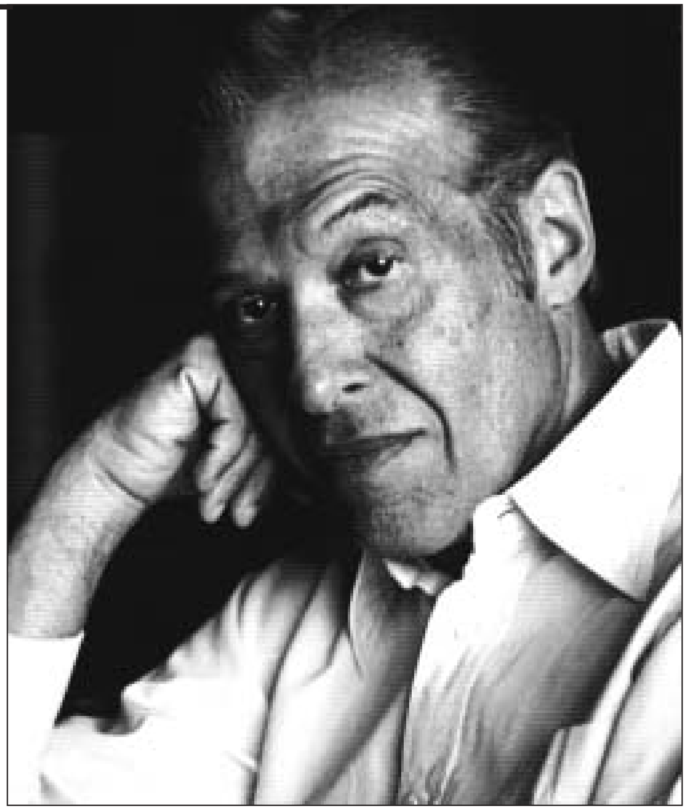
A lecture by cold fusion theorist Nobel Laureate Julian Schwinger, November 11, 1991, at MIT celebrating the 60th birthday of Professor Kenneth Johnson—a former student

In Nobel Laureate Julian Schwinger's eloquent talk at MIT, he compared the possible theoretical foundation of cold fusion with that of the much more accepted but equally mysterious phenomenon, sonoluminescence. Julian Schwinger had resigned from the American Physical Society (APS) to protest its censorship of his theoretical work on cold fusion from APS publications. It was an honor for me to have become a good friend of Schwinger's due to my involvement with cold fusion. His praise for my book, Fire from Ice, *was a very great honor (see prior page). Unfortunately, Schwinger's 1991 message at MIT was not absorbed by the assembled MIT physicists.—EFM*



A Progress Report: Energy Transfer in Cold Fusion and Sonoluminescence

by Julian Schwinger, University of California

Birthday celebrations are inevitably somewhat nostalgic. Appropriately, then, I found the cover title for this lecture in my own distant past. I first came to Berkeley on the day that World War II began. Not long after, Robert Oppenheimer gave a lecture—perhaps on cosmic ray physics—which he called "A Progress Report," in the sense, he explained, that time had elapsed. A similar expression of modesty is in order here. I have no great discoveries to announce; only feelings, hypotheses, and programs. As Mort Sahl once proclaimed:

The future lies ahead.

I am sure that my first topic, cold fusion, has caused many eyebrows to levitate. Cold fusion? Isn't all that nonsense dead and buried? How can anyone be so insane as to talk about this totally discredited subject?

Well, to the extent that sanity implies conformity with the mores of a society—didn't the Soviets clap their egregious dissidents into insane asylums?—sanity, I submit, is not a canon of science. Indeed, isn't it a goal of physics, specifically, to push at the frontiers of accepted theory through suitably designed experiments, not only to extend those frontiers, but, more importantly, to find fundamental flaws that demand the introduction of new and revolutionary physics?

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The seemingly bizarre behavior of some key players in the cold fusion melodrama has managed to obscure a fundamental challenge that this episode presents. Whether or not the reality of cold fusion has been demonstrated experimentally, one must ask if any conceivable mechanism now exists, or might be devised, whereby nuclear energy could be extracted by manipulations at the atomic level.

One is mindful of the high temperature superconductivity story. Despite the assurances of theorists that superconductivity could not exist much above absolute zero, that barrier was broken experimentally. Although it took time to get reproducible results, the reality of the phenomenon is completely established, despite the absence (to my knowledge) of any accepted theory.

High temperature superconductivity is an atomic process. Cold fusion is that too, but also involves the much shorter space and time scales of nuclear physics. It should therefore be much more difficult to control this phenomenon by manipulations at the atomic, perhaps better said: at the chemical, level. More difficult, but not necessarily impossible.

Despite my earlier qualification of the established reality of cold fusion, one cannot ignore the evidence accumulated in many laboratories—of excess heat production, of tritium production—all of which is characterized by irreproducibility and by uncontrollable emission in bursts. But, from what has just been said, that kind of behavior is expected; it is not a basis for rejecting the reality of the phenomena.

This brings me to study the validity of the case against cold fusion, as seen by a hot fusioneer—henceforth known as HF—who rejects the possibility that new physics is involved.

In the hot fusion of two deuterons—the D-D reaction—the formation of a triton (^3H) and a proton proceeds at about the same rate as that for the creation of ^3He and a neutron. But, given the claims of tritium production in cold fusion experiments, neutrons at the expected intensities are conspicuously absent, although low levels of neutrons, appearing in bursts, have been observed. To HF the conclusion is obvious: No neutrons—no tritium—no cold fusion. Moreover, the two cited reactions are the only important ones in hot fusion. So: No neutrons—no cold fusion—no excess heat.

Very soon after March 23, 1989—which one might well call D-day—-the idea was advanced that excess heat is produced by the formation of ^{4}He in the ground state. To this HF responds that the suggested reaction is weak, and no one has detected the γ-rays of roughly 20 MeV that should accompany the formation of ^{4}He.

Then came the suggestion that excess heat might result from the HD, rather than the DD, reaction. Heavy water (D_2O) always has some small contamination of light water (H_2O). The fusion of a proton and a deuteron produces ^{3}He. To which HF responds that no γ-ray of roughly 5 MeV, which should accompany this reaction, has been observed.

With heat production and tritium production allocated to the HD and DD reactions, respectively, how can one understand the suppression of neutron production? It may be that two fusing deuterons populate, not the quite remote ground state, but rather the first excited state of ^{4}He. That excited state decays into a triton and a proton. But, decay into ^{3}He and a neutron is energetically forbidden. Tritium—Yes. Neutrons—No. HF responds to this by pointing to the absence of the roughly 4 MeV γ-ray that should accompany the ^{4}He excited state.

Thus presented, the experimental aspects of HF's indictment of cold fusion come down to the non-existence of various γ-rays that the tenets of hot fusion require. What rebuttal can one give to these charges?

Well, consider the following bit of insanity:

The circumstances of cold fusion are not those of hot fusion.

In contrast with hot fusion, where energies are measured in substantial multiples of kilovolts, cold fusion deals with energies that are a fraction of a volt. The dominant electromagnetic mechanism for hot fusion is electric dipole radiation, in which the parity of the particle system reverses.

Now, at the very low energy of cold fusion, two deuterons, for example, which carry even intrinsic parity, have very little chance of fusing in other than the orbital state of zero relative angular momentum—of even orbital parity. Thus, an excited state of ^{4}He is formed that has even parity. Possibly it radiates down to the first excited state, or the ground state of ^{4}He. But both of the latter states also have even parity. With no parity change, electric dipole radiation is forbidden. There are, of course, other mechanisms that might intervene, albeit much more weakly—electric quadrupole radiation, magnetic dipole radiation, electron-positron pairs. But, much more important is the impetus this result gives to considering the following additional bit of insanity:

The excess energy liberated in cold fusion is not significantly transferred by radiation.

If not radiation, what? HF, with his focus on near-vacuum conditions, would have no answer. But cold fusion does not occur in vacuum—it appears in a palladium lattice within which deuterium has been packed to form a sub-lattice. Which leads to the next bit of insanity:

The excess energy of cold fusion is transferred to the lattice.

This is the moment to introduce HF's theoretical ace in the hole. In hot fusion work it is taken for granted that the fusion reaction rate is the product of two factors: the barrier penetration probability that stems from the Coulomb repulsion of like charges; and the intrinsic reaction rate that refers mainly to the nuclear forces. At the very low energy of cold fusion, the penetrability of the Coulomb barrier is so overwhelmingly small that nothing could possibly happen.

How does one respond to that? By sharpening the initial insight:

The circumstances of cold fusion are not those of hot fusion.

At the very low energy of cold fusion, one is dealing essentially with a single wave function, which does not permit the factorization that HF takes for granted. The effect of Coulomb repulsion cannot be completely separated from the effect of the strongly attractive nuclear forces. This is a new ball game.

All very well, but can one be a little more specific about the new mechanisms that might produce cold fusion?

If, as I hypothesized, the lattice is a basic part of that mechanism, some knowledge of the palladium lattice, loaded with deuterium, is needed. That knowledge exists for light loading, but, as far as I am aware, not for heavy loading. There is, however, a theoretical suggestion that, for sufficiently heavy loading, a pair of new equilibrium sites, for hydrogen or deuterium ions, comes into being within each lattice cell. The equilibrium separation of such a pair is significantly smaller than any other ionic spacing in a cell.

It would seem that, to take advantage of those special sites, a close approach to saturation loading is required. (Indeed, that is so if a steady output is to occur.) But, the loading of deuterium into the palladium lattice does not proceed with perfect spatial uniformity. There are fluctuations. It may happen that a microscopically large—if macroscopically small—region of the lattice attains a state of such uniformity that it can function collectively in absorbing the excess nuclear energy released in an act of fusion.

And that energy might initiate a chain reaction as the vibrations of the excited ions bring them into closer proximity. This burst of energy will continue until the increasing number of irregularities in the lattice produce a shut-down. The start-up of another burst is an independent affair. It is just such intermittency—of random turnings on and off—that characterize those experiments that lead one to claim the reality of cold fusion.

Now we come to barrier penetration, or rather, what replaces it. HF accepts a causal order in which the release of energy—at the nuclear level—into the ambient environment, follows the penetration of the Coulomb barrier. The response to that carefully crafted statement is surely: Of course! What else? Well, how about this major bit of insanity?

Other causal orders and mechanisms exist.

Unlike the near-vacuum of HF, the ambient environment of cold fusion is the lattice, which is a dynamical system capable of storing and exchanging energy.

The initial stage of one new mechanism can be described as an energy fluctuation, within the uniform lattice segment, that takes energy at the nuclear level from a dd or a pd pair and transfers it to the rest of the lattice, leaving the pair in a virtual state of negative energy. This description becomes more explicit in the language of phonons. The non-linearities associated with large displacements constitute a source of the phonons of the small amplitude, linear regime. Intense phonon emission can leave the particle pair in a virtual negative energy state.

To illustrate the final stage of this mechanism, consider the pd example where there is a stable bound state: ^{3}He. If the energy of the virtual state nearly coincides with that of ^{3}He a resonant situation exists, leading to amplification, rather than Coulomb barrier suppression. Between the two extremes of causal order there are, of course, a myriad of intermediate energy transfer mechanisms, so that the mechanism, as a whole is devoid of causal order.

I note here the interesting possibility that the ^{3}He produced in the pd fusion reaction may undergo a secondary reaction with another deuteron of the lattice, yielding ^{5}Li. The latter is unstable against disintegration into a proton and ^{4}He. Thus, protons are not consumed in the overall reaction, which generates ^{4}He.

The suggestion that nuclear energy could be transferred to an atomic lattice is usually dismissed (contemptuously, I might add) because of the great disparity between atomic and nuclear energy scales; of the order 10^7, say. It is, therefore, of great psychological importance that one can point to a phenomenon in which the transfer of energy between different scales involves--and here I quote—"a focusing or amplification of about eleven orders of magnitude."

It all began with the sea trials, in 1894, of the destroyer HMS Daring. The onset, at high speeds, of severe propeller vibrations led to the suggestion that bubbles were forming and collapsing—the phenomenon of cavitation. Some twenty-three years later, during World War I, Lord Rayleigh, no less, was brought in to study the problem. He agreed that cavitation, with its accompanying production of pressure, turbulence, and heat, was the culprit. And, of course, he devised a theory of cavitation. But, there, he seems to have fallen into the same error as did Isaac Newton who, in his theory of sound assumed isothermal conditions. As Laplace pointed out in 1816, under circumstances of rapid change, adiabatic conditions are more appropriate.

During World War I, the growing need to detect enemy submarines led to the development of what was then called (by the British, anyway) subaqueous sound-ranging. The consequent improvements in strong acoustic sources found no scientific applications until 1927. It was then discovered that, when a high intensity sound field produced cavitation in water, hydrogen peroxide was formed. Some five years later came a conjecture that, if cavitation could produce such large chemical energies, it might also generate visible light. This was confirmed in 1934, thereby initiating the subject of sonoluminescence (SL). I should, however, qualify the initial discovery as that of incoherent SL, for, as cavitation noise attests, bubbles are randomly and uncontrollably created and destroyed.

The first hint of coherent SL occurred in 1970 when SL was observed without accompanying cavitation noise. This indicates that circumstances exist in which bubbles are stable. But not until 1990 was it demonstrated that an SL stream of light could be produced by a single stable cavity.

Ordinarily, a cavity in a liquid is unstable. But it can be stabilized by the alternating cycles of compression and expansion that an acoustic field produces, provided the sonic amplitudes and frequencies are properly chosen. The study of coherent SL, now under way at UCLA under the direction of Professor Seth Putterman, has yielded some remarkable results.

What, to the naked eye, appears as a steady, dim blue light, a photomultiplier reveals to be a clock-like sequence of pulses in step with the sonic period, which is of the order of 10^{-4} seconds. Each pulse contains about 10^5 photons, which are emitted in less than 50 pico seconds, that is, in about 10^{-11} seconds.

When I first heard about coherent SL, some months ago, my immediate reaction was: This is the dynamical Casimir effect. The static Casimir effect, as usually presented, is a short-range non-classical attractive force between parallel conducting plates situated in a vacuum. Related effects appear for other geometries, and for dielectric bodies instead of conductors.

A bubble in water is a hole in a dielectric medium. Under the influence of an oscillating acoustical field, the bubble expands and contracts, with an intrinsic time scale that may be considerably shorter than that of the acoustical field. The accelerated motions of the dielectrical material create a time-dependent—dynamical—electromagnetic field, which is a source of radiation. Owing to the large fractional change in bubble dimensions that may occur, the relation between field and source could be highly nonlinear, resulting in substantial frequency amplification.

The mechanisms that have been suggested for cold fusion and sonoluminescence are quite different. But they both depend significantly on nonlinear effects. Put in that light, the failures of naive intuition are understandable.

So ends my Progress Report.

Julian Schwinger's cold fusion work has been published in non-APS journals, including the *Proceedings of the National Academy of Sciences*. We proudly reprinted his "Cold Fusion: A Brief History of Mine," in Issue No.1 of *Infinite Energy*, 1995.

For a few years, the "cold fusion underground" at MIT held a well-attended cold fusion symposium during the IAP (Independent Activities Period). Since 1996, this activity has moved off campus.—EFM

COLD FUSION
A Massachusetts Institute of Technology
IAP Program—Video-Lecture-Demonstration Program

January 21,1995, Saturday 9AM-5PM
Room 6-120, Physics Lecture Hall
First floor, main building of MIT.

TENTATIVE PROGRAM - Subject to Change

Start at 9:00 am sharp

* Dr. Eugene F. Mallove, MIT'69, Organizer -—Introduction, outline, and overview of latest results (30-45 min)
* Dr. Peter Graneau (Video tape of water plasma explosions) "Anomalous Forces in Water Plasma Explosions" (45-60 min)
* J. Patterson's U.S. Patent and Technology—video tape and lecture by staff of Clean Energy Technology, Dallas, TX (30 min)
* James Griggs—The Hydrosonic Pump (video and lecture) (45 min)
* Coffee Break
* Ray Conley, MIT -- Results of Light Water Excess Heat Experi–ments (20min)
* Fred Jaeger, ENECO (Patents and Commercialization) (10 min)
* Recent results of experiments at E-Quest Sciences—Helium and Excess Heat (10 min)
* Lunch Break of 20-25 minutes, refreshments to be served outside 6-120
* Professor Peter L. Hagelstein, MIT "Neutron Transfer Reactions"—Progress in theory (45 min)
* Professor Keith Johnson, MIT, Progress in Theory of Excess Heat and Progress in Producing "Cold Fusion: The Movie" (45 min)
* Professor Vesco Noninski, Fitchburg State College "Nuclear measurements—new understandings" (20 min)
* Bertil Werjefelt, PolyTech(USA) (45 min) "'Magnetic Energy': Experiments, Commercial Prospects, and Theory"
* Video Tape from Japan, Fuji Television (8 minutes)—"Magnetic Energy"
* Time allotted for late-arriving additions in cold fusion and enhanced energy
* CBC Cold Fusion Program, "Too Close to the Sun" (50 min)
* Evening Break at 5:00 p.m. for dinner and possibly resume for 7:00-8:30

General Discussion of Business and Social Issues—Possible Panel Discussion. Refreshments and organizing costs contributed by ENECO, a company committed to commercialization of cold fusion and enhanced energy technologies.

The full tapes of the program and a written record summarizing the meeting will also be available through Dr. Gene Mallove, Bow, NH.