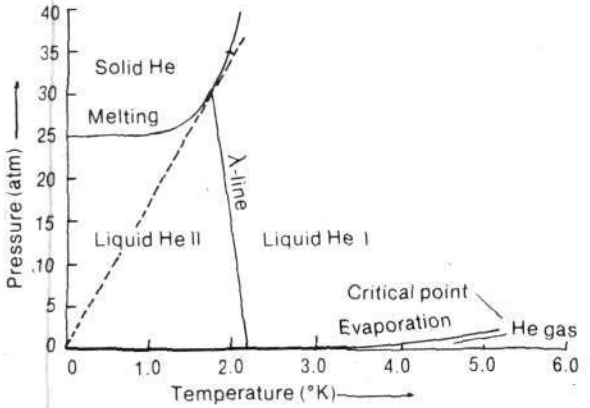
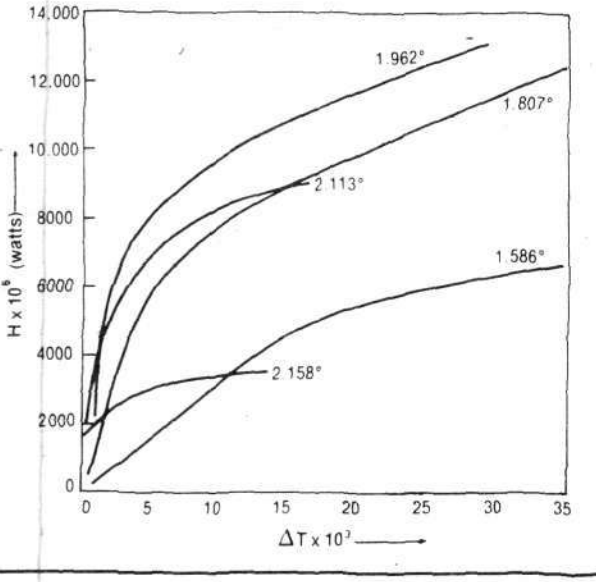


Figure 5

HEAT CURRENT AS A FUNCTION OF TEMPERATURE GRADIENT



Viscosity - a measure of surface "friction" between contiguous fluid particles

Figure 6

VISCOSITY OF GASEOUS AND LIQUID HELIUM AND OF GASEOUS AND LIQUID HYDROGEN AS FUNCTIONS OF TEMPERATURE

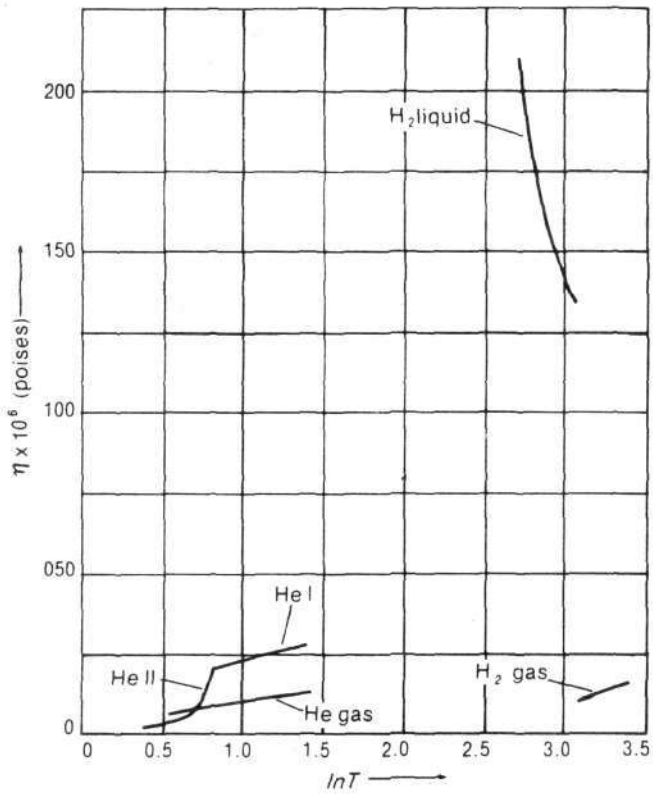
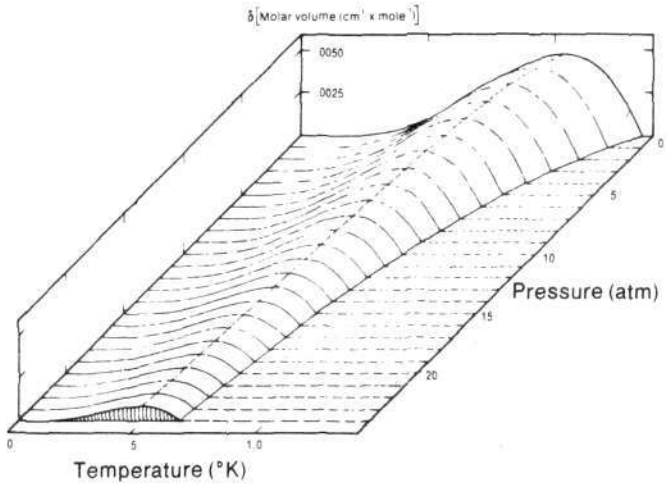


Figure 7

THE LOW TEMPERATURE MOLAR VOLUME OF HELIUM II AS A FUNCTION OF PRESSURE



The maximum in molar volume [the zero expansion coefficient] is shown as a dashed line along the maximum.

curve of L_1 as a function of T can be drawn. It is found that, if the moment of inertia M_1 of the rotating fluid at T_1 is deduced from L_1, then M_1/M_0, the fraction of the initial moment of inertia, decreases monotonically with increasing T_1, from a value of unity at $T_1 = 0°K$ to the value zero at $T_1 = T_\lambda$ [see Figure 8a]. By repeating the series of experiments for other M_0 and other gyroscopes, it can be shown that the curve is independent of M_0 and of details of construction of the gyroscope.

Despite the persistent currents just demonstrated, helium II can, rather paradoxically, behave as a classical Newtonian fluid. For example, if a circular disc of radius a is suspended by a fiber lying along its axis of symmetry and is set in small-amplitude torsional oscillation about that axis, the angular displacement decreases in amplitude and ultimately disappears in a time of order a^2/ν, where ν is comparable with the kinematic viscosity of helium I. Again, if, as in Figure (9), a number of equal circular discs are attached together rigidly along a common axis of symmetry and at a separation small compared with the viscous penetration depth $(\nu/\omega)^{1/2}$ for the frequency ω of oscillation of the system about the fiber on which it is strung, it is found from the decrease in ω that occurs when the system is placed in the fluid, that helium is trapped viscously between the discs, giving the system an enhanced moment of inertia. On closer perusal, it is found that this "pile-of-discs" experiments...beautifully complements the fluid-gyroscope experiments already described. For it is found that the moment of inertia M_1 of the trapped fluid depends sensitively on the temperature T_1 at which the experiment is performed. If M_0 is the moment of the inertia that would have obtained were the complete volume of fluid between the discs trapped, it is found that M_1/M_0 increases monotonically with increasing T_1 from a value of zero at $T_1 = 0$ to the value unity at $T_1 = T_\lambda$ (see Figure 8b). By repeating the experiments for other disc separations and other systems, it can be shown that M_1/M_0 is independent of these factors.

A remarkable fact is apparent from comparison of Figures [8a and 8b]. The statement

$$(1.1) \qquad (M_1/M_0)_{gyroscope} + (M_1/M_0)_{discs} = 1$$

is closely true at all values of T_1. This leads naturally to a two-fluid picture. Helium II may be thought of as a mixture of two components that can flow freely through each other. One component, the *superfluid*, is capable of flowing indefinitely without applied force. It can therefore have no viscosity. The other component, the *normal fluid*, behaves much as an ordinary viscous fluid. When the gyroscope is clamped, it is only the normal fluid that is brought to rest relative to the walls, the presence of the honeycomb effectively accelerating this process. The superfluid, however, remains unaffected and continues its circulation about A. For the disc experi-

ment, on the other hand, only the normal fluid is entrained by the oscillating boundaries. It is clear that the densities of superfluid and normal fluid can be experimentally determined for temperature T_1 by

(1.2) $\varrho_s = \varrho\,(M_1/M_0)_{\text{gyroscope}},\ \varrho_n = \varrho(M_1/M_0)_{\text{discs}}$

where ϱ is the (total) density of the fluid and is nearly independent of temperature. Equation (1.1) now reads

(1.3) $$\varrho_s + \varrho_n = \varrho$$

When the experiments just described are performed at an elevated pressure p, it is found that (1.1) and (1.3) are still true, even though at any T_1 the densities ϱ_s ϱ_n, and ϱ will be different.

The gyroscope experiment raises an apparent anomaly: the persistent motion is assumed to be the result of the inviscid component, but a classical inviscid fluid is irrotational (see page 31) that is, it generally cannot support vortical motion. However, an inviscid fluid can support internal fluid motions having nonzero overall angular momentum, and in fact, obeys the Kelvin-Helmholtz theorem that the line integral of the tangential component of fluid velocity around any closed path (called the "circulation") is conserved under appropriate changes of pressure and temperature. As superfluid mass is added by cooling, subject to constancy of circulation, a torque acts via the clamp to alter the angular momentum to its final observed value.

The conservation — and allowed changes — of circulation are intimately connected to the "quantum" character of He II.

C: Coupling of Superfluid Thermal And Flow Properties; Macroscopic Theory of the Two-Fluid Model; Mechanocaloric and Thermomechanical Effects*

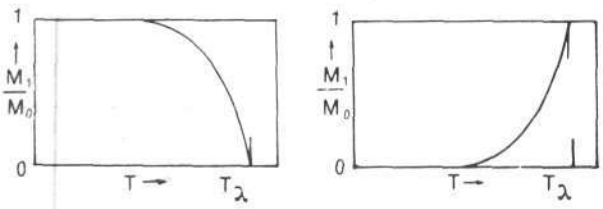
Macroscopic theory of the two-fluid model and the mechanocaloric and thermomechanical effects

The fact that a superfluid involves a totally different order of interaction from a normal, Newtonian fluid fundamentally alters not only the thermodynamic and hydrodynamic properties of the liquid, but also how these properties are interrelated. Described below are the two most basic types of phenomena that result from this coupling, the mechanocaloric and thermomechanical effects and the simplest of their time-dependent

*Some algebraic detail of the description of these simple models is given here but the description and explanation of more subtle effects are omitted to give you a feel for the basics of the subject at an algebraic-macroscopic level. These details, of course, must be subsumed by more fundamental — not more detailed — hypotheses.

Figure 8

THE RATIO M_1/M_0 FOR THE OSCILLATING DISC EXPERIMENT



(a) The ratio M_1/M_0 for the liquid helium gyroscope

(b) The ratio M_1/M_0 for the oscillating disc experiment

Plot **a** *indicates that the amount of fluid mass that continues to circulate after the container is stopped is a maximum at 0° K and falls to zero at the critical temperature for superfluidity. As the temperature is increased from absolute zero* [**b**]*, more normal component is present in He II; and as the pendulum traps it between its discs, its mass in rotation* [*moment of inertia*] *increases.*

Figure 9

CONSTRUCTION OF ANDRONIKASHVILI'S OSCILLATING PENDULUM CONTAINING A PILE OF DISCS

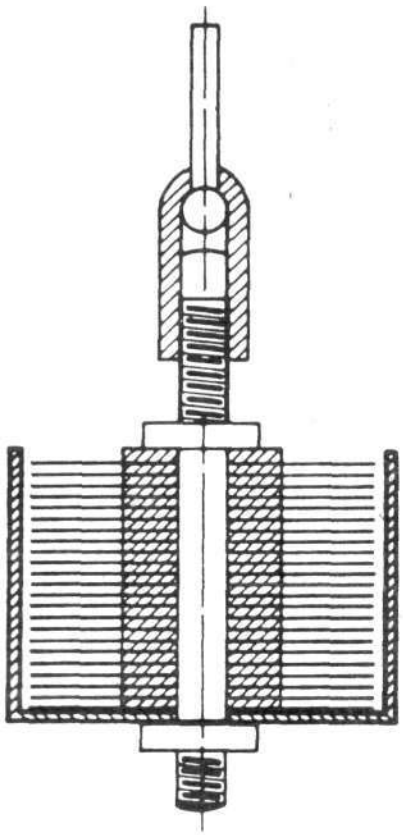
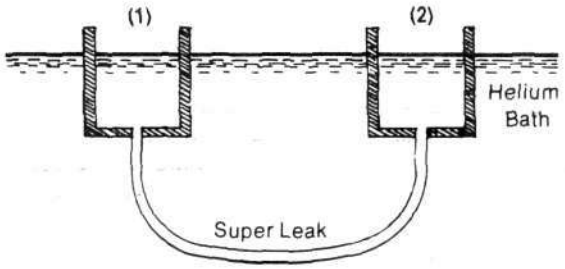


Figure 10
TWO VESSELS CONNECTED BY A SUPERLEAK



If the capillary is so small that only the superfluid component can flow through it, flow from [1] to [2] results in a rise in temperature of vessel [1]. If vessel [1] is heated, it will draw superfluid from the cooler vessel.

byproducts, second sound. Along with the gyroscope and pendulum experiments, these effects provide the essential experimental basis for the macroscopic two-fluid model of He II.

The effects to be described reflect the two unusual mechanical and thermal properties of the superfluid component of He II; namely, that it is *irrotational* and has *zero entropy*. The simplest linear approximations (that is, matching first-order causes to first-order effects) for the fluid equations (these are derived from conservation of mass and energy/ the "mass transport" and "Bernoulli" equations for He II) indicate that although superfluid and normal components are affected similarly by the internal pressure and external forces acting on the fluid as a whole, they also experience an equal and opposite (for each component) effective force, known as the thermo-mechanical force and given by

$$F = \pm \varrho_s S \nabla T$$

As a result of this force, the simplest condition that can be obtained across a superleak connecting two baths of He II is

$$\Delta P/\Delta T = \varrho S$$

where S is the conserved total entropy and $\Delta P, \Delta T$ are respectively the pressure and temperature gradients across the leak.

In the mechanocaloric effect, a displacement of the liquid causes it to heat up. For example, consider two baths of He II connected by a thin capillary that transmits only superfluid, as shown in Figure 10. If one of the containers slowly is elevated, its increase in potential energy is matched by a decrease of free energy associated with flow of superfluid into the stationary container. Since the amount of entropy in the elevated container is now distributed over a smaller amount of total fluid, the temperature increases.

If such a capillary arrangement is now made large enough also to transmit the normal fluid component and one of the containers is subjected to heating, the change in thermodynamic state causes superfluid to be absorbed; at the same time a counterflow of normal fluid is produced at the heat source and expelled out through the capillary as a strong jet.

A simple explanation for these results can be derived on the basis of the elementary two-fluid model. The essential features of the latter as described by London are:

The two-fluid theory is based on the *following assumptions* which, although originally borrowed from the Bose-Einstein condensation, may be considered quite independent of such an interpretation.

1. Liquid helium consists of two mutually interpenetrating fluids, the "superfluid" of density ϱ_s and the "normal fluid" of density ϱ_n. Each of them is supposed to have its own velocity field, $\mathbf{v}_s$ and $\mathbf{v}_n$ respectively. Hence at any point in space the mass density ϱ is written in the form

$$\varrho = \varrho_s + \varrho_n \tag{1}$$

and the mass current density $\mathbf{J}$:

$$\mathbf{J} = \varrho_s \mathbf{v}_s + \varrho_n \mathbf{v}_n \tag{2}$$

2. The *superfluid* corresponds to the condensed phase of the Bose-Einstein liquid. Accordingly, ϱ_s is supposed to increase from 0 to ϱ when the temperature decreases from 2.19° K (λ-point) to 0° K .... Furthermore, it is taken over from the Bose-Einstein model that the superfluid as a whole is virtually *one* quantum state, and as such determined by the macroscopic boundary conditions. Accordingly it does not contribute to the entropy:

$$S_s = 0 \tag{3}$$

If the superfluid as a whole is represented by a single quantum state, there is no place for a collision mechanism of the usual kind within the superfluid, though there may be transitions of molecules to and from the superfluid state, i.e., *fluctuations of the density ϱ_s of the superfluid* caused by the interaction with the normal fluid. Accordingly it is assumed that viscosity coefficient of the superfluid is zero:

$$\eta_s = 0 \tag{4}$$

at least within certain limits with respect to the velocity of the superfluid flow.

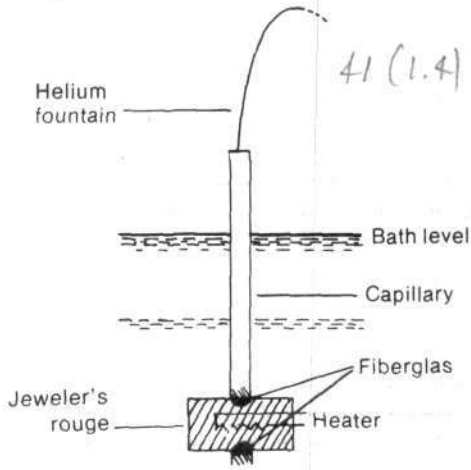
3. The *normal fluid* is supposed to be the carrier of the whole thermal excitation of the liquid. Thus the entropy of liquid helium II is entirely attributed to the normal liquid, and we may write:

$$\varrho S = \varrho_n S_n \tag{3'}$$

where S and S_n refer to entropies per gram of the whole liquid and of the normal fluid respectively. Furthermore the normal fluid is supposed to have a viscosity η_n of the order of magnitude of that of

Conservation of Entropy = Thermo Reversibility

Figure 11

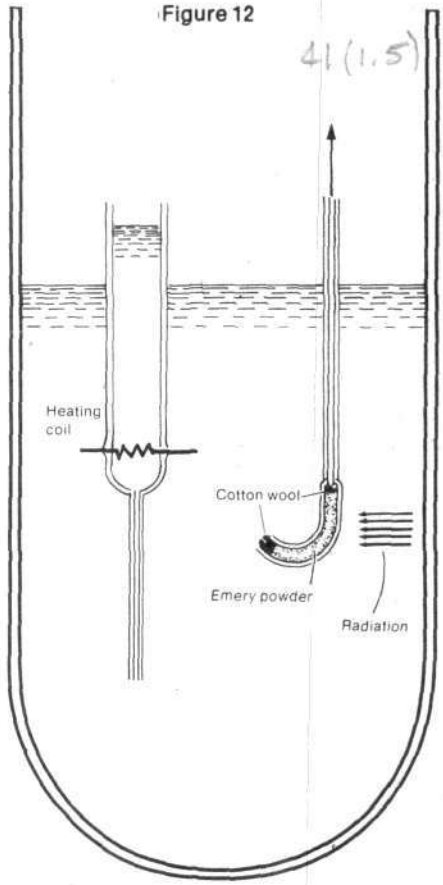


41 (1.4)

$\Delta P = \rho s \Delta T$

Figure 12

41 (1.5)



Figures 11 and 12

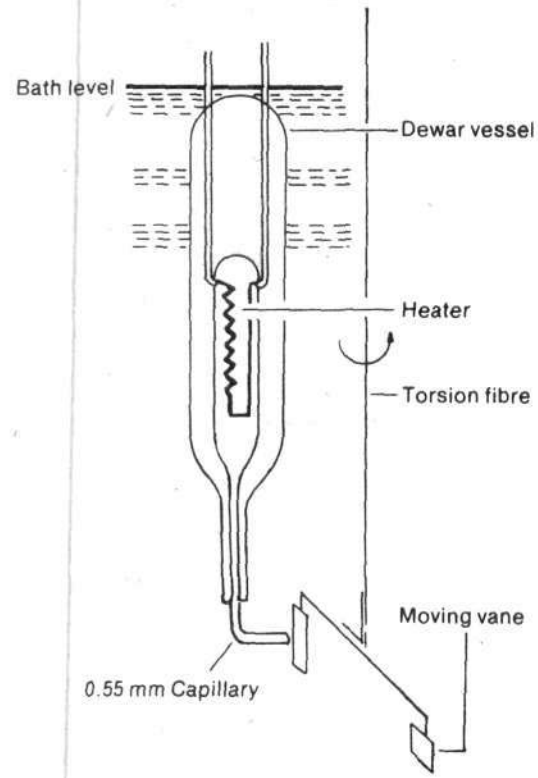
APPARATUSES FOR THE TWO FORMS OF THE FOUNTAIN EFFECT

When the vessel on the left in Figure 12 is heated, superfluid is pumped into it by the pressure difference across the thin capillary connecting the vessel to the bath. This pressure difference elevates the liquid in the vessel above the level of the bath. In either the situation on the right of Figure 12 or that shown in Figure 11, if the vessel itself becomes a thin capillary, and if it is connected to the bath by thin slots formed from emery powder or jeweler's rouge, the flow of superfluid up into the capillary gives the spectacular fountain effect upon heating by radiation or an electric heater.

Figure 13

41 (1.6)

KAPITZA'S DEVICE FOR STUDYING THE PROFILE OF A THERMALLY INDUCED SUBMERGED JET



The capillary is large enough that heating the vessel produces a jet of normal fluid component whose force is measured by the small torsion balance.

liquid helium I and going over into this value continuously at the λ-point:

$$\lim_{T=T_\lambda} \eta_n(T) = \eta_l(T_\lambda) \tag{5}$$

The related results described here — that the entropy of the superfluid component is zero, that restricted superflow is thermodynamically reversible (since there is no change in entropy), and that this all happens at temperatures above absolute zero — are devastating to thermodynamics.

In particular, the results are devastating to the advanced developments of thermodynamics by Planck and Nernst who based their work on the following hypotheses:

(1) Thermodynamic principles are strictly nonmechanical; therefore, physical processes are thermodynamically *irreversible* in accordance with the universal validity of the Second Law of Thermodynamics (Planck).

(2) There is an absolute measure of the entropy of a system (Planck following Boltzmann's statistical formulation), and its value is zero if the system is at the absolute zero of temperature (Nernst's Theorem or the Third Law of Thermodynamics).

Superfluidity is a phenomenon in which physical process is *reversible but nonmechanical*; that is, it is "conservative," but lies outside the territory of potential theory, and it achieves a zero-entropy component at temperatures well above absolute zero. In this situation, Planck's and Nernst's hypotheses obliterate each other and are shown to be invalid as universal principles.

Just as Planck's researches on the heat radiation spectrum pointed inescapably to the quantization of the electromagnetic field, the energy distribution in a superfluid points to the higher-order reality subsuming thermodynamics; the *transfinite nature of the field-particle relationship.*

Application to Mechanocaloric Effect

The flow of the superfluid through a thin capillary does not carry any entropy as discussed below, and so is a purely mechanical process. If two containers A and B containing a mass of liquid helium M_A and M_B are connected so that a mass ΔM moves from A to B through a thin capillary, then the entropy of each container remains unchanged:

$$\Delta S_A = -s_A \Delta M + M_A \Delta s_A = 0$$

$$\Delta S_B = s_B \Delta M + M_B \Delta s_B = 0$$

where s_A and s_B are the entropies per gram in vessels A and B. The temperature increase in A and the accompanying decrease in B, if the vessels are each isolated, are then given by the energy relationships for the respective adiabatic changes:

$$c_A \Delta T_A = T_A \Delta s_A$$

$$c_B \Delta T_B = T_B \Delta s_B$$

where c_A and c_B are specific heats per unit mass. Then, by the entropy relationships above,

$$\Delta T_A = \frac{T_A s_A}{c_A} \frac{\Delta M}{M_A}, \quad \Delta T_B = \frac{-T_B s_B}{c_B} \frac{\Delta M}{M_B}$$

This effect had not been observed when Tisza predicted it from the two-fluid model in 1938. Subsequently it was discovered by Daunt and Mendelssohn who reported in *Nature* in 1939 that liquid helium passing through the tiny passages in a fine powder was cooled.

If the vessels are held at constant temperature, then

$$\Delta s_A = \Delta s_B = 0,$$

and heat will be carried from A and supplied to B, according to

$$Q_A = T_A s_A \Delta M, \; Q_B = T_B s_B \Delta M.$$

This effect was measured and confirmed by Kapitza in 1941.

The Fountain Effect

The conservation of entropy (that is, thermodynamic reversibility) also permits simple description of the fountain effect (thermomechanical) discovered by Allen and Jones in 1938.

If u_i is the energy per gram of the i^{th} vessel, U is the total energy and the total entropy and volume of each vessel ($M_i s_i$ and $M_i v_i$) are constant then it must follow that at equilibrium

$$\delta U = \sum_i \delta(M_i u_i) = \sum_i (u_i - s_i T_i + v_i P_i)\delta M_i = 0.$$

This is equivalent to the condition that the Gibbs potential per unit mass

$$g = u - sT + vP,$$

is the same in each vessel:

$$g_A(P_A, T_A) = g_B(P_B, T_B).$$

This result can be rewritten as

$$\frac{\partial g}{\partial T} \Delta T + \frac{\partial g}{\partial P} \Delta P = 0$$

where g is the common equilibrium value and $\Delta P, \Delta T$ are pressure and temperature differences between the two vessels. With the additional standard thermodynamic definitions

$$\left(\frac{\partial g}{\partial T}\right)_P = -s \quad \text{and} \quad \left(\frac{\partial g}{\partial P}\right)_T = 1/\varrho$$

it follows finally that

$$\Delta P = \varrho s \Delta T.$$

If a heater is placed in a vessel to maintain it at temperature T elevated by an amount ΔT above a bath of helium, then helium will be driven by a pressure $\varrho s \Delta T$ (ϱ, s taking the values appropriate to T) *from the cooler to the warmer* location. The amount of heat Q (per unit mass)

supplied to the container also has to provide the entropy s to the arriving superfluid according to

$$Q = Ts$$

and so the heat is related to the thermomechanical pressure difference by

$$Q = \frac{T}{\varrho}\frac{\Delta P}{\Delta T}$$

The relationships of the connected mechanocaloric and thermomechanical effects were verifed by Kapitza in 1941 in measurements on the flow of He II through a 10^{-5} cm-wide channel between two polished quartz discs connecting a helium bath and an insulated, heated container. He showed that measured values of

$$\left(\frac{T}{\varrho}\right)\left(\frac{\Delta P}{\Delta T}\right)$$

as a function of T fell on the same curve as Q versus T, as did values of Ts.

This explains the first observation of the thermomechanical effect by Allen and Jones as shown in Figure 12. (The height of elevation was found to vary empirically as 213 $T^{5.6}$ ΔT cm.) The more spectacular "fountain effect" involved the arrangement shown in figure 11. When the emery powder is heated by flashlight radiation a jet of liquid helium rises up from the tube to a height of as much as 30 centimeters (see also 12, right.)

The production of a jet or normal fluid involves the more general action of the thermomechanical force when flow is not restricted to the special case of flow across a superleak. This effect also was measured quantitatively by Kapitza in 1941 (Figure 13).

The combined mechanocaloric and thermomechanical effects can be induced as reciprocating effects producing wave propagation when an oscillating temperature change is set up at a boundary of the superfluid. This wave disturbance does not have the usual bulk compressional (pressure) features of a normal sound wave associated with normal heat conductivity; instead it shows up as a propagating fluctuation in the temperature or entropy. The effect is called *second sound* and satisfies the wave equation

$$\frac{\partial^2 s'}{\partial t^2} = c_2^2 \nabla^2 s'$$

where s' is the perturbation in local entropy and the second sound velocity, c_2, compares with first (normal) sound according to

$$c_1^2 \cong \frac{dP}{d\varrho} \text{ for } (s' \cong 0,\ P' \neq 0);\ c_1 \cong 236 \text{m/sec}.$$

$$c_2^2 \cong \frac{Ts^2}{c}\left(\frac{\varrho_s}{\varrho_n}\right) \text{ for } (p' \cong 0,\ s' \neq 0),$$

(c = specific heat; $c_2 \cong 20$ m/sec at $T = 1.4°k$)

The first experimentally produced and measured thermal waves were achieved by Peshkov in the Soviet Union in 1944.

D: Microscopic Theory Of the Two-Fluid Model

The two simplest microscopic pictures developed to account for the properties of He II are the ideal Bose gas and quasi-particle excitation models. The former begins with the Bose statistics for an ideal noninteracting gas of bosons given by

$$n_i = \frac{g_i}{e^{(e_i/kT+\alpha)}-1}$$

where n_i is the number of particles in the i^{th} level having energy e_i and g_i is the relative statistical weighting of the level. At low temperatures and for N bosons, this takes the form

$$n_o = N\left[1-(T/T_c)^{3/2}\right]$$

for occupation of the ground state (and hence for the ratio ϱ_s/ϱ), where

$$T_c = \left(\frac{h^2}{2\pi mk}\right)\left(\frac{N}{2.612V}\right)^{2/3}$$

is the boson critical temperature which is assumed to provide the lambda point.

On the basis of this model the normal and superfluid densities vary with temperature as shown in Figure 14, and the specific heat at constant volume,

$$C_v = \left(\frac{\partial E}{\partial T}\right)_v$$

(where

$$E = \Sigma_i n_i e_i)$$

can be obtained by using in the expression for E the phase space weighting function for a free Bose gas

$$g(e) = \left[\frac{2\pi V}{h^3}(2m)^{3/2}\right]e^{1/2}$$

as shown in Figure 15.

In contrast, the Landau quasi-particle model takes the following line of attack which Landau developed in his original 1941 paper "Theory of Superfluidity of He II." The essential section on "The Energy Spectrum of a Quantum Liquid" is so crucial to all of Landau's work on quantum physics of fluids that it must be quoted in full:

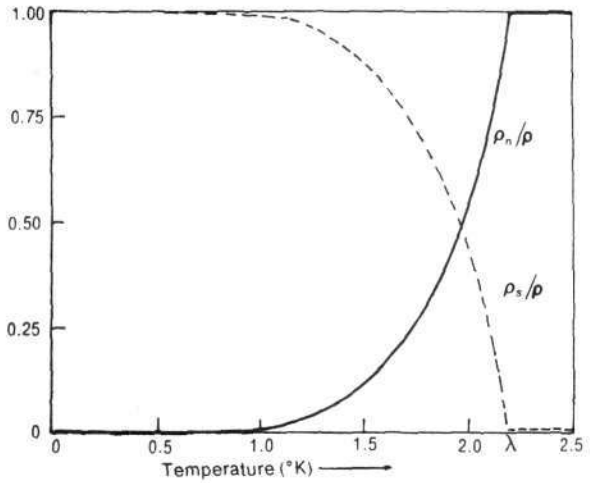
The Energy Spectrum of a Quantum Liquid

In the classical hydrodynamics of ideal liquids it is shown that if, at a certain moment of time, the motion is potential (curl $v = 0$) in the whole volume of the liquid, it will be potential for all other moments of time (Lagrange's theorem). It appears that this classical theorem finds its analogy in quantum hydrodynamics.

According to the commutation rules...; curl **v** always commutes with the density ϱ The compon-

Figure 14

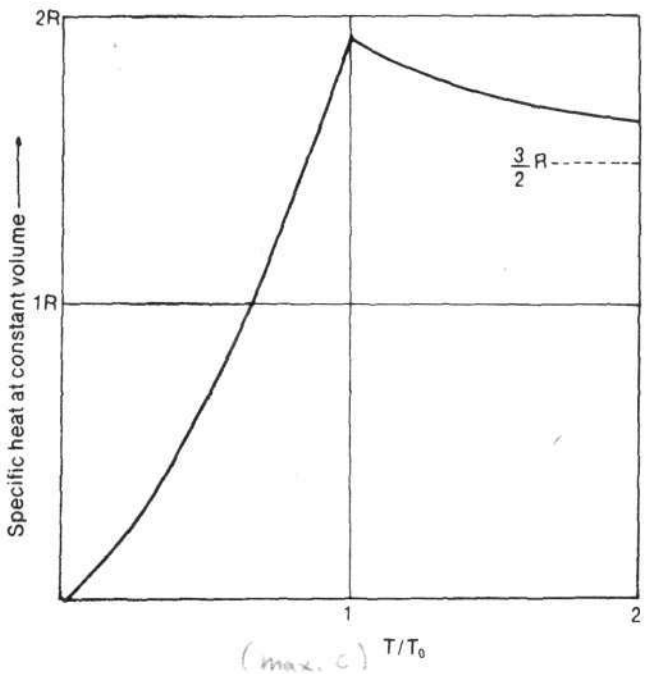
NORMAL AND SUPERFLUID DENSITY ACCORDING TO THE TWO-FLUID MODEL



If the lambda point is adjusted to occur at 2.2° K, the relative densities of normal and superfluid components predicted by the Bose condensation model vary with temperature approximately as shown.

Figure 15

SPECIFIC HEAT, AT CONSTANT VOLUME, OF THE IDEAL BOSE-EINSTEIN GAS



The similarity of the peak at critical temperature T_0 to the lambda point of helium suggested to experimenters that the two phenomena might be related.

ents of curl **v**, however, do not commute, generally speaking, either with each other or with the components of velocity **v**. Therefore, curl **v** does not, generally speaking, commute with the Hamiltonian, i.e. is not conserved.

An exception is the case when over the whole volume of the liquid curl **v** = 0. In this case...curl **v** commutes with ϱ and **v** and, therefore, also with the Hamilitonian.

In this way curl **v** is conserved if it is zero. In other words, a quantum liquid always possesses stationary states in which curl **v** equals zero over the whole volume of the liquid. Such a state might be called, by analogy to classical hydrodynamics, a state of potential motion of the liquid.

Concerning these results an analogy can be made with the angular momentum M in quantum mechanics. The commutation of two components of M with each other leads to the third component of M, with the result that all the components of M commute with each other if they are all equal to zero. It is also known that there exist no states with an infinitely small angular momentum, its first non-zero eigenvalues are of the order of $\hbar$. This is a consequence of the fact that the commutation rules are inhomogeneous—their left-hand sides are quadratic in M and the right-hand sides are linear.

A similar statement can be advanced concerning curl **v** in quantum hydrodynamics. Namely, no states can exist in which curl **v** would be non-zero, but arbitrarily small over the whole volume of the liquid. In other words, between the states of the potential (curl **v** = 0) and vortex (curl **v** ≠ 0) motions of a quantum liquid there is no continuous transition.

From this the principal features of the energy spectrum of a liquid directly follow. The presence of a gap between the states of the potential and vortex motions means that between the lowest energy levels of vortex and potential motions a certain finite energy interval must exist. As to the question which of these two levels lies lower, apparently both cases are logically possible. It will be shown below that we get the phenomenon of superfluidity if we suppose that the normal level of the potential motion lies lower than the normal level of vortex motions. Hence we must suppose that this very case exists in liquid helium. It must be remarked, however, that, as only one quantum liquid exists, liquid helium, the question as to whether such a distribution of the levels and hence the property of superfluidity is a general property of a quantum liquid cannot be solved experimentally.

This brings us to the following picture of the distribution of the levels in the energy spectrum of liquid helium (it must be emphasized that we do not here refer to the levels for single helium atoms but to the levels corresponding to the states of the whole liquid). This spectrum is made up of two superimposed continuous spectra. One of them corre-

sponds to the potential motions and the other — to vortex motions. The lowest level of the vortex spectrum is situated above the lowest level of the potential spectrum, this latter level being the normal unexcited state of a liquid; the energy interval between these two levels we denote by Δ.

The value of the energy gap Δ cannot be calculated exactly. Its order of magnitude is

$$\Delta \sim \frac{\hbar^2 \varrho^{2/3}}{m^{5/3}} \tag{1}$$

(m being the mass of the helium atom and ϱ — the density of the liquid). This is the only quantity of the dimension of energy which can be built up from m, ϱ and $\hbar$. This gives numerically $\Delta/k \sim 1°$. i.e. Δ, as was expected, is of the order of kT_λ. T_λ being the temperature of the λ-point of helium.

Consider an excited level which is situated not too high above the beginning of the spectrum (vortex or potential one).

Every weakly excited state can be considered as an aggregate of a number of single "elementary excitations." As far as the excited levels of the potential spectrum are concerned, the potential internal motions of the liquid are longitudinal waves, i.e. these motions are sound waves. Therefore, the corresponding elementary excitations are simply sound quanta, i.e. phonons. The energy of the phonons is known to be a linear function of their momentum p:

$$\varepsilon = cp, \tag{2}$$

c being the velocity of sound. Thus, at the beginning of the potential spectrum the energy is proportional to the first power of the momentum.

An "elementary excitation" of the vortex spectrum might be called a "roton." Those special reasons which stipulate a linear dependence of ε and p for phonons do not exist for rotons. For small momenta p the energy of the roton can be simply expanded in powers of p; in view of the isotropy of the liquid the expansion of the scalar ε in powers of the vector p only contains terms with even powers, so one may write:

$$\varepsilon = \Delta + \frac{p^2}{2\mu} \tag{3}$$

where μ is an "effective mass" of the roton (in [2] and [3] the energy is measured from the normal state).

If the number of phonons and rotons (per unit volume of the liquid) is not large, their aggregate can be regarded as a mixture of two ideal gases — a phonon gas and a roton gas. It is known that the phonon gas obeys Bose statistics. As to the rotons, they too probably obey Bose statistics. It must, however, be remarked that inasmuch as the energy of a roton always contains a quantity Δ large compared with kT (at low temperatures only when the aggregate of rotons can be treated as a gas) the

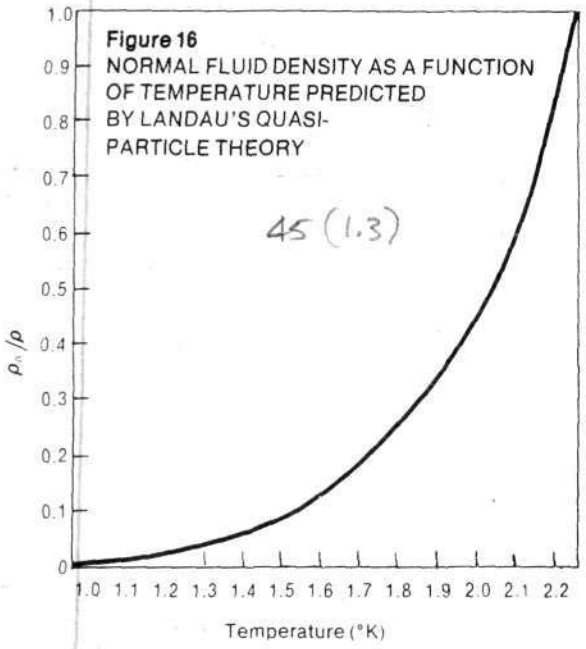


Figure 16
NORMAL FLUID DENSITY AS A FUNCTION OF TEMPERATURE PREDICTED BY LANDAU'S QUASI-PARTICLE THEORY

Unlike the Bose-condensation theory, Landau's theory is based on calculation of the energy contained in the actual collective excitations [quasi particles] in the fluid, the phonons and rotons, and not just the single atoms.

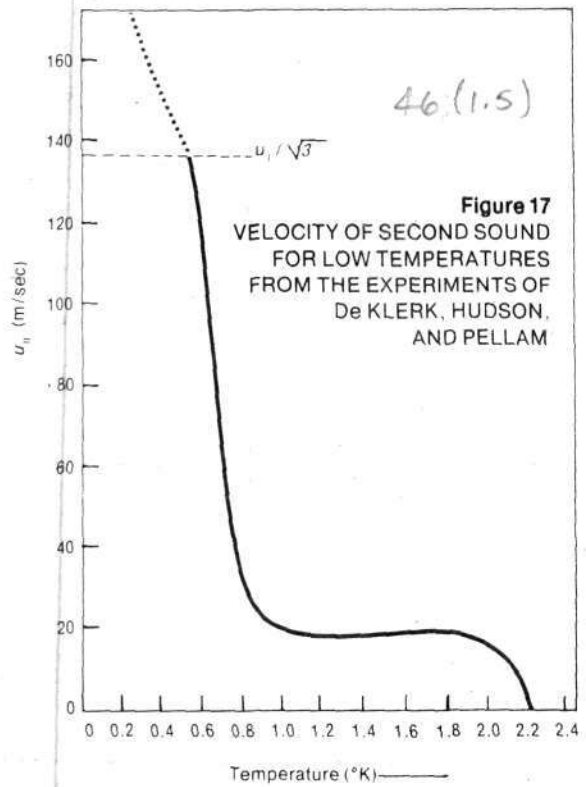


Figure 17
VELOCITY OF SECOND SOUND FOR LOW TEMPERATURES FROM THE EXPERIMENTS OF De KLERK, HUDSON, AND PELLAM

The minimum in second sound velocity at about 1.2° K and the increase in velocity with decreasing temperature below this point strikingly confirm Landau's theory of the phenomenon.

difference between the Bose and Fermi statistics is not essential and one can use Boltzmann's distribution for the rotons.

London's Criticisms

London raised several important criticisms against Landau's line of reasoning: (1) Landau had provided no model for the interactions producing the roton; (2) rotational properties might arise from suitable semimacroscopic averages over the strictly microscopically irrotational potential flow; (3) the macroscopic two-fluid theory as corroborated by the initial experimental results was basically the same whether based on the models of Tisza or Landau; and (4) most tellingly, according to London, Landau's spectral theory did not explain the lambda point and should give comparable results for helium 3, even though the latter isotope had shown no evidence of superfluidity at low temperature.

However, the overwhelming experimental evidence, much of it reviewed by London, demonstrates conclusively that London's criticisms of Landau's theory without exception were invalid. The basic results of these experiments are reviewed here in order to underscore that the critical physical questions must involve the interrelationship of elementary excitations, intermediate structures, and the global state. What is important is to see the significance of where Landau's results reach their limits, rather than questions of individual particle motions and interactions.

As London notes, there is no question that experimental measurements (especially at temperatures of 0.6° K and less) involving the specific heat and second sound velocity validate the values for ϱ_n/ϱ predicted by Landau's theory. Landau's theory predicts that most of the excitation energy at several tenths of a degree is located in phonons that obey Bose statistics. At higher temperatures, he adds in the sum over roton states, which are energetic enough to be described by Maxwell statistics. At low temperatures both the specific heat and second sound velocity

Figure 18
VISCOSITY OF THE NORMAL COMPONENT OF LIQUID HELIUM PLOTTED AGAINST TEMPERATURE

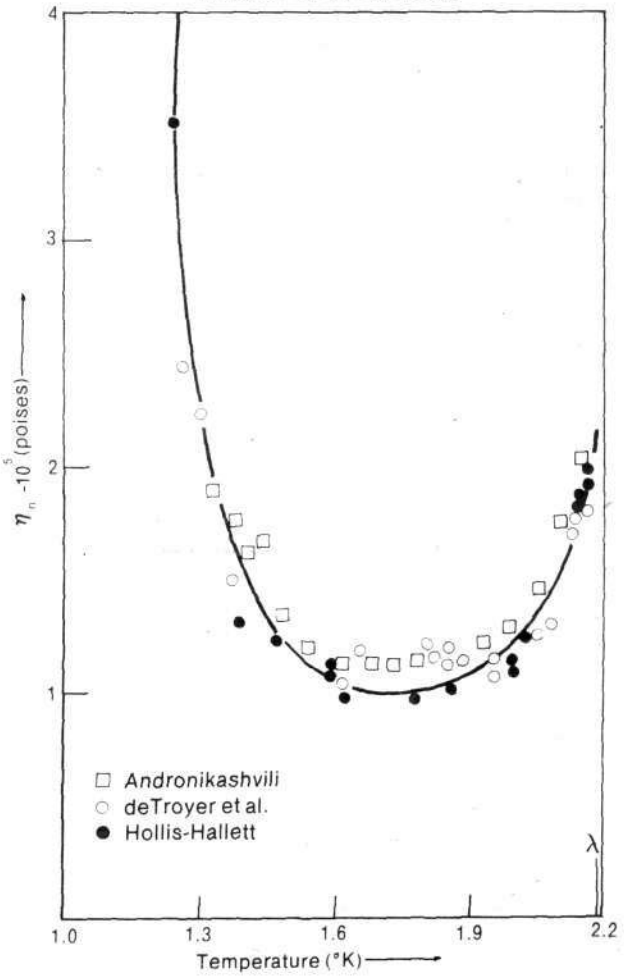
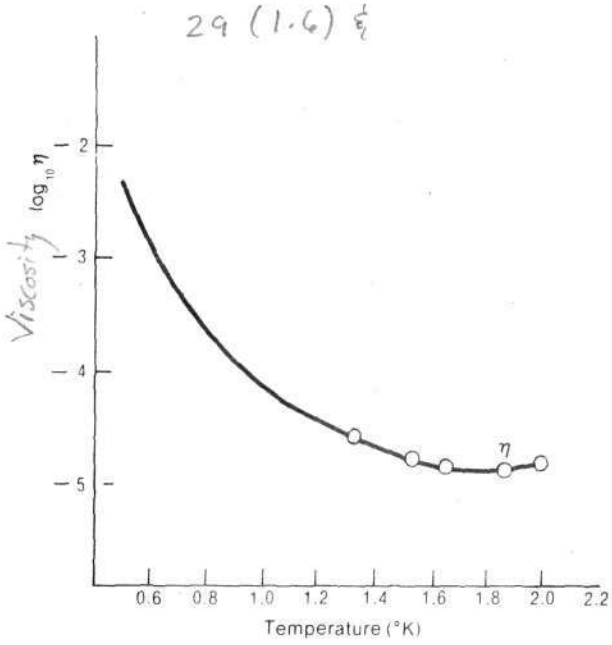


Figure 19
LANDAU THEORY OF TEMPERATURE DEPENDENCE ON VISCOSITY



Figures 18 and 19

Landau's quasi-particle collision theory correctly predicts the measured low temperature behavior of the viscosity due to the normal component of He II [Figure 19]. The symbols in Figure 18 represent data from three different experimental groups, and the solid curve is the function that best fits the data.

dependence on ϱ_n/ϱ clearly indicate that ϱ_n/ϱ fits very well Landau's predicted result that

$$\frac{\varrho_n^{(\text{phonon})}}{\varrho} = 1.24 \times 10^{-4} T^4$$

(Data on heat capacity at higher temperatures, where the rotons presumably dominate, indicate that

$$\Delta/k \cong 8 \text{ or } 9^\circ\text{K and } \mu \cong 7 \text{ or } 8\ M_{He}.)$$

Furthermore, the simplest approximation to the total normal fluid density yields the result

$$\varrho_n = \varrho_n^{(\text{phonon})} + \varrho_n^{(\text{roton})} = \left(\frac{4}{3}\frac{E_{ph}}{c^2} + \mu N_r\right)\varrho$$

where

$$E_{ph} \propto T^4 \text{ and } N_r \propto \left(\frac{\mu kT}{2\pi\hbar^2}\right)^{3/2} e^{-\Delta/kT}$$

Plotted in Figure 16, this not only gives a reasonable fit to thermal data, but also, by extrapolation, predicts a lambda point at 2.3° K, which is far more accurate than the particle Bose condensation value of 3.13° K.

If these are indeed the elementary excitations, then Landau rigorously shows that superfluidity at temperatures near absolute zero results directly from the fact that motion of the superfluid cannot be transformed into energy of excitation unless the superfluid velocity (for example, relative to its containing walls) exceeds either c for phonons or

$$\sqrt{\frac{2\Delta}{\mu}}$$

for rotons. Landau succinctly developed the argument in his original 1941 paper as follows:

> Let us consider the helium when flowing through a capillary at a constant velocity v ....
>
> Let us suppose that a phonon can be excited in the liquid. Then the energy E_0 of the liquid (in the coordinate system in which it was initially at rest) is equal to the energy ε of the phonon (we will agree to take the energy of the normal state as zero)and the momentum $\mathbf{P}_0$ of the liquid is the momentum $\mathbf{p}$ of the phonon. As $\varepsilon = cp$ we have:
>
> $$E_0 = cp\ ,\ \mathbf{P}_0 = \mathbf{p}$$
>
> We will now return to the coordinate system in which the capillary is at rest. According to the known formulae for the transformation of energy and momentum in classical mechanics we have, for the energy E and the momentum $\mathbf{P}$ in this system
>
> $$E = E_0 + (\mathbf{P}_0 \cdot \mathbf{v}) + \frac{Mv^2}{2},\ \mathbf{P} = \mathbf{P}_0 + M\mathbf{v}$$
>
> M being the mass of the liquid. Inserting E_0 and $\mathbf{P}_0$ for the energy
>
> $$E = cp + (\mathbf{p} \cdot \mathbf{v}) + \frac{Mv^2}{2}$$
>
> The term $Mv^2/2$ is the initial kinetic energy of the flowing helium, the expression $cp + (\mathbf{p} \cdot \mathbf{v})$ being the change of energy owing to the excitation of the phonon. This change must be negative as the energy of the flowing liquid must decrease:
>
> $$cp + (\mathbf{p} \cdot \mathbf{v}) < 0$$
>
> To fulfill this condition the absolute value of the velocity V must be, in any case, greater than the velocity of sound
>
> $$v > c.$$
>
> At smaller velocities the interaction with the walls of the tube cannot give rise to an excitation of phonons.

In a subsequent 1947 paper "On the Theory of Superfluidity of He II," Landau modified his original spectral model on the basis of more accurate measurements by Peshkov on second sound, especially in the interval of about 1.3° to 1.7° K. In order to fit the data better, the roton spectrum was altered to include a minimum around which

$$E = \frac{(p-p_0)^2}{2\mu}$$

In this region also, Δ is found to vary inversely with temperature.

A year later in a paper titled "On the Theory of Superfluidity," Landau is at his sharpest in reassessing the past decade's results and directly responding to the criticism of his approach by Tisza.*

Landau's reply is based on the rock-bottom principles of quantum mechanics or quantum Hamiltonian physics applied to a macroscopic system, which reduce to two principal points:

(1) There is a direct quantum mechanical connection between the macroexcited state and a distribution of "elementary excitations" describing the "collective" motions of particles. Individual particle motions are meaningless in systems of strongly interacting particles.

(2) The general microspectrum must be of phonon type at low energies. *This alone produces superfluidity.*† A recent result of that period by Bogoliubov for the general form of the spectrum of weakly interacting bosons shows qualitatively how this occurs:

> As it should be, the "elementary excitations" appear automatically, and their energy E as a func-

*At the very outset of the paper, Landau sets the tone in a footnote as follows: "I am glad to use this occasion to pay tribute to L. Tisza for introducing, as early as 1938, the conception of the macroscopical description of helium II by dividing its density into two parts and introducing, correspondingly, two velocity fields. This made it possible for him to predict two kinds of sound waves in helium II. (Tisza's detailed paper...was not available in USSR until 1943 owing to war conditions, and I regret having missed seeing his previous short letter....) However, his entire quantitative theory (microscopic as well as thermodynamic-hydrodynamic) is in my opinion, entirely incorrect."

† As Landau puts it elsewhere in his text on *Statistical Physics*: "The condition for the presence of superfluidity which we have obtained reduces simply to the requirement that the curve $e = e(p)$ should not touch the abscissal axis at the origin (neglecting the unlikely possibility that it might touch this axis further along). Hence, in fact, superfluidity will occur for every spectrum in which sufficiently small excitations are phonons."

tion of the momentum p is represented by a single curve, which has a linear initial part. Although the model of such a gas does not have any direct bearing on the actual liquid helium II, it shows the manner in which the quantum-mechanical mathematical formalism leads, in fact, from a macroscopical body to an energy spectrum with the indicated properties.

The further trend of the E vs. p curve cannot be established in a general form *by purely theoretical considerations* (emphasis added).*

Tisza's Misunderstanding

Landau then contrasts his hydrodynamics (which, admittedly, are not — yet — dependent on the particular assumptions about the spectrum) with Tisza's. These reduce to his result only accidently — by compounding errors. "Therefore," Landau says, "one must consider as a mere misunderstanding Tisza's assertion that this formula [Landau's] is in conflict with experiment." This leads naturally to the critical question of the relationship between collective excitations and the specific results of the two-fluid concept. In Tisza's model phonons are assigned to the liquid as a whole instead of to the normal part, which is assigned elementary excitations of single-particle translational states.

A key test of the difference between the theory built on these assumptions and Landau's theory is the dependence of second sound on temperature (and thus on $\varrho_n / \varrho = f(T)$. Landau asserted unequivocally with respect to this test, "...I have no doubt whatever that at temperatures of 1.0° to 1.1° K the second sound velocity will have a minimum and will increase with the further decrease in temperature." The figure above shows that Landau's prediction was clearly confirmed in the early 1950s by the measurements of DeKlerk, Hudson and Pellam.

A parameter even more directly dependent on spectral-related results is viscosity. Tisza predicted a decrease in viscosity with decreasing temperature according to a T to the one-half power law. Landau computed the viscosity on the basis of all possible types of roton and phonon collisions. This theory predicted that the most important terms at temperatures below about 1.4° K were due to the phonons and that the viscosity should *increase* with decreasing temperature. This is, in fact, the result obtained by Andronikashvili (Figure 18), shown together with the Landau theory. (Figure 19).

A final word on the role of Bose condensation in superfluidity: In his useful introductory comments on superfluidity in helium, G.V. Chester (1975) points out that the relationship between the Landau criterion for superfluidity (no low-lying modes of excitation) and the presence of a Bose condensate — that is, a fraction of particles with zero momentum — is not certain. Chester remarks, however, that:

> It is generally believed that the absence of low-lying single particle modes in He 4 is due to the presence of a Bose condensate.... [This refers to the Bogoliubov result referenced by Landau above.]
>
> One is thus tempted to say that Bose condensation in an *interacting* system is sufficient to ensure stable superflow. Is the converse true: is Bose condensation necessary for superfluidity?

This problem is complicated further by the fact that while theoretical calculations converge on a value of 10 percent for the condensate fraction at zero temperature and pressure, the value deduced from neutron scattering experiments is only 3 percent. This result, however, does corroborate Landau's view of the collective nature of the superfluid and the secondary role of the condensate.

Landau answered the last of London's points concerning the lack of superfluidity in helium 3 by stressing the totally different nature of excitations and spectrum in a Fermi liquid and the pioneering developments in this field in the late 1950s. Interestingly, Landau also indicated that this by no means rules out the possibility of helium 3 superfluidity by other mechanisms.

The Energy Spectrum, Quantum Theory, and Relativity

We have now established that London's (and like) criticisms of Landau's approach are inconsistent as well as incorrect. Before reviewing the experimental results that indicate the critical limitation of Landau's formulation, let us give appropriate credit to London by considering some final elements of his treatise. These crucial results from his early work on the kinetics of the radiation field and the quantization of the hydrodynamical continuum will allow us to locate more precisely the fundamental nature of the problem to be overcome in grasping superfluidity.

In outline form, the London results are the following: If the expressions for the momentum transfer of the propagating collective excitations in a macroscopic fluid medium are transformed by the usual procedures from classical to quantum form, then the simplest linear terms associated with irrotational motion give the characteristic phonon relationships

$$e_k = \hbar \omega_k,\ J_k = \hbar k,$$

$$e_k = \frac{\omega_k}{k} J_k = uk,$$

where e is energy, ω is frequency, k is reciprocal of wavelength, $\hbar$ is Planck's constant, and u is excitation velocity of propagation in the medium, ($\omega = 2\pi\nu$).

The application of Bose statistics to an ideal "gas" of these excitations (making the assumption of uniform distribution of excited states over unit volumes of phase space) whose center of mass is moving with velocity v, gives the following result for the total momentum density:

$$J = \frac{4}{3}\frac{E}{u^2}\left(\frac{1}{1 + \frac{1}{2}(\nu/u)^2}\right) v$$

For $\nu/u < 1$, and noting that by definition $J = \varrho v$, the mass density of the collectively moving phonon gas is then given by

$$\varrho \cong \frac{4}{3}\frac{E}{u^2}$$

Now, the amount of energy actually transferred by the moving fluid from the standpoint of thermodynamics is given by the enthalpy, $H = E+PV$, or since $P = E/3V$ for an ideal gas, $H=(4/3)E=\mathcal{E}$. Then

$$\varrho \cong \mathcal{E}/u^2,$$

which is the phonon analogue of the pure electromagnetic result of special relativity theory, †

$$E = mc^2.$$

Similarly, it can be shown using a transformation among thermodynamic basis variables from J,S,U to V,T, and volume used by Planck in his work on the black body radiation problem (1907) that an analogue of the Lorentz transform for the electron

$$P = \frac{m_0}{\sqrt{1 - v^2/c^2}}\, v$$

is obtained for the phonon field as given by

$$J = M_0 v/\sqrt{1 - (v/u)^2}$$

where $M_0 = (s/u)^2 (3P/a)^{1/4}$ and

$$a \text{ (from } E = aT^4) = \frac{4\pi^5 k^4}{15h^3u^3}$$

and

$$\mathcal{E} = M_0u^2\sqrt{1 + \left(\frac{J}{M_0u}\right)^2}$$

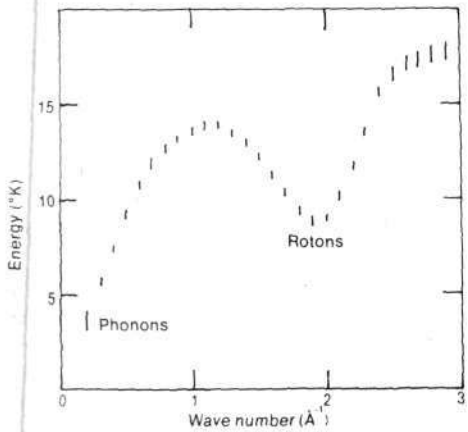
The lowest order effects in a superfluid are thus directly analogous to the basic relations obtained in a moving, source-free electromagnetic field. ‡ In both cases, excitations move with constant velocity within the field relative to the overall motion of their center of mass with respect to the background continuum "vacuum" or superfluid according to a Lorentz-type velocity addition law.

The critical, additional aspect of the problem for the superfluid is that the continuum to be quantized is *already* discrete; therefore, one cannot consistently start at the macrolevel, then quantize, spectral analyze, and compute macroproperties by summing over the spectrum, and finally return to the same continuum (in other words, accurately predict its macroscopic properties). The riddle of the spectrum of superfluidity, therefore, is of the same quality as that of introducing sources into quantum field theory, with superfluidity's special feature being the high degree of screening of the sources.

Superfluidity thus can be thought of as an intermediate situation between the sourceless field and the quantized field that contains unscreened sources. The low temperature spectral anomalies in He II (see next section) accordingly are a very sensitive reflection of how the nonlinear metric of the physical continuum is altered by sources in a self-reflexive way, giving rise to new composite structures and interactions. Although this is closely linked conceptually to the problem of the self-interaction of a source with its own field, it must be connected as well to the specific problem of the absolute ground state and how the superfluid moves as a whole, coherently, without dissipative interaction. This is comparable to the age-old problem of the structure of the elementary electromagnetic continuum, the "ether"!

Figure 20 Pg 49 (1.6)

EXPERIMENTAL DISPERSION CURVE FOR ELEMENTARY EXCITATIONS IN SUPERFLUID HELIUM AS MEASURED BY NEUTRON SCATTERING



The experimental results for the variation of energy with frequency of the quasi-particle excitations in the superfluid [here measured in convenient energy units of degrees Kelvin and frequency units of inverse angstroms] indicate a Landau-type spectrum.

Even at our present state of knowledge, however, it is clear that the mathematical connection (via the nonclassical statistics) between the relativistic and quantum aspects of the simplest physical systems just discussed is but a lower order reflection of the true, "unified field" — that is, unitary — nature of reality. Superfluidity, in particular, directly demonstrates the fundamental nonlinearity of physical geometry. This feature holds not only when the troublesome sources are present, but also when there is the purest of fields (even if this is normally "marginal"), as attested by the statistical-dynamical results just cited and, more spectacularly, by pair production of electrons and positrons from the ubiquitous photons.

It is not mere speculation to assert that the geometry of

*More recently Aldrich and Pines (1976) have shown theoretically that the He II spectrum is well fit by calculations based on a model that stresses short-range *strong* interactions, rather than statistics. "...These modes represent the analog, for a neutral system, of the plasma oscillations characteristic of charged particle systems," Aldrich and Pines reported.

Biswas, on the other hand, has claimed recently (1976) that the attractive force component is responsible for those features of the spectrum that yield a critical velocity greater than zero: "We conclude that the critical temperature for a free Bose gas is zero and a Bose system with purely repulsive interaction cannot exhibit superfluidity."

† The black body energy-mass density result was derived by K. von Mosengeil in 1907 (cited by London).

‡ In superconductors, where particle velocities are much higher than in helium, it has also been thought that it may be possible directly to observe relativistic effects on superconductivity. See Putterman 1974, p. 397.

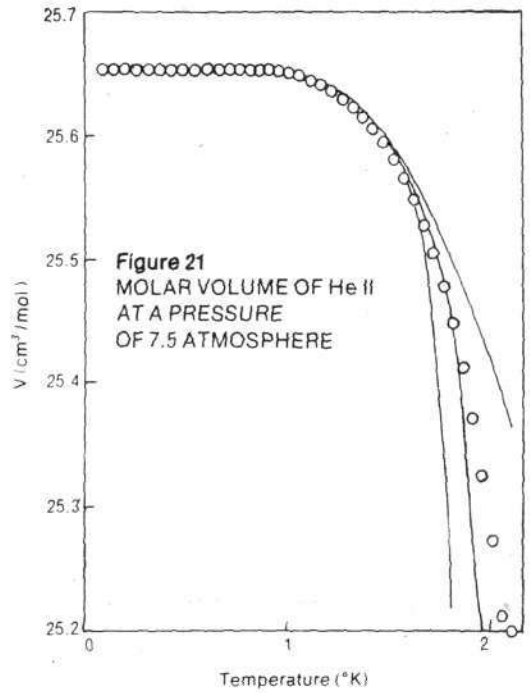


Figure 21
MOLAR VOLUME OF He II AT A PRESSURE OF 7.5 ATMOSPHERE

The circles represent empirical results, while the solid lines represent theoretical results based on various forms of the excitation spectrum. In no case can this type of theory be brought into correspondence with experiments at temperatures above about 1.8° K.

... the geometry of the quasi particles in dynamic relationship to the continuum as-a-whole is the "source" of these effects. This is, of course, entirely in the spirit of Landau's many comments that the difficulties of quantum field theory are located in the assumption of singular point sources. This view is confirmed also by the asymmetries in empirical results as we go to the other end of the energy density spectrum in fusion plasmas and high energy particle collisions.*

Finally, these phenomena and Landau's notion of critical velocity, considered in conjuction with the analysis presented here, indicate that the "absolute" limit to the speed of light is actually a limiting condition of one special form of field-particle interaction. Advances in space-time theory (that is, higher-order relativistic conceptions) should also, therefore, reveal the conditional nature of the universal constant, c, and the metrics for which it loses its physical significance. Just as in the variety of "hot" and "cold" phenomena in fusion-tending plasmas, superfluids and superconductors reveal the conditions under which Planck's constant, h, loses its significance as a coupling constant under conditions in which the primary relationships of the continuum dominate the secondary, determined two-body interactions of the singularities in the field.

E: The Limits of the Landau Theory

We turn now to the experimental evidence, especially that accumulated in the 1970s, of the shortcomings of the Landau approach. The most important research consists of the direct measurements of the details of the He II excitation spectrum over most of the He II temperature range (and at various pressures) by neutron scattering, and the meticulous comparison of macroparameters calculated from the neutron results with detailed thermohydrodynamic data over a wide range of He II pressures and temperatures.

The most recent and comprehensive review articles in this field have stressed that there are two fundamental problems associated with the quasi-particle theory: first, that there is no way at present to account theoretically for the excitation spectrum; and second, that the measured phonon-roton spectrum is not consistent with the observed macroscopic properties of He II. The second problem surely confirms that the first is not due simply to mathematical misbehavior, but is of the same fundamental quality as the inability of quantum field theory adequately to handle interactions of particles with their own fields. This, in turn, accounts for the so-called discrepancy in the second case.

The situation as recently summarized by Roberts and Donnelly (1977) is as follows:

> ...the overall success of the quasi-particle model as applied to thermodynamics leaves much to be desired. The first systematic neutron studies of He II at the vapor pressure by the Los Alamos group brought forth the reassuring conclusion that the Landau theory was applicable up to temperatures of the order of 1.8° K providing one used the actual dispersion curve for the calculation rather than the Landau approximation of roton and phonon branches. Subsequent thermodynamic studies, such as are surveyed in Wilks's monograph, however, contained disturbing discrepancies, such as differences between neutron and thermodynamic quantities (roton effective mass, for example) which could be as great as a factor of two.
>
> Since that time, neutron scattering measurements have had two principal thrusts. The Chalk River group has extended measurements to higher energy and momentum, revealing a richness in the dispersion spectrum heretofore unsuspected; and the Brookhaven group has produced systematic studies of the roton spectrum over the entire temperature pressure plane. The latter report, however...showed that there exist very serious discrepancies between thermodynamic measurements of the entropy at finite temperatures and pressures and the values deduced from neutron studies. The discrepancies are serious enough to render the excitation theory all but useless except for order-of-magnitude estimates. It

appears that difficulties arise whenever the linewidth of the scattered neutron group becomes finite, and one is led to suspect that there might be a serious problem with the statistical formulation of the thermodynamics whenever the observed energy levels are broadened. Further complications involve the existence of temperature-dependent energy levels. To appreciate the magnitude of the temperature dependence, note that the roton energy parameter Δ/k...changes from 8.54° K at 1.26° K to 4.61° K at 2.1° K.

The Experiments

The Los Alamos results were reported in 1959, and the Canadian work at Chalk River was reported in a series of papers by Cowley and Woods in the early 1970s. We briefly describe these experiments here, how they are used to deduce the spectrum, what the basic results look like, and where the problems arise.

If a beam of neutrons of momentum, $p_i = \hbar k_i$, is incident on a sample of He II maintained at some pressure and temperature (P,T), the intensity of the neutron beam with final wave number k_f scattered at some angle Θ with respect to the incident beam, due to inelastic collisions with phonons of frequency ω and wave number q is given in most general form by

$$I(\Theta) = (K_f)^4 S(q, \omega).$$

The term $S(q, \omega)$ is called the dynamic structure factor for the collision process and is determined by both the change in neutron momentum ($\hbar q$) and the relationship between ω and q in the liquid. In practice, the intensity (number per second) of neutrons of various momenta at a given angle is measured by a neutron spectrometer; then assumptions must be made about the form of $S(q, \omega)$ to "unfold" the spectral relationship, $\omega(q)$.

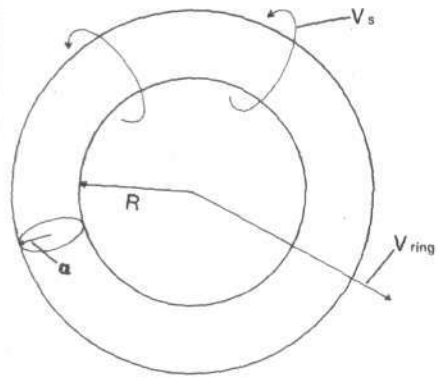
The basic results for the spectrum from the research of Cowley and Woods are shown in Figure 20. The curve is of the general sort intuited by Landau, with the traditionally defined dividing line between phonons and rotons at a wave number of 1 angstrom($q = 10^{-8}$ cm^{-1}). When this is translated into the relationship between the velocity and wave number of basic excitations, it is found that at small momentum the velocity is equal to the sound velocity c (2.4×10^4 cm/sec), but for higher momentum it first *increases* before falling off. This is called *anomalous dispersion*, since it is opposite to results in most crystalline solids. However, it is the same sort of relationship as for photons in an optical medium. (Recall the discussion at the end of section D.)

So far, so good. An essential form of nonlinearity enters, however, at higher pressures and temperatures of the He II domain. Only if the quasi-particle energies are well defined (that is, if there is a one-to-one correspondence between energy and momentum), can the function $\omega(q)$ be derived unambiguously from neutron scattering data. For the case of rotons, the quasi particles no longer can be considered independent entities: they interact with each

*See Lerner's article on quarks (1977).

Figure 22

IDEALIZED MODEL OF A QUANTIZED VORTEX RING

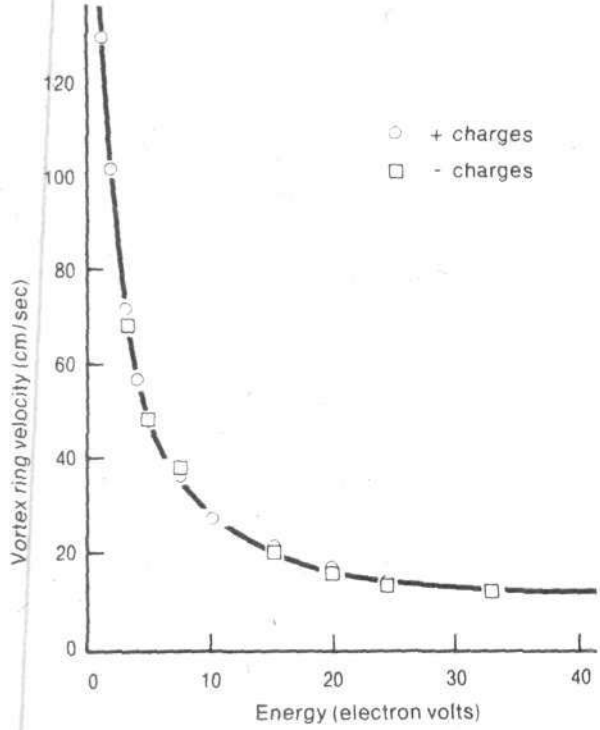


The amount of fluid circulation carried by the ring is limited to discrete multiples of a characteristic circulation valve. Motion of the ring as a whole is determined by the direction of fluid flow within the ring, as shown.

For a real ring, the physics of the situation at the core [center], where a charged particle may be attached, and within the filamentary structure of the ring itself is not well understood.

Figure 23

RELATION BETWEEN THE VELOCITY, V, AND ENERGY, E, IN A VORTEX RING



These experimental results of Rayfield and Reif beautifully confirm that vortex rings in He II are quantized but otherwise obey the classical hydrodynamic relationship between energy and velocity.

other, thereby spreading the range of q's associated with a given ω. The interaction can be physically depicted most simply as a roton's flow pattern that polarizes the rotons around it, that, in turn, react back on the original roton's flow and lower its energy. This is called the Onsager reaction flow.

In turn, this effect shifts the relationship between $I(\Theta)$ and $\omega(q)$ in a complex way. The net result is that at temperatures above about 1.8° K and for pressures of several atmospheres and higher, the neutron data cannot be applied in a self-consistent way to make calculated thermodynamic parameters, such as entropy or volume per mole, fit the measured values of those parameters in the high (P,T) region. (See a typical result above in Figure 21.)

Just as the quasi-particle conception has been shown to be more appropriate in He II than the idea of individual atoms, the neutron line-broadening data strongly indicate that aggregates of quasi particles — a new microflow field topology — are involved in mediating the overall thermo-hydrodynamic properties.

F: Structure in Helium II

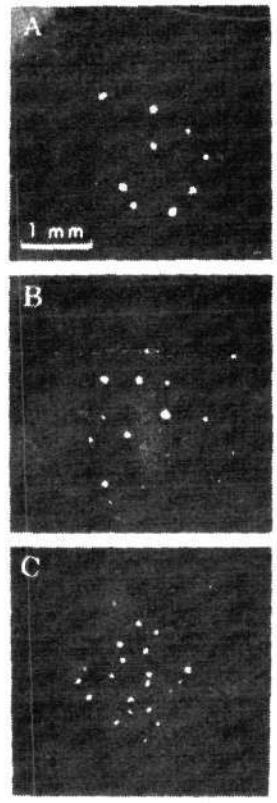
The theoretical and experimental results cited in the previous two sections provide the basis for an alternative viewpoint of the significance of ordered structures in the superfluid, particularly those whose dimensions fall in the borderline region between the microscopic and macroscopic domains (although in He II both may now be quantum regimes). As the discussions of fluid turbulence, rapid rotation of He II, and small-scale vortex ring excitation indicated, the symmetric structuring of the fluid in at least some critical situations represents the solution nature provides — in the form of appropriate internal boundary conditions — to the problem of "bridging" between regions that obey different laws and metrics. The viewpoint stressed here is that *ordered, symmetric structures in these situations reflect the fundamental nonlinearity of the media.*

Some of the experimental observations of various types of structure in He II are summarized below.

Vortex Rings

The experiments of Rayfield and Reif in 1964 provided conclusive demonstration of the existence of vortex rings and measurements of their basic parameters.* The basic experimental technique involved attaching an alpha particle (a positively charged helium nucleus) to an excited vortex ring in order to detect and monitor its motion. By working at relatively low temperature (0.28° K) and initially accelerating the charged, quantized vortex ring in an electric field $\mathcal{E}$, such that the condition $e\mathcal{E}l \gg kT$ (l is the mean free path and e is the unit of charge) is satisfied, the ring will have enough energy to be approximately free of collisional losses by interaction with excitations in the liquid and will have a more or less constant velocity v associated with the vortex energy E (=eV). The energy is measured by adjusting a retarding potential (-V)

Figure 24 52 (2.6)
PHOTOGRAPHS OF DISCRETE QUANTIZED VORTEX LINES *IN He II* ROTATING AT
(A) $\omega = 0.25\ \text{sec}^{-1}$
(B) $\omega = 0.5\ \text{sec}^{-1}$
(C) $\omega = 1.0\ \text{sec}^{-1}$



Source:
Williams and Packard, "Photographs of Quantized Vortex Lines in Rotating He II," *Physical Review Letters, Vol. 33, p. 280 (1974).*

The results indicate fundamental nonlinearity of interaction among the arrays: average density differs from the quantum hydrodynamical theory, and there is no predictable [empirical or theoretical] time dependence of the array geometry.

in the collection region, and the velocity is measured independently by a time-of-flight technique.

The geometry and motions of a vortex ring are shown in Figure 22 along with the basic experimental results (Figure 23). The plot of velocity versus energy indicates that v is much smaller (by a factor of 10^5) than that of an alpha particle in vacuum and that the velocity varies *inversely* with the energy. This can be understood from the basic hydrodynamics of a vortex ring, where the simplest classical results take the form

$$E = \tfrac{1}{2}\varrho\kappa^2 R(\eta - {}^7/_4),$$

$$v = \left(\frac{\kappa}{4\pi R}\right)\left(\eta - \tfrac{1}{4}\right),$$

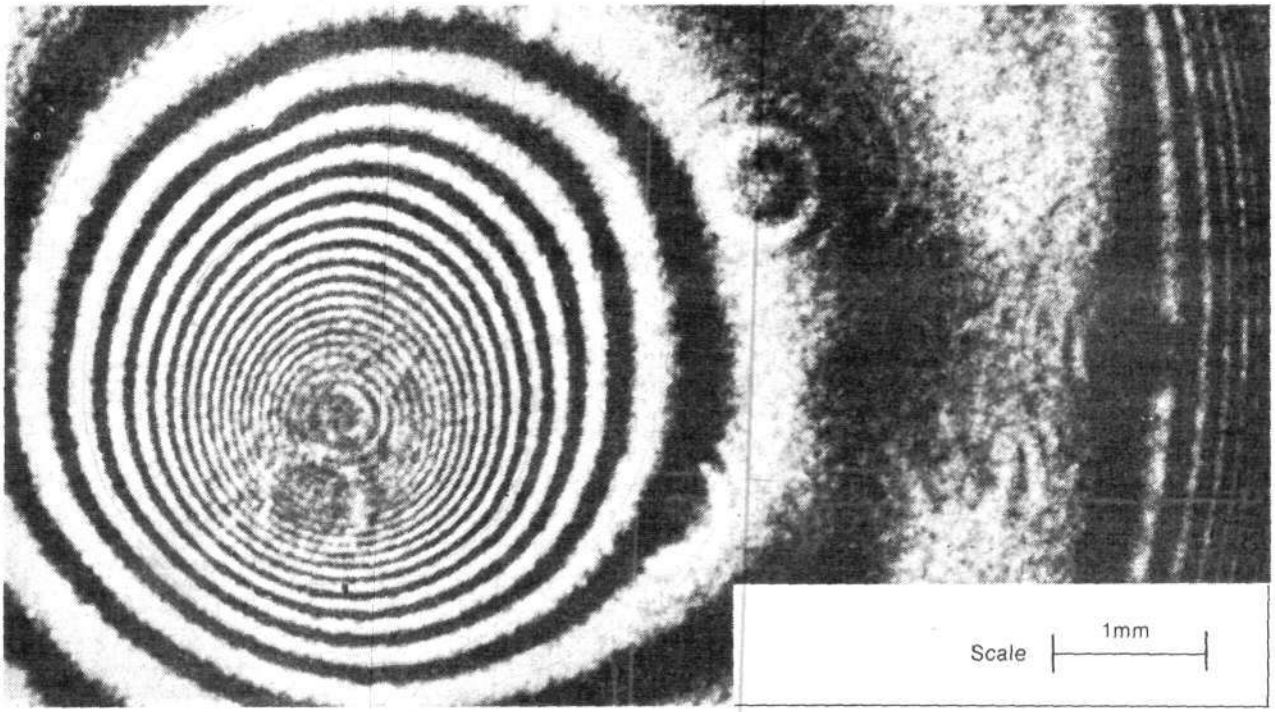
$$\eta = \ln\left(8R/a\right),$$

where κ is the quantum of circulation, ϱ is density, R is vortex radius, and a is core radius. In first approximation these results reduce to

$$E \propto \kappa^2 R,\ v \propto \kappa/R$$

Figure 25 pg 53 (1.9)

OBSERVED INTERFERENCE PATTERN
FOR A "GIANT" QUANTIZED VORTEX RING IN ROTATING SUPERFLUID HELIUM



A large vortex in rotating He II can be produced by carefully changing the rate of rotation. The special optical pattern [above] is produced by the interference between light reflected from the bottom of the container and refracted at the liquid surface. It has the special whirlpool shape for the distribution of fluid at its upper surface shown in Figure 26.

Source: Marston and Fairbank, "Evidence of a Large Superfluid Vortex in Helium 4," *Physical Review Letters, Vol. 39, p. 1208 (1977).*

so that

$$v \alpha \kappa^3 E^{-1}.$$

Since a vortex ring has "momentum" or "impulse,"

$$p = \pi \rho \kappa R^2$$

it also follows that in first order approximation

$$E \alpha p^{1/2}, \quad v = p^{-1/2},$$

unlike an ordinary particle for which $E \alpha p^2$.

Plotting of the data according to a theoretical relationship of the form

$$(vE)^{1/2} = f(v, E, k, a)$$

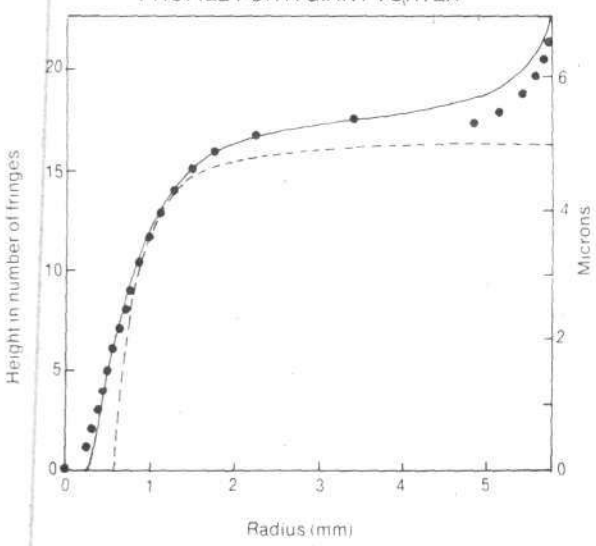
yields κ and a to have the values

$$\kappa \cong 1 \times 10^{-3} cm^2 sec^{-1}, \quad a \cong 1.28 A°,$$

indicating that only the minimum circulation case is excited.

Figure 26 53 (1-7/8)

CALCULATED SURFACE GEOMETRY
PROFILE FOR A GIANT VORTEX



* We omit discussion of earlier, less conclusive experiments by Vinen employing a vibrating wire technique of vortex excitation and measurement (reviewed by Rayfield and Reif, 1964).

The results are not sensitive enough to distinguish whether the ring has a hollow core or a constant velocity core, and it is not clear exactly how the presence of a trapped charge alters the effective core dimension, where the charge is most likely to be located surrounded by a tiny sphere of solid helium.

The speculated connection of the vortex ring to the roton excitation is made more plausible by the fact that the initial ionic velocity determined by ε is of the order expected for the critical velocity for creation of a roton, about 50 meters/sec. The dispersion relation is apparently different, however. In any case, the experimentally confirmed dispersion relation for the vortex ring strikingly illustrates the physical-geometric significance of the anomalies in the spectrum of the elementary excitations.

Most important, if the derived value of a can indeed be interpreted as the minor radius of the vortex ring, we once again have direct evidence of the superfluid continuum having a metric superior to the "stick and ball" scale lengths of interatomic distances. How else could a characteristic structural dimension be less than atomic spacings?

In other theoretical terms the superfluid quantized vortex ring is another "Waterloo" of the superfluidity theorists. As might be expected from our previous discussion, there is at present no way to bring together satisfactorily the elements of a complete description of vortex formation and properties, such as core dimensions of individual vortices and dynamics of vortex arrays. However, there does appear to be an interesting interrelationship of vortex structure and critical flow velocity that may be important for a better understanding of the present anomalies of vortex structure and flow through small channels.

On the one hand, the simplest expression for quantization of circulation gives the fluid velocity as a function of radius as $w = \kappa / 2\pi r$. At a radius of about 2.65 A°, w reaches the Landau critical velocity, so this forms a natural lower bound to the values of the circulation radius. Experiments involving flow through very fine slits show that the situation is not so simple. The critical velocity is found to be dependent on the slit dimension, d. For not too small slits (d = 1 cm), the critical velocity varies as d^{-1}, indicating probable connection with the formation of quantized vortices. For smaller dimensions the critical velocity dependence is different; some experiments and statistical theory fit $d^{-1/2}$ dependence.

The obvious importance of microscopic effects under appropriate boundary conditions means that the critical velocity-healing and quantum circulation phenomena are linked together (at smaller radii, there is a different critical velocity, shifting the critical radius, which shifts the critical velocity...) *self-reflexively*. This reemphasizes the earlier point on the mediating role and nonlinear determination of fluid structures.

Other Structures, Other Experiments

The other basic type of structured motion consists of vortex lines (or filaments) and arrays. The general situation here is as described in the following statement by Fetter in 1976:

> At present, some indirect experimental evidence indicates that the vortex array in bulk [rapidly] rotating helium has the short-range order of a close-packed lattice...but no convincing demonstration of long-range triangular order has yet been given. One promising approach to this problem is direct photography...,either of the induced dimples on a rotating free surface...or after decorating the vortex axes with neutral...or charged...impurities. This elusive and difficult experiment remains one of the most interesting challenges in low-temperature physics...
>
> When the angular velocity increases still further, the vortex configuration again becomes relatively simple, for it approaches a uniform array with density $2\Omega/\kappa$ ....The first experiment on this regime was performed by Osborne...who actually tried to detect vortex-free states. Since Landau's original theory...predicted that the superfluid was everywhere irrotational, Osborne expected that v_s would vanish in a simply connected rotating cylinder, giving a reduced meniscus proportional to ρ_n / ρ In fact, he observed a purely classical free surface, which is now interpreted as arising from the combined effect of many vortices, each contributing to the angular momentum....The existence of this dense array is now well established through its attenuation of second sound and ion currents....

These vortex arrays have, in fact, been recorded photographically by Williams and Packard (1974). Their results (see Figure 24) confirm that the preferred energy state for the usual case of rapid rotation is a densely packed array of small angular momentum vortices.

Williams and Packard performed their experiment by injecting and trapping electrons onto vortex lines produced by rotating He II at frequencies of about 1 sec^{-1}. The electrons were then extracted from the lines at the liquid surface by an applied voltage and impinged on a phosphor screen illuminated for photographing.

The initial results not only provided direct evidence of the Onsager-Feynman predictions of vortex filament arrays, but also showed significant deviations from several of the predictions of properties of the equilibrium state. In particular, fewer lines per unit area appeared than theoretically predicted and no stable vortex lattice or pattern of vortex motions was obtained, indicating a highly nonlinear situation.

According to Williams and Packard:

> We point out that according to current ideas the vortex core is a node in the macroscopic wave function. This is one of the only measurements we know which directly measures the positions of the nodes of a wave function....It appears that under our experimental conditions no stable vortex array is

observed; rather the rotating He II exists in a dynamic state involving complex motion of vortex lines.

Further, no evidence was presented of the condensation of the line vortex arrays into a smaller number of larger vortices (as reviewed by Bardwell 1976 for normal fluids and plasmas), possibly indicating the special quantum features of the superfluid at the given boundary conditions of fluid size and rotation.

A more recent experiment also has provided direct evidence of the microscopic angular momentum associated with quantum vortices. Lynch and Pellam observed, to their surprise, that macroscopically measurable amounts of angular momentum are transferred to a disc of porous material when vortices are destroyed as liquid helium flows through the disc. This might also indicate "symmetry-breaking" (left or right handedness) in the superfluid angular momentum.

The very recently reported experiments of Marston and Fairbank have demonstrated, however, that large vortices can be generated as well. This is an extremely important result on two counts. First, it confirms Landau's conjecture on macroscopic superfluid rotation states, although the internal structure and dynamics are undoubtedly quite different; and second, it illustrates that a realized physical state can be more than — and not reducible to — a statistical array of dynamic entities of the simplest generic type to which it is apparently related (in this case, a large, metastable vortex of $N \cong 400$ compared to an array of several hundred interacting $N=1$ vortices), or simply a bigger version of the "primal" type.

The Marston-Fairbank vortex was produced by finding the conditions of increasing, decreasing, and stabilizing He II angular momentum (rotation) under which large-scale semistable vortex production is possible. (Note the possible correspondence to production of large-scale vortices in turbulent fluids.) The technique of observation depends on the fact that both the mean diameter and the change in fluid height at the surface are much larger for a high angular momentum vortex than for the $N=1$ vortex filament. The latter has only about a 50 A° (half a millionth of a cm) depression of surface liquid, which is too small to be detected by light that has wavelengths of the order of several thousand angstroms. For the large vortex, liquid depths relative to the surface of several microns — thousands of times larger — are produced and can be illuminated via the interference of light reflected from the flat surface of the cylinder containing He II and the curved surface of the vortex. The experimental optical interference pattern and the derived shape of the vortex surface profile are shown in Figures 25 and 26.

This crucial illustration of the relationship between boundary conditions (whether self-determined or in conjunction with external factors) and the form of energization in determining dynamic structure and its evolution is perhaps the simplest analogue at hand for phenomena as diverse as nuclear and climatological "phase" transitions.*

These results also provide insight into another general problem. Vortices are normally thought of as purely *dissipative* mechanisms. Indeed, they have been shown in some experiments to be an important factor in the slow "running down" of persistent superfluid flow. More generally, however, their properties of energy quantization and of nonlinear interaction indicate their potentiality for *building up* and not just degrading structure — a point stressed from an experimental standpoint in the plasma focus research of Bostick and in the reviews of plasma and fluid dynamics by Bardwell. In all interesting media like superfluids or plasmas the "laws" are not fixed, but self-determined by the geometry of energy concentration, flow, and interaction.

*See Lerner's article on the vortex model of climate.

Part III

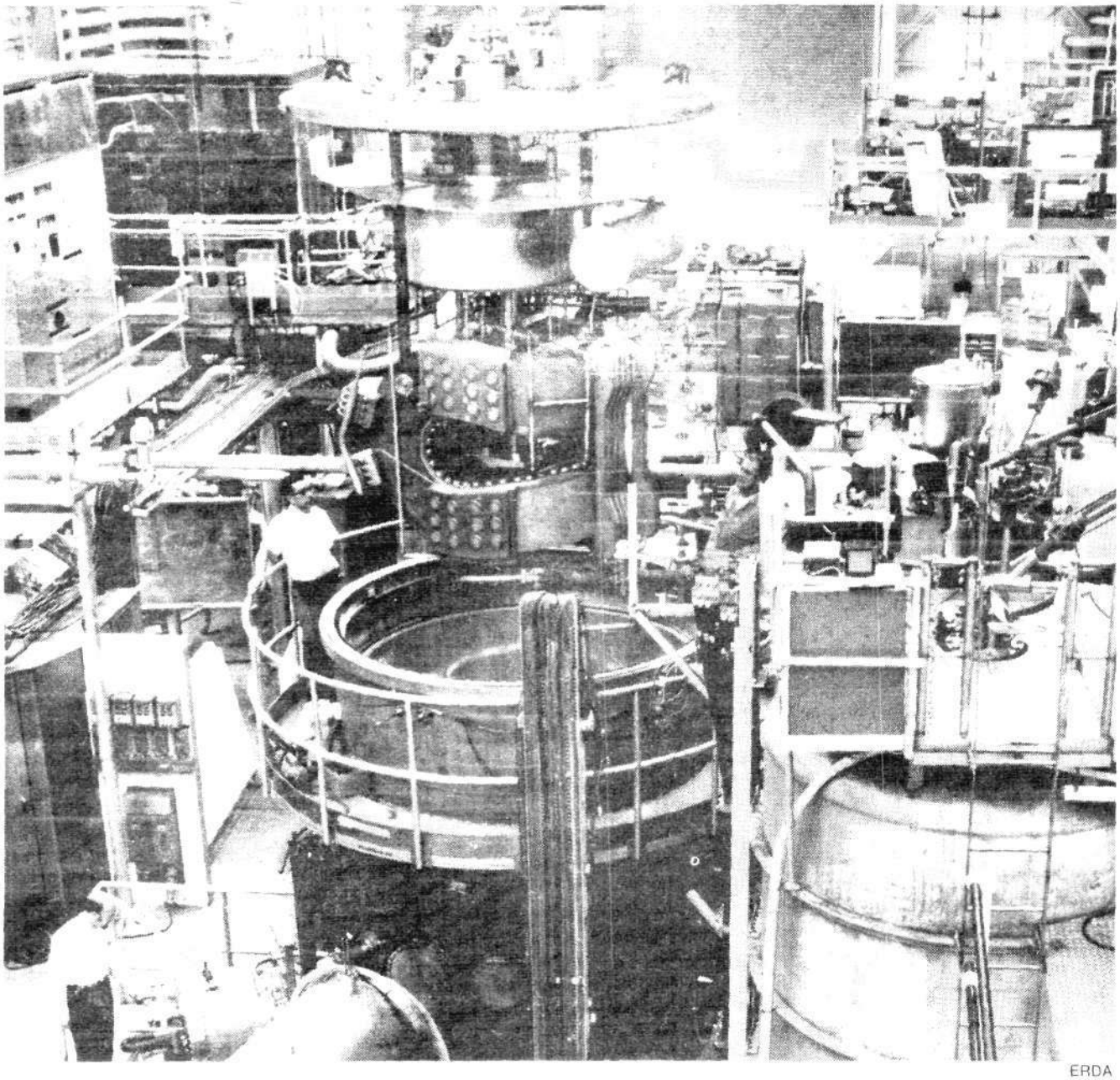
Technological Frontiers

As might be expected, there are extremely important technological applications that depend directly on scientific breakthroughs in the area of superfluidity. The appropriate complement to the increased rates of energy production and efficiency associated with the onset of controlled fusion, especially the advanced fuel cycle reactions (that will eliminate thermal-mechanical energy conversion processes) would be high-temperature superconductivity. There is some evidence now for superconducting effects in body temperature physiological processes (Cope 1971), and some researchers have argued that it can be produced in nonbiological organic-metallic complexes (Little 1965, Davis 1976).* So far, however, all that is available are two- or three-element alloys and compounds that require expensive cooling systems and have not yet exceeded a high temperature of 23° K. (For a general review of the problem, see Ksander and Singer 1974.)

Imagine human productive powers if we had an energy throughput grid powered by advanced, compact fusion reactors and employing simple (noncryogenic) lossless

* The present, basic theory of low-temperature superconductivity is due to Bardeen, Cooper, and Schrieffer and is called the BCS theory. It essentially describes the superconducting electronic state as a linear *sum of pairs* of electrons, each pair having the same linear momentum. The binding of the pairs is assumed to be due to low-frequency interactions with the phonons of the metal or alloy crystalline lattice.

The simplest mechanism proposed for high temperature superconductivity is due to Little. It is still based on electron pairing, as in the BCS state, but the binding interaction is due to a higher frequency (and thus, higher energy and temperature) coupling to a third electron. This requires a model involving a two-dimensional filament to provide the paired conduction electrons and accurately placed organic side structures on the filament to provide a polarizable electron state for the high frequency coupling interaction.



ERDA

This overview of the Baseball II magnetic bottle fusion machine shows the 13-ton supercooled, superconducting magnet [center of photo] shaped like the seams of a baseball. A schematic of Baseball II is on p. 26.

transmission of electricity and other forms of electromagnetic energy to integrated production and scientific centers! At that point, exponential increases in the negentropy of expanded social reproduction become directly, self-consciously determined by the willful scientific control of fundamental nonlinear processes.

The problem facing physicists like William Little of Stanford University and others who have been working for more than a decade to develop high temperature superconductors is not unlike the problem brought to the fore by papers just released by the Los Alamos Laboratory summarizing recent laser fusion calculations. As long as the researcher assumes only the modes of interaction described by contemporary theoretical physics, there are hypothetical solutions both to the problems of laser fusion and of room-temperature superconductivity. But in both cases, the work is then restricted to incredibly small regions of phase space and the investigator must construct physical systems of a sort not engineered before yet with much higher degrees of precision in fabrication than ever previously achieved. Even if one could technically surmount these obstacles, unforeseen (higher order) effects not accounted for by the theoretical computation would probably defeat the experimentalist's attempt to do

what is in effect equivalent to balancing a ball on the point of a cone.

KEY

The key is to approach the problem from the standpoint of the higher-order interactions in the system; then the study of the boundary conditions that correlate with super behavior may open up entire new territories in previously unconsidered phase spaces and new physical geometries for investigation.

Along these lines of inquiry, there is at hand the result that not only electrons in metallic crystals, but also self-bounding Fermi liquids are superconducting. That is the discovery at Cornell University, mentioned at the outset of this paper, that the manmade isotope He 3 becomes superfluid at several *thousandths* of a degree Kelvin. Even more striking are subsequent discoveries that the additional very weak magnetic forces associated with the He 3 nuclei (as opposed to their zero value for He 4) result in coupled anisotropic (asymmetric) magnetic field and fluid flow geometries (Wheatley 1976).

We also know that certain so-called type II superconductors can support extremely high magnetic fields (and somewhat higher than usual critical temperatures) without breaking down, by internally forming force-free electron conduction vortex filaments. Extensions of these results, approached from the unified standpoint exemplified by this discussion of He 4 superfluidity, may provide the clue to the line of inquiry required for achievement of high temperature superconductivity.

In any case, it is clear that the crucial investigations throughout this century of "hot" and "cold" nuclei in nuclear and low temperature physics not only intersect now in their potential technological applications but have always been different nonlinear aspects of the same unified physical field.

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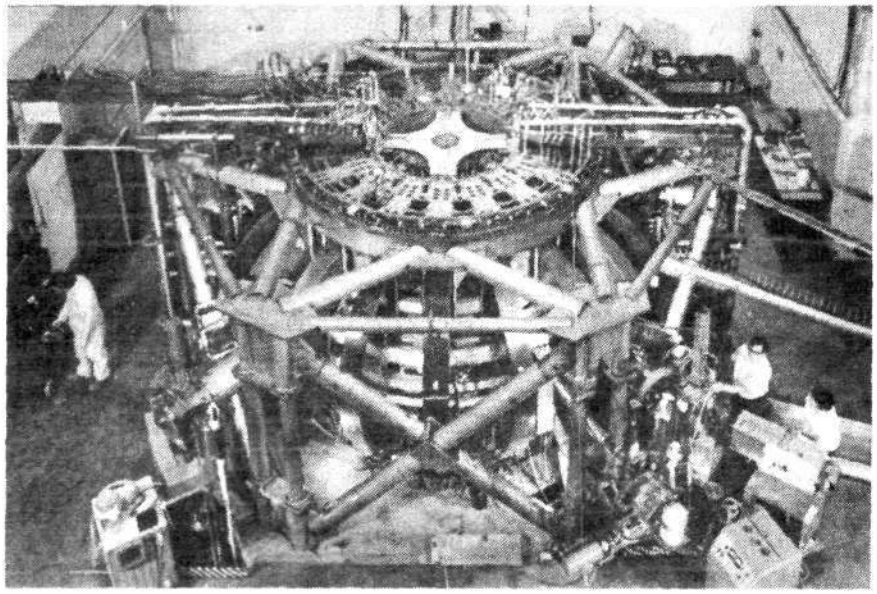
Research

Princeton Large Torus Near to Breakeven



The Princeton Large Torus

The Princeton Large Torus fusion device for the first time reached plasma confinement results within the 2,000 electron volt range, the highest temperature ever achieved in experimental work using a neutral beam heating device.

The Princeton results were announced at the FEF conference on Middle East Peace and Economic Development Jan. 24 by Dr. Stephen O.Dean, Assistant Director for Confinement Systems of the U.S. Energy Department's Division of Magnetic Fusion Energy. Dean said that the 2 keV temperature range verges on that necessary to complete the experimental fusion research immediately preparatory to the construction of working fusion reactors. As a result, Dean said he was confident that "fusion is ready to be treated and considered as a practical option for future energy use."

The neutral beam device, built by the Oak Ridge National Laboratory for use at Princeton, is used first to accelerate hydrogen isotopes, then to neutralize them (bring the number of electrons and protons in each atom into correspondence), and finally to direct a concentrated beam of neutral atoms into the center of the plasma that is magnetically confined in the donut-shaped fusion reactor.

Breakeven Relatively Easy

According to Dr. Harold Furth, director of the Princeton neutral beam project, energy breakeven (producing more energy from the fusion reaction than that necessary to heat and confine the plasma), will be relatively easy to achieve in the neutral beam compared with other heating devices. The neutral beam allows a high temperature to be achieved with a lower magnetic field strength than that used in the magnetic heating of magnetically confined plasmas.

In the small region in the center of the plasma where the neutral beam is injected about 30 percent of the confined ions are immediately brought to 20 keV and then diffuse to heat through the rest of the plasma. It is now thought that an overall temperature of between 5 and 6 keV will be sufficient for breakeven. During the spring, further PLT experiments will include raising the neutral beam energy approximately by a factor of three, which is expected to increase overall plasma temperature to about 3 to 4 keV.

The new experiments will be carried out on the fusion reactor designed to achieve breakeven that is now under construction at Princeton. This device, the Tokamak Fusion Test Facility, is expected to use neutral beam heating to the 5 to 10 keV range in order to reach energy breakeven.

The TFTF is expected to be completed by late 1981, if the projected construction schedule is maintained. However, cutbacks in funding for fusion research announced in the national budget for 1979 may postpone the timetable. Although specific funding for the project has not yet been revealed, Project Director Furth thinks funding will be "skimpy but not catastrophic."

—Dr. John Schoonover

Soviet Breeder Advances

Soviet scientists report promising developments with a 300 megawatt fast breeder reactor under construction in Minsk. The reactor has a one-loop turbine made possible by the use of an original heat transfer agent, nitrine, a gas based on nitrogen tetroxide. The nitrine creates a more intensive heat transfer from the reactor core, which speeds up the reaction and conversion process. Nitrine does not become radioactive and can be used directly to turn the electric turbine, greatly simplifying the breeder's design. The nitrine reactor will reproduce its initial amount of fuel in 5 to 9 years, nearly twice as fast as Western breeders that use liquid sodium metal.

U.S. Laser Work Overlooks Basis of USSR Success

A recent paper on laser fusion by a leading researcher at the U.S. Los Alamos Scientific laboratory, one of the two primary centers of U.S. laser fusion research, has reported that the U.S. laser fusion effort has overlooked the important areas of nonlinear interaction that have been the basis of striking breakthroughs in the Soviet laser fusion effort.

The paper, "An Overview of Design Space for Small Fusion Targets" delivered by Ronald C. Kirkpatrick at the November meeting of the American Physical Society in Atlanta, in effect indicates that there is substantial theoretical basis for the breakthroughs outlined by Soviet laser fusion expert Nikolai Basov before an audience of top U.S. fusion scientists and energy industry officials in Ft. Lauderdale, Fla. in November.

Basov had reported that Soviet researchers achieved near energy-producing conditions using far less laser output (hence more economically) than U.S. researchers had thought possible, by taking advantage of nonlinear, self-stabilizing properties of the fusion process.

Several officials of the U.S. Lawrence Livermore Laboratory had dismissed the Basov results with the statement, "We don't believe him."

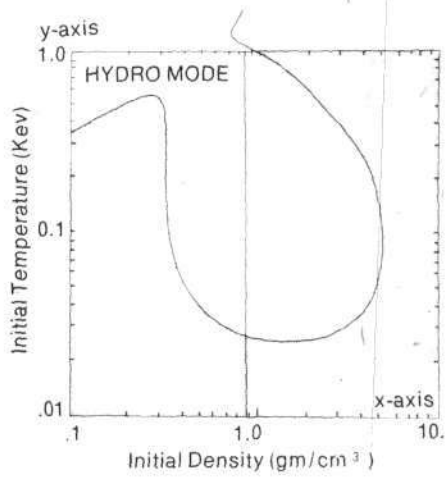
Computer Codes

The present American program has been guided by the extensive use of detailed computer programs (codes) that model the laser and plasma interaction. The results from these codes have indicated that the most favorable conditions for fusion will be achieved using small pellets of fusion fuel and very high power lasers to heat and compress the pellet. Experiments conducted with small pellets of the type modeled have so far confirmed the predictions of the codes.

However, any computer code suffers an important hereditary defect—it cannot reproduce qualitative changes in a system. In a nonlinear system, exactly such qualitative "phase changes" define the dynamics of the system, and computer codes by nature can at best only indicate the points at which such qualitative changes occur; they cannot trace the actual course of nonlinear development. This problem becomes severe in the realm of laser fusion, where the combination of intense energy sources (the lasers used in these experiments produce more energy in a billionth of a second than flows through all the world's power grid during that same instant), the strong interaction between the laser and the pellet, and the natural tendency of the plasma to concentrate energy even further, lead to a series of different regimes of behavior, each characterized by different physical interactions.

The current U.S. codes and their predictions apply only to the regime applicable to small targets. Within that regime, the U.S. program has produced a locally optimized solution to the problem of laser fusion, but the very reliance on these codes means that the U.S. program can never find a "global optimum," because these computer codes model only one regime. In at least one, still highly classified attempt to test these codes in differenct plasma regimes, called Project Albino, these codes failed to predict the appearance of what investigators described as a "series of phase changes" in the core of the fusion plasma.

In his paper, Kirkpatrick showed that the big U.S. codes had not



"WINDOW" TO FUSION?

This graph prepared by Ronald Kirkpatrick shows an area in which the nonlinear, self-stabilizing properties of laser-fuel pellet interactions in the fusion process may provide a "window" to fusion at much lower laser-energy input than existing U.S. computer models have shown as possible. The y-axis shows the temperature of the plasma , and the x-axis shows the initial density of the fusion pellets. Both scales are logarithmic. That is, increments are by a factor of 10. The line perpendicular to the x-axis at approximately 0.8 grams per cubic centimeter is the maximum initial density that can be achieved in fuel pellets.

The unshaded area in the upper left, marked 'hydro mode', is an area in which U.S. computer models have predicted ignition to occur. This area is characterized by the requirement of very high laser energy input to heat the plasma. Soviet researchers, however, report near-ignition conditions achieved with much lower plasma temperatures. The "window" plotted on Kirkpatrick's graph [unshaded area, center] shows an area where, by taking advantage of the nonlinear properties of the fusion reaction, such reactions may occur with far lower laser input.

detected a "window" in the possible configurations of target and laser that made ignition much easier. He concluded: "There appears to be an isolated region (see accompanying graph) for which ignition may be achieved with the least driving energy. Because this region can be small and isolated, detailed design studies using large burner codes (that is, the U.S. computer codes) may not detect it without specifically searching for it. Also it appears that the process of maximizing neutron output at low initial densities (finding the local maximum neutron output for present codes) leads toward the hydro mode of ignition rather than the more desirable mode represented by this island (the "window").

Large Targets, Small Lasers

Kirkpatrick's results lead to another striking conclusion: the window for ignition seems to be much closer to where the Soviets have been experimenting, using large targets and smaller lasers. As Kirkpatrick notes, as the pellet size decreases, the conditions necessary for achieving the most favorable conditions become physically inaccessible. The illustration shows the window which Kirkpatrick found and which may be the basis for the Soviet success.

Much work remains to be done to discover the physics of this "window," to develop an understanding of the nonlinearities that create the favorable plasma conditions, but such work is almost impossible in the context of the linear extrapolation of present computer based work. Global studies such as Kirkpatrick's show in a very striking way the necessity of a new approach, based more on the Soviet method.

—Dr. Steven Bardwell

Carter Uses Cosmos As Pretext To Sabotage Space Technology

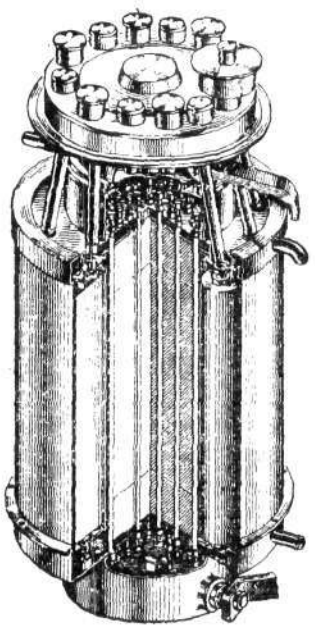
The information provided by the Soviet Union on its nuclear-powered satellite, Cosmos 954, (see international news) demonstrated that the Soviets are at least five years ahead of the U.S. in the development of space satellite power-source technology. The reaction of the Carter Adminstration, however, was to use the Cosmos 954 incident as a pretext to sabotage the next stage in U.S. space technology by suggesting the prohibition of high density, miniature nuclear reactors for satellites.

The present stage of space technology, in both earth orbit and for satellites on interplanetary missions, is limited only by the lack of sufficient quantities of electrical energy for scientific instruments and new technological devices on board the satellites. By far the most efficient and compact method for supplying quantities of energy in excess of 10 kilowatts (about 100 light bulbs' worth) is a nuclear power plant. Solar cells, placed on large surfaces like wings on a satellite, have been used below 10 kilowatts, but they have the serious disadvantages of every diffuse source of energy: They require high capital investment, are difficult to maintain, and are impossible to use farther away from the sun than the earth's orbit. The energy density of space-borne fission reactors, on the other hand, is of the same high quality that makes their use so necessary on earth.

Until 1965, the U.S. had a research program to develop a nuclear reactor whose high density of energy and compact size could solve the requirements for powering a more advanced generation of satellites. However, that was the last year that the U.S. has had such a nuclear-powered satellite in operation, and its research program has been continued on only a piddling level.

The Soviets, however, have continued their program on a high level, and can now deploy a satellite powered by a 100 kilowatt nuclear power plant! The Cosmos 954 was a military surveillance satellite that used its nuclear energy to power a strong radar beam capable of detecting and monitoring all U.S. seagoing surface ships no matter what the weather is.

Some of the nonmilitary uses for such satellites include geographical surveys of global areas previously inaccessible to engineers, prospecting for oil and minerals from space, and studies of global climate, wind, and precipitation as well as measurements of ground movement in order to predict earthquakes.



Since the Cosmos 954 affair, U.S. scientists have concluded that the gap in satellite technology is not so much the Soviet's more advanced ability to create miniature nuclear reactors but the tracking capability that allowed them to predict well in advance almost exactly the spot where the Cosmos 954 would fall.

Above is an artist's version of a new Soviet reactor-converter model called Topaz, which will be used to turn the atomic heat into electricity without any intermediary equipment. the Topaz units tested have demonstrated the stable generation of 7,000 to 10,000 watts of electricity, and they are compact and lightweight.

Books

Solving the Field-Particle Problem and Much More

by Dr. Morris Levitt

Photo by Ulanowsky

Carol White at the U.S. Labor Party's January 1977 Gresham Memorial Lecture in New York City.

Energy Potential:
Toward a New Electromagnetic Field Theory, Carol White,
New York: Campaigner Publications University Editions, 1978
$5.95 paperback

Students and practitioners of science need no longer suffer the mental disorder caused by the century-old gulf between textbook formulas like Maxwell's equations and the conceptual development of electromagnetic theory. Carol White, a former mathematics and philosophy teacher who is now a member of the national executive committee of the U.S. Labor Party, has provided the cure.

White's book cuts through the usual epistemological indifferentism of treatises on the chronological development of electromagnetic theory. She reveals clearly that the essential line of progress is not, as usually supposed, through the French "force law" experimentalists and Michael Faraday to Clerk Maxwell, but rather through field theorists of the caliber of Christiaan Huygens and Bernhard Riemann. In fact, but for its broader thesis, *Energy Potential* might have been titled "Rediscovering Riemannian Electromagnetic Theory," and the book provides the reader with a unique source of Riemann's work in electromagnetism, translated from the German by James Cleary.

White poses the broader theme at the outset of the book:

> Energy is a predicate of the self-development of the universe. We who have emerged from that process of development may now wilfully order it to the deliberate advantage of our species. This is man's freedom. Just as there are no fixed limits to the resources at our disposal, so there can be no fixed laws which describe the universe.

As White's book makes clear, however, to go forward one must begin with the highest theoretical level achieved and a coherent understanding of the historical-intellectual process of its development and realization.

Riemann: The Mozart of Mathematical Physics

Bernhard Riemann (1826-1866) was the Mozart of mathematical physics; he might have been its Beethoven had not vicious antirepublicanism and policing operations against real science prevailed in Europe after the Treaty of Vienna, especially after the defeat of the republican revolution in 1848 in Germany. Since Riemann's work and its crucial generalization by Georg Cantor and pedagogical elaboration by Felix Klein into the early 20th century, physics has progressed in practice through a series of "Brahms"-like figures including Max Planck, Albert Einstein, Erwin Schrödinger, and L.D. Landau. However, their work still awaits reunification with the classical 19th century results.

White's original analysis of the 19th century developments up through the theory of relativity makes clear that Riemann's work contains the kernel of the unified field conception, subsuming the previous continuum theories and anticipating the 20th century quantum results.

A passage from Riemann's "On the Hypotheses Which Lie at the Foundations of Geometry" demonstrates the point:

> Determinate parts of a manifold, distinguished by a mark or by a boundary, are called quanta. Their comparison as to quantity comes in discrete magnitudes by counting, in

continuous magnitude by measurement....

In a concept whose various modes of determination form a continuous manifold, if one passes in a definite way from one mode of determination to another, the modes of determination which are traversed constitute a simply extended manifold and its essential mark is this, that in it a continuous progress is possible from any point in only two directions, forward or backward....If one considers his object of thought as variable instead of regarding the concept as determinable, then this construction can be characterized as a synthesis of a variability of $n + 1$ dimensions out of a variabiltiy of n dimensions and a variability of one dimension.

As White comments:

In Riemann's conception, the particular point-object is constantly reevaluated as a subsumed feature of the self-expanding creation of higher-ordered conceptual manifolds. There can be no fixed position or momentum in such a universe. His answer to the Copenhagen School would be a hearty laugh that they thought they had uncovered a paradox separate from their own reductionist thinking practices.

Energy Potentiation

White's book provides a broader framework for the scientist, student, or layman to get his or her bearings. This is accomplished by a masterful interweaving of the book's ontological premise—"It is this ability to wilfully create new higher order universes which is human nature"—with a pedagogy based on successively more complex elaborations of the core conception of energy potentiation.

White reconstructs the evolution of the ever-more-appropriate conceptions of energy, beginning with the threshold the world is now approaching of controlled fusion energy, in which the higher-order potentiation of energy-dense plasmas is realized in fusion processes as a new relationship of the singularities to the field.

From this standpoint, she develops several important aspects of Lagrangian mechanics. It is absolutely incorrect to think that the Newtonian universe of two-body forces, their interactions, and action-at-a-distance is simply a form of notation that is clumsier mathematically, but otherwise equivalent to the Euler-Lagrange system based on the energy characteristics of a system taken as a whole. As White argues, Newton and Euler-Lagrange are in different universes conceptually. The Lagrangian approach clarifies the incoherence of the Newtonian outlook and, more important, provides the implicit basis for the higher-order conceptions appropriate first to electromagnetic field theory and then to the desired combination of mechanical-gravitational and electromagnetic phenomena in a unified field theory.

What is crucial in the advanced formulations of mechanics, White points out, is their emphasis on the irreducible energy of the totality and the constraints that produce a particular system, whether a bicycle wheel or a plasma. Once the nature of the interactions that actually govern the mechanical constraints is revealed with the opening up of investigations of electrical and magnetic phenomena, these formulations, in turn, provide the basis for an appropriate general energy-field conception. This leads finally to the resynthesis of electromagnetism with the earlier, extraordinarily advanced viewpoint of Huyghens on optical phenomena and the light field — not via Maxwell's equations (they had already been developed a decade earlier by Neumann!) but through Riemann's geometrical physics.

White's Major Contribution

Thus White provides in one volume not only a coherent overview of classical physics, but also the actual line of its conceptual development. She accomplishes this by drawing heavily on and extending the pedagogy of Felix Klein, the last direct link to Riemann prior to Schrödinger's capitulation to the Bohr-Heisenberg antinomies of quantum mechanics.

White's major contribution here is to rigorously demonstrate, in analogy with fluid-continuum mechanics, the profound relationship between field geometry and energy potential of even the simplest electrostatic case. Simultaneously, White debunks the bad metaphysics of those who attribute primacy to the lines of force, particularly as Faraday did with the magnetic field. Instead, White insists, "the field is a geometric transformation of space as a whole." This concept sets the stage for the synthesis of electricity and magnetism in relativistic form: not as algebraic formalisms, but in terms of the complex geometry of Riemannian manifolds and surfaces.

White's approach also provides the corrective to the misguided efforts of poor, nonmathematical Faraday to submerge concentrations of matter into his otherwise useful electric and magnetic pure-field circuits. Finally, White's development of the subject makes clear that mathematical physics is a product of centuries of Neoplatonic thought and thus has always had as its purpose the solution of the field-particle problem and not the miserable obfuscation hegemonic since Maxwell. White concludes her treatise with the general form of the solution to the problem:

To bridge the gap between the wave and particle geometries of radiation, it will be necessary to define the essential singularities which render possible a geometry which subsumes them. Such a higher-order geometry will not develop merely as a theoretical enterprise. It will necessarily emerge as a byproduct of work now in progress on nonlinear effects in plasmas, to subsume those only apparently linear effects known to those scientists of the 19th century who studied the electromagnetic field.

The challenge to the reader of

Energy Potential is twofold: first, to internalize the freedom and necessity of humanity to force those singular moments through which the physical universe is reconfigured for human progress; and second, to get beyond the frozen formalization of mathematical science to grasp what Riemann's project really was so that we may carry it forward.

The specific program demanded by this challenge is that to reach fusion power, "we must absorb an enormous quantity of free energy and stretch our existing system to its limits without violating those constraints which would destroy it." We will "nullify that entropic growth by the negentropic emergence of a qualitatively new characteristic universal energy with new higher order constraints."

As a model for future texts to provoke the reader to think as well as to learn, and as a catalyst for appropriate new theoretical and experimental work in science that will take us to the fusion age and beyond, *Energy Potential* is the most significant scientific publication of the year.

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

Carol White on Naderism

The following are excerpts from the remarks of Carol White at a symposium on electromagnetic field theory sponsored by the campus affiliate of the Fusion Energy Foundation at Columbia University, Dec 8,

I want to discuss the question of Naderism, starting on the point that the book I wrote integrates a political view of the universe with a scientific view of the universe. That is what is really unique to my book. The fact of the matter is that every scientist who ever made a genuine contribution to science, that is, the kind of contributions we have been discussing here tonight, has been part of what can be broadly called the humanist tradition. They have been the dedicated opponents of Naderism, even though sometimes they don't realize it themselves.

It is literally impossible internally to be a Naderite and to be a creative scientist. Naderism is not a discussion of fixed resources, or of the environment. Nor is it solely an intelligence deployment against industries. Far more than this, Naderism is a psychology. It is a psychological attack on human beings and their identity as human beings. It says that human beings can no longer hope to be human.

The identity of human beings ultimately rests in the existence of people like Eric Schwartz and Winston Bostick [participants at the symposium], people who are carrying the human race forward. People who are discovering how we can have more control of our universe, how we can know that universe, how we can direct that knowledge of the universe toward the furtherance of the humane purposes of our own species. Not plants, us. Absolutely us.

Naderism is an attack on that human identity because it says that science is somehow mysterious, evil, destroys the universe; that people are threatened by it. It introduces the notion of a threatening outside world that mammothly oppresses human beings. This outside world fundamentally is one's own fear and inability to think about the universe. It is a transformation, a projection of extreme paranoia that purports to be talking about the outside universe but is really talking about one's self conception....

What my book is about and what our research since my book has uncovered is that all the scientists who made fundamental discoveries in science were political in the sense that they fought for a coherent view of the universe that included human beings and human creative processes....

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FEF News

PARPART TOURS WEST COAST

Uwe Parpart, director of research for the Fusion Energy Foundation, addressed the Lawrence Berkeley Laboratory and the Applied Science Division of the University of California at Davis on the "Politics of Fusion Power" during a week-long tour of the West Coast in early February. At both invited talks, Parpart focused on the administration's role in sabotaging scientific cooperation with the Soviet Union on fusion research and the reasons behind it.

Parpart spoke at the University of British Columbia in Vancouver, Canada and at the University of Washington in Seattle, outlining the FEF program for nuclear development. The British Columbia student newspaper gave front-page coverage to Parpart's address, refuting the claims of the environmentalists on the inefficiency of nuclear power, and CJOR radio featured Parpart on an hour-long talk show. The *Seattle Times* Feb. 12 reported the Parpart talk in an article headlined, "U.S.-Russian Cooperation Urged on Satellites."

Parpart was also the guest of honor at a reception for scientists hosted by Stefan Possony of the Hoover Institute.

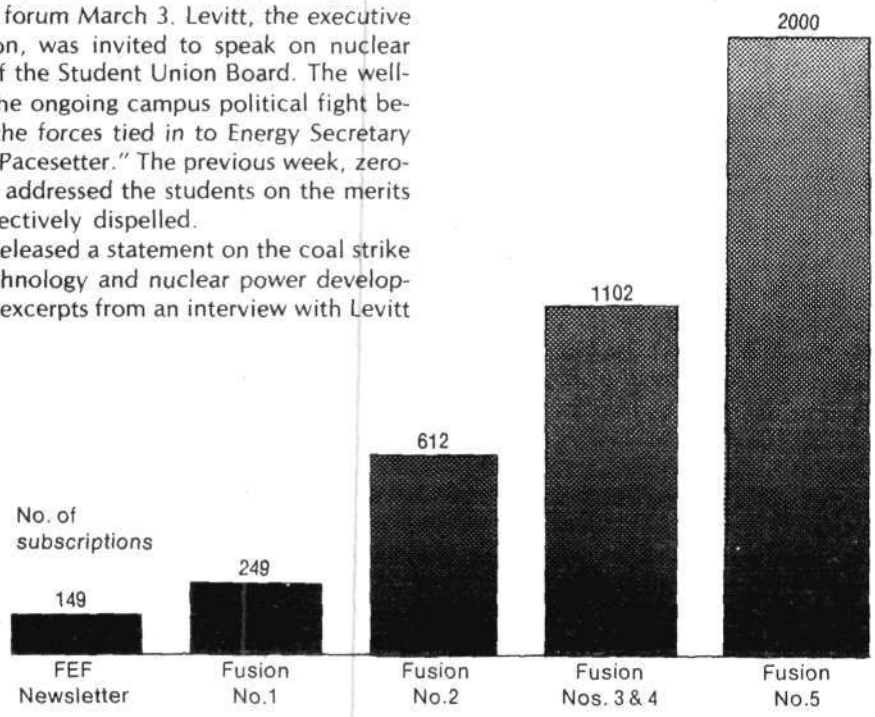
LEVITT AT UNIVERSITY OF PITTSBURGH

"The current fight for energy is as important as the Civil War; this week the decisive battle of Clinch River was declared," Dr. Morris Levitt told 50 students and faculty at a University of Pittsburgh forum March 3. Levitt, the executive director of the Fusion Energy Foundation, was invited to speak on nuclear power by the public affairs committee of the Student Union Board. The well-attended event represented a victory in the ongoing campus political fight between the protechnology elements and the forces tied in to Energy Secretary Schlesinger's conservationist "Operation Pacesetter." The previous week, zero-growther Senator George McGovern had addressed the students on the merits of solar energy, myths which Levitt effectively dispelled.

At a press conference March 3, Levitt released a statement on the coal strike which focused on the need for high technology and nuclear power development. The all news radio station KQV ran excerpts from an interview with Levitt for two days.

FUSION SUBSCRIPTIONS UP 800 PERCENT

Subscription sales for *Fusion* magazine have increased by 800 percent since the first issue of the magazine in July 1977, and with this current issue, the magazine circulation has jumped to 30,000. *Fusion* was on the newsstands in four cities for the Dec.-Jan. issue. The business office plans to vastly increase newsstand and book store distribution of the March issue, particularly in university press.



FUSION SUBSCRIPTION GROWTH

FEF IN THE PRESS: L'OSSERVATORE ROMANO

The official newspaper of the Vatican, L'Osservatore Romano, *reported in detail on the FEF's three-day conference in Milan Nov. 7-9 on World Development and the Role of Nuclear Energy. A translation of parts of the Dec. 31 article appears below.*

The Fusion Energy Foundation is an association of scientists, engineers, and scientific advocates who see in controlled fusion energy the energy source of the future.

The FEF, however, does not consider controlled thermonuclear fusion simply

L'OSSERVATORE ROMANO

IN MARGINE AD UN CONVEGNO INTERNAZIONALE

L'energia nucleare nello sviluppo mondiale

as a possibility for quantitative and linear expansion of energy, but as a possibility for gaining practical experience on nonlinear effects that occur in a plasma. Along with research on nonlinear phenomena in different fields, such as chemistry and biology, this can contribute to the solution of fundamental scientific problems.

World development has come to a crossroads; the decisions made by politicians, industrialists, trade unionists, and scientists will open either a prospect of worldwide prosperity — with unprecedented progress in the field of science and with a new technological revolution that has the potential of infinitely extending the actual limits of humanity — or such decisions will lead to an aggravation of the existing economic crisis, to technological stagnation, to internal and external political tensions, and to an ecological disaster that will enormously intensify the danger of war.

The decision for or against the further increase in energy consumption, for or against nuclear energy, is a decision that will determine politics in the most far-reaching sense....

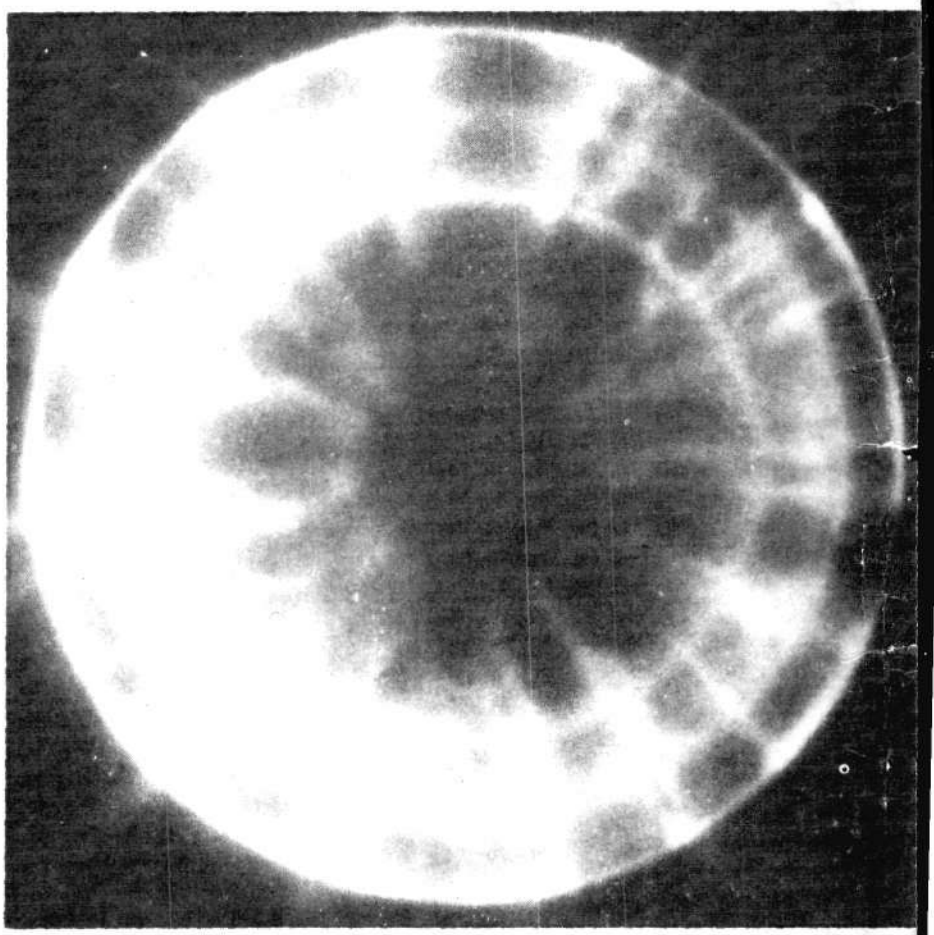
In the next months, a situation will be created in the European countries whereby a labor-industry alliance will become an urgent necessity. The common basis for such an alliance is the interest of the vast majority of the population in the rapid expansion of the scientific and productive base of the economy. An open and explicit commitment to such a policy on the part of the governments, political parties, trade unions, and industry is the first step toward creation of such an alliance....

The FEF meeting has confirmed that humanity can provide new and abundant sources of energy. Science is continually progressing toward the resolution of the grave problems that exist in society.

Coherence In Fundamental Processes

The cover pictures show two of the most extraordinary forms of self-ordered behavior in physical systems — the superfluid vortex in liquid helium [front cover] and the plasma vortex [right]. The vortical structures are almost identical, except that the superfluid is at a temperature of less than 2 degrees above absolute zero [-273 degrees centigrade], and the energy-dense plasma is at more than 100 million degrees.

This highly ordered behavior at such divergent temperatures poses a dual problem for scientists: first, to develop a coherent theory of fundamental processes that incorporates the nonlinear coupling of fields and particles demonstrated by the plasma and superfluid; and second, to develop fusion reactors that will use low-temperature superconductors as high field magnet windings just inches away from where a toroidal plasma is being heated to fusion producing conditions.



Back cover photo courtesy of Dr. Winston Bostick; front cover photo from *Physical Review Letters*.