Paradigm of Cold Fusion:
A Perspective on Scientific Philosophy

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Abstract

Technical differences between cold fusion and hot fusion, and scientific distinctions between low energy nuclear reactions (LENR) and classical nuclear reactions, are presented. It is pointed out that LENR is realized through interactions of multi-scale coupling; it is characterized by nonlinearity, non-equilibrium and complexity. The techniques of cold fusion are small-scale, distributed and flexible. All of these characteristics are consistent with trends of contemporary science and technology, whereas hot fusion departs from these tendencies.

It is well known that the truth of cold fusion has been discredited or ignored in the science world since its infancy until now. Obviously, the poor reproducibility of cold fusion experiments is mostly to blame for this widespread, long-lasting denial. However, there is another important reason: the fact that the arbitrary refusal or neglect by most of the skeptics has prevented them from realizing and reconsidering new findings and progress made by the cold fusioners. While they remained on the sidelines, a new paradigm of science and technology has developed along with the evolution of cold fusion research. This has monumental significance regarding the explanation and understanding of cold fusion. It was their clinging and depending on the old paradigm, their ignorance and refusal to acknowledge the new paradigm that trapped cold fusion R&D in so many scientific and political difficulties. The history of cold fusion includes the failure of the old paradigm, and the development and success of the new one. The author deeply feels an obligation to write this article to present to the scientific community this paradigm, with the fervent wish that cold fusion will be re-evaluated with a more objective attitude rather than shunned away without the due responsibility, even in a time when the experimental facts are not yet clear and theoretical explanations vary.

Differences between cold fusion and hot fusion are summarized in Table I. The most important difference is the temperature. The working temperature of cold fusion is from ambient (the characteristic energy is 0.03 eV) to 200°C (0.05 eV). Even in gas-discharge or beam-target systems, the particle energy is only a few keV. These temperatures or energies are 6 orders less than the hot fusion values, which is on the order of 100 MK (10 keV) for D-T fusion, the easiest nuclear fusion.

There is an analogy between nuclear fusion and chemical reactions. Hot fusion resembles an inorganic chemical reaction. Increasing temperature and pressure to extremely high values are traditional procedures to accelerate reaction rates. Cold fusion is similar to a biochemical reaction, the reaction rate of which is modified through choice of catalyst (enzyme), control of the pH, and other subtle conditions. This similarity is also embodied in the spectrum of products. Hot fusion products are simple, *e.g.* the ashes of D-T fusion are helium and neutron, in addition to tritium and proton for D-D fusion. The products of cold fusion are more complicated—they range from helium (the product of D-D fusion),[1] silver (the product of a reaction involving a palladium cathode),[2] to praseodymium and molybdenum (products of multi-body reaction involving surface additives, *i.e.* Cs + 4D → Pr, Sr + 4D → Mo),[3] and many sorts of nucleons with Miley-type spectra[4] even for the Pd-D system, the original and simplest one in this field. Product spectra depend on reactants, temperature, impurities and other conditions not clear yet today. The way these elements affect the reaction rate is something like the way yeasts affect the flavor of wine during brewing, *i.e.* different yeasts give different tastes. Another merit of cold fusion is that the nuclear products are stable nucleons only with trace amount of tritium (in ppb order) and neutron (in ppt order); this is in contrast to the radioactive nucleons, charged particles, neutrons or γ rays in hot fusion or nuclear fission. The green and safety nature of cold fusion is similar to that of biochemistry too. And these also are the trend of R&D of modern chemical engineering, materials and renewable energy.

Another remarkable feature of cold fusion is on engineering and organizing. Hot fusion requires the involvement of many scientists and technicians from various backgrounds cooperating together for one purpose, as done in the Manhattan Project seven decades ago or the Apollo Project four decades ago. A hot fusion reactor is always a huge device with complicated design. Its operation depends on orders from the central control system. Its electrical supply, radiation protection and daily maintenance must be carefully arranged and strictly executed. It is no surprise that this sort of system has inherent fragility similar to that of a fission plant (*e.g.*, the Chernobyl reactor in Ukraine) or a big dam (*e.g.*, Three Gorges Dam in China). Geological and meteorological disasters, management defects and wars all may result in the sudden interruption or breakdown of the regional electricity supply, or even horrible disasters such as happened before. In a word, big plants make for big trouble.

For cold fusion, all of these issues are no longer problems. Its small scale makes the operation, management and commercialization very easy by comparison. The cooperation in R&D of cold fusion depends only on the free will of researchers and manufacturers. Application of cold fusion will be similar to that of solar and wind energies, *i.e.* every family, community or office will be the consumer and manufacturer at the same time; and the electrical system will be the network structure, in which trouble in any unit does not affect the stability of the overall system. In light of this, it is reasonable to conclude that hot fusion is the technology of the industrial era and cold fusion will be the technology of the web era.

The technical, administrative and commercial characteristics of these two types of fusion will determine the fate of their futures: hot fusion vs. cold fusion in the energy market will be similar to the story of the Iridium Satellite Constellation vs. the Global System for Mobile communications (GSM) in the wireless communication market, which happened about one decade ago.

Because hot fusion falls away from the evolving direction of modern science, technology, society and economy, the author is sure that this Cold War's sci-tech plot has no future. Its end is only a matter of time and price, *i.e.* human beings (specifically governments of some large countries) will not pay much more money on this dead technology. This technology will not be the first loser. Similar examples were the Analog High-Definition Television Project[5] and the Robot Project[6] in Japan. The phenomenological reasons for these two lessons were the mistakes of industrial decision-making; the deep reason was the limitation of sci-tech paradigm at that time.

The terms low energy nuclear reaction (LENR) and condensed matter nuclear science (CMNS) are gradually being accepted to replace cold fusion in describing the related phenomena in a broader sense. As a scientific field, LENR differs from classical nuclear reactions in many ways, as listed in Table I and especially in Table II. First of all, beam interactions with target are the classic method to study nuclear physics and particle physics since Rutherford established the planetary model of the atom by electron backscattering. As the research in these fields evolve, beam energies become higher and higher, accelerators grow bigger and bigger, seemingly with no end in sight. A sidenote of this mode is the term high energy physics, which has the same meaning as particle physics. A sharp contrast hence occurs, *i.e.* only the maximum accelerator on earth can be used to study the physical processes in the minimum scale in the universe. The explanatory fact is that some accelerators and their accessories are bigger than the extent of small cities, and building a new accelerator is a tremendous undertaking both economically and politically. However, the discovery of LENR interrupted this big-small mode. It needs only a tabletop device rather than town-size buildings to achieve the high energy process. The truth that a mini-size device produces something much larger than expected is unprecedented. For example, pyroelectric fusion can achieve D-D fusion with a temperature difference of only 40°C,[7] and laser wakefield can accelerate electrons to GeV (10^9 eV) on a scale of centimeters.[8] LENR is the leading method in this new tide of discoveries, although many scientists, especially physicists, do not understand that now. This wave is not only revolutionary but also as progressive as that which happened in the information industry, *e.g.* electronic storage and publication will end the ever growing need for library buildings. LENR will start a new era: an amateur can carry out particle experiments in his/her garage; national laboratories or research universities will not be the kings in high energy physics. Physics will begin far away from politics, thus ending their close relationship which was formed in World War II. This process also resembles the development of computers: the personal computer has replaced the workstation and mainframe computer as the mainstream; individuals and families rather than enterprises and governments have become the main customers.

Because nuclear reactions take place in scales below fm (10^{-15} m), while angstrom (10^{-10} m) and above are the scale of chemical reactions, nuclear reactions release/absorb energies from 1 to 10^2

Table 1. Technical comparisons between hot fusion and cold fusion.

	hot fusion	cold fusion
reaction condition	high temperature (10^8 K)	low temperature (300 to 500K)
stability requirement	avoid instability	requiring non-equilibrium
effects of complexity	pursue simplicity, avoid complexity	use complexity
products	radioactive nucleons	stable nucleons
sorts of product	few	abundant
form of released energy	radiations	heat
key discipline	high temperature plasma physics	inter-disciplinary, including chemistry, condensed matter physics, nuclear physics, etc.
number of technical routes	one or two (TOKMAK, ICF)	many
social traits of technology	artificial multi-tech integration, purposive design	self-organization, spontaneous evolution
management style	dictatorial & rigid	distributed & flexible
scale	big	small
safety	low	high
commercial investment	high cost & high risk, long period	low cost & low risk, short period

Table 2. Scientific comparisons between a classical nuclear reaction and a low energy nuclear reaction.

	classical nuclear reaction	low energy nuclear reaction
experimental equipment	accelerator	tabletop device
correlation between nuclear physics and chemistry	no	yes
chemistry analogy	inorganic chemistry	biochemistry
particle number involved	two-body reaction	multi-body reaction
mechanism	simple	complex
theoretical field	electromagnetism, quantum mechanics	quantum mechanics, corporative interaction in condensed matter
coherency	incoherent	coherent

MeV, while the chemical energy is around 1 eV, the irrelevance of chemical environments is the essential feature of nuclear reaction. In contrast to classical nuclear reactions, LENR depends not only strongly on temperature and reactant concentrations etc., as in chemistry but also on sample pretreatments as in metallurgy as discussed above. It means that the multi-scale coupling (from 10^{-10} m to 10^{-15} m) occurs in LENR. This coherent feature is same as that in nano-science and biological engineering, and LENR is far ahead in this direction.

Although nuclear reactions are quantum phenomenon, the key discipline of hot fusion is plasma physics, which is confined in classical mechanics (Newton-Maxwell paradigm). The simplicity, stability and certainty are both the basis and the purpose; complexity and instability should be avoided as far as possible. For example, at least 50 destructive instabilities occur in Magnetic Confinement Fusion (TOKAMAK)[9]; the Raleigh-Taylor instability is also fatal in Inertial Confinement Fusion (ICF). In contrast, non-equilibrium and instability are the necessary condition for LENR. The LENR mechanism is also related to the cooperative and complicated interactions in condensed matter, although exact processes are unknown today. These non-linear, non-equilibrium and complexity characteristics are the tendencies of modern science, *e.g.* chaos, dissipative structure, complex fluid (soft matter) and neuroscience, etc.

Two politics-science decisions can be cited as evidence of the present viewpoint in some sense. One is the cancellation of the Superconducting Super Collider project (SSC, $11 billion USD cost, $2 billion USD spent) in 1993.[10] Another is hot fusion. The largest thermonuclear reactor, International Thermonuclear Experimental Reactor (ITER), planned as early as in 1985, is now being constructed by China, Europe, India, Japan, Korea, Russia and the USA. It will cost 11 billion Euro. A meaningful decision is that the U.S. Congress passed a bill rejecting the payment of $149 million USD due for the project in December 2007.[11] Although most reviewers consider these two decisions as only finance issues, the author considers them to be signals of failure of the old paradigm in modern society.

One scholar once commented that the cancellation of SSC could be described as the extinction of a science dinosaur. Without doubt, the ITER is the technology dinosaur in the world now. The annihilation of dinosaurs on earth was unavoidable. Biological evolution was faster after that. For similar reasons, the dinosaurs of science and technology will encounter economic and political difficulties sooner or later, but human beings will not lose their ways to explore and utilize the nature. The problem with low energy nuclear reactions is whether human beings are willing to suppress their prejudices and learn what has been discovered during the past 20 years.

Acknowledgements
This work was supported by the National Natural Science Foundation of China (20673129) and Innovation Project of Center for Molecular Sciences (CMS-CX200816). Thanks to Profs. Xin-Wei Zhang and John Dash for valuable discussions.

References

1. Arata, Y. and Zhang, Y.-C. 1999. "Observation of Anomalous Heat Release and Helium-4 Production from the Highly Deuterated Palladium Fine Particles," *Jpn. J. Appl. Phys.*, 38, L774.
2. Zhang, W.-S. and Dash, J. 2007. "Excess Heat Reproducibility and Evidence of Anomalous Elements After Electrolysis in Pd|D_2O+H_2SO_4 Electrolytic Cells," *Proc. ICCF13*, Dagomys, Sochi, Russia, June 25-July 1, pp. 202-216.
3. Iwamura, Y., Sakano, M., and Itoh, T. 2002. "Elemental Analysis of Pd Complexes: Effects of D_2 Gas Permeation," *Jpn. J. Appl. Phys.*, 41, 1A, 4642.
4. Miley, G.H. 1996. "Quantitative Observation of Transmutation Products Occurring in Thin-film Coated Microspheres During Electrolysis," *Proc. ICCF6*, Hokkaido, Japan, October 13-16, p. 629.
5. http://en.wikipedia.org/wiki/Analog_high-definition_television_system
6. http://search.japantimes.co.jp/member/member.html?nn20030820b8.htm
7. Naranjo, B., Gimzewski, J.K., and Putterman, S. 2005. "Observation of Nuclear Fusion Driven by a Pyroelectric Crystal," *Nature*, 434, 1115.
8. Leemans, W.P., Nagler, B., Gonsalves, A.J., Toth, C., Nakamura, K., Geddes, C.G.R., Esarey, E., Schroeder, C.B., and Hooker, S.M. 2006. "GeV Electron Beams from a Centimetre-scale Accelerator," *Nature Physics*, 2, 696.
9. http://en.wikilib.com/wiki/Instability#Plasma_instabilities
10. http://en.wikipedia.org/wiki/Superconducting_Super_Collider
11. http://physicsworld.com/cws/article/news/32312

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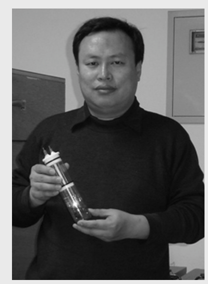

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