Introduction to the Theory Papers

Persistent resistance to accepting the Fleischmann–Pons Effect (FPE) as an attribute of a nuclear process is due to the need to accept two "miracles": suppression of the Coulomb barrier and lack of high-energy emissions. Both observations contradict textbook nuclear physics and experience with hot fusion. The first problem is how deuterons (or other nuclei) get together to undergo nuclear reactions despite the electrostatic repulsion between them. If one assumes a two-particle scattering model and collision energies commensurate with the temperatures in the experiments, calculations of the tunneling rate through the barrier yield values too low by some tens of orders of magnitude to account for the observed output powers. The second problem is the lack of observed high-energy gammas, alphas, neutrons, protons, or other prompt nuclear signatures. (There are experiments in which low-level energetic emissions from metal deuterides or hydrides *have* been reported, often without measured excess heat. These lend credence to the proposition that nuclear effects are taking place, but the levels are not commensurate with the power observed in excess-heat experiments.) In the hot-fusion regime, the dominant channels for deuterium fusion are $d + d \rightarrow p + t + 4$ MeV and $d + d \rightarrow n + {}^3He +$ 3.3 MeV; the expected energetic reaction products are typically not seen in cold-fusion experiments. Correlation of ^4He production with heat production suggests $d + d \rightarrow \alpha + 24$ MeV (or $d + d + X \rightarrow \alpha + X + 24$ MeV, with X to be determined), but again energetic outputs such as 24 MeV gammas are conspicuously absent. We thus need an explanation for how energy born in multi-MeV nuclear events gets transferred to the lattice as heat.

Over half of the papers in this section—fourteen of the twenty-three—address in some way the suppression of the Coulomb barrier. We will say something about each of them below. Six of the fourteen *also* address the lack of high-energy emissions. Three papers can be classed under the heading of "transmutation," which is used here to refer to transformations of isotopes other than those of hydrogen and helium. Nine other papers attempt to lay a foundation for anyone trying to develop models and theories of the FPE. These are discussed first.

Table 1 has been constructed to provide a characterization of the various papers in this section. The numbers of the papers in the table, and at the end of this introduction, are referred to in the remainder of this introduction. The table answers the following questions:

1. What is the form of the reaction considered? ("*Which LENR?*")
2. Does the paper deal with the Coulomb barrier? ("*Coulomb barrier*")
3. Does the paper deal with the presence or absence of energetic particles? ("*Hi-energy particles*")
4. What is the conceptual foundation of the theory? ("*Concept*")
5. Has the concept been reduced to equations? ("*Equations?*")
6. Have numerical results been provided? ("*Numerical Results?*")
7. Have the results been applied? ("*Use of Results?*")

Table 1. Characterization of the Theory Papers in This Section

	Authors	Which LENR?	Coulomb barrier	Hi-energy particles	Concept	Equations?	Numerical Results?	Use of Results?	Comments
1	Adamenko, Vysotskii	Transmutation	N/A	N/A	Magnetic monopoles	Yes	Approx. bounds	No	
2	Alexandrov	$e+p \rightarrow n+\nu$	Neutrons	No	Band theory, effective mass	Yes	Yes	Applied to semicond.	
3	Bass, Swartz	D fusion	No	No	Control theory	Computer simul.	Yes	Future work	
4	Breed	$4d \rightarrow \alpha + \ldots$	Yes	Yes	Band theory, effective mass, resonance	Yes	No	N/A	
5	S. Chubb	$d+d \rightarrow {}^4He$+heat	Yes	Yes	Nonlocal quantum effects, resonance	Yes	Yes	No	"Real barrier is conceptual"
6	T. Chubb	Various	Yes	Yes	"Ion band states"	No	No	N/A	
7	Cook	Transmutation	No	N/A	Nuclear lattice model	Yes	Yes	Compare with exp't	
8	Dufour et al.	Pd+D, D+D	Yes	Indirectly	New force	No	No	N/A	
9	Fou	d+d fusion	Yes	No	Neutron exchange, electrostatic fields	No	No	N/A	
10	Frisone	D plasma oscillations	Yes	N/A	Gamow and Preparata theory	Yes	Yes	No	
11	Godes	$e+p \rightarrow n+\nu$	Neutrons	No	Various	No	No	N/A	
12	Hagelstein, Chaudhary	$d+d \rightarrow {}^4He$+24 MeV	Yes	Yes	Coupling 2-level systems to phonons	Yes	Qualitative	N/A	
13	Hagelstein, Melich, Johnson	Various	Yes	Yes	Various	N/A	N/A	N/A	Survey of experiments
14	Hagelstein et al.	Various	No	No	Existing theory	Yes	No	N/A	Gen. framework
15	Kim	$d+d \rightarrow {}^4He$+heat	Yes	Yes	Bose-Einstein condensate	Yes	Yes	Yes	
16	Kozima	Not stated	No	No	Cellular automata, recursion equations	No	No	N/A	Complexity theory
17	Kozima, Date	Transmutation	Neutrons	No	"Neutron drops"	No	No	N/A	
18	Li et al.	$d+p+e \rightarrow {}^3He+e+\nu+\bar{\nu}$	Neutrons	Indirectly	Resonance, tunneling	Yes	Yes	No	
19	Sinha, Meulenberg	D fusion	Yes	No	Screening via local e^- pairs	Yes	Yes	No	
20	Swartz	D fusion	No	No	Relations between operating params.	Yes	Approx.	Yes	
21	Swartz, Forsley	D fusion	No	No	Relations involving operating params.	Computer calculations	Qualitative	Yes	
22	Takahashi	$4d \rightarrow {}^8Be^* \rightarrow 2\alpha$	Yes	No	"Tetrahedrally symmetric clusters"	Yes	Yes	No	

Foundations: Experimental Evidence, Models of the Physical System, Theoretical Concepts

Explanations or even simple models of the PdD system that account for the FPE heat require simultaneously addressing the problems at nuclear scales, femtometers (fermis), and both atomic and chemical scales, nanometers, in a solid or a liquid where transport of hydrogen isotopes is occurring. We have few integrated theories for any physical science problem of this wide scale and complexity. Instead we develop small model systems to help us explain certain observations and use them to guide our experimental exploration. This is not a problem new to science. Herbert Frohlich in his 1961 review of The Theory of Superconductivity provides us some guidance on what has succeeded in these situations.

> By 1933, when it was clear that the basic physics required for the development of a theory of superconductivity was well understood, many physicists had tried in vain to propose such a theory. A general feeling of frustration arose such that the first thing one did when acquainted with another attempt was to try to find where it was wrong. This feeling found its expression in Pauli's remark, "Theories of superconductivity are wrong", and by Felix Bloch's theorem, "Theories of superconductivity can be disproved". It was astonishing to see how my first paper in 1950—soon followed by Bardeen's first paper—led to a complete reversal of opinion. Schafroth (1951) followed Pauli's suggestion to work further on this theory and he was the first to show that perturbation theory could not be applied. Yet neither he, nor most others, doubted the correctness of the basic assumption that electron-phonon interaction should be principally responsible for superconductivity. This, so far as I have seen, was principally due to the fact that no 'new' interaction between electrons had to be invented but that the theory was completely based on the empirically successful free electron model. …
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> Yet it appears that all this did not affect some of those physicists who had previously formed an opinion in a different direction. A striking example can be found in the article by W. L. Ginsburg published in 1953…
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> In contrast to this dangerous dogmatic approach, the development of the theory of superconductivity is an excellent example of the intuitive approach. My idea was foremost that one should consider the small energy involved in the superconductive transition as the first problem to be answered. Electron-phonon interaction provided this possibility from a purely dimensional point of view. When the early attempts did not succeed in solving the problem, then it was required, I thought, to find a new approach to the many-body problem involved. However, intuition won again: Bardeen, Cooper and Schrieffer (1957) proposed their state vector which virtually solved the problem of the gap.

What is to be explained?

Peter **Hagelstein**, Michael **Melich**, and Rodney **Johnson** (13) give a survey of experimental results that have an important feature in common. They show effects, likely nuclear, not explained by existing treatments of nuclear physics, and occurring in condensed-matter systems at relatively low temperatures. These are presented as sources of questions that need to be addressed by possible new theoretical statements or models.

How compelling is the experimental evidence?

The paper by Rodney **Johnson** and Michael **Melich** ("Weight of Evidence for the Fleischmann-Pons Effect") addresses this question and can be found in the section on "Challenges and Summary" The introductory comments on this paper are to be found in that section.

Where shall we start?

The paper by Peter **Hagelstein** *et al.* (14) presents a general framework for formulating problems in CMNS in terms of generally accepted basic principles. The framework is broad enough to encompass problems of nuclear physics and condensed-matter physics on an equal footing, together with interactions between them. The starting point is a representation of a system as a set of electrons and nucleons, interacting via electromagnetism and the strong nuclear force, supplemented if necessary by weak-interaction terms and neutrinos. A set of reductions and approximations is described that allows a problem to be made computationally tractable while retaining necessary detail: empirical potentials may be used for interactions between nucleons; most lattice nuclei may be treated as single entities by writing in terms of center-of-mass coordinates and integrating out the relative coordinates of constituent nucleons; the Born-Oppenheimer approximation may be used; and in problems involving phonons, the center-of-mass coordinates may be re-expressed in terms of phonon-mode amplitudes. The coupling between phonons and internal nuclear coordinates is discussed as an example. This approach reflects Frohlich's notion that progress depends on our dependence on "intuition" or in the jargon, induction as opposed to deduction from axiomatic approaches. John Bardeen, when faced with the 1987 high-temperature superconductivity results, turned immediately to tabulating the experimental data and trying to understand what it was telling us. Bardeen's method of "wallowing in the data" puts the foundation under intuition and lets the experiments guide in the selection of models, as advocated in this paper.

Are there other kinds of mathematical relationships that could be useful in CMNS?

Hideo **Kozima** (16) hints at intriguing connections between cold-fusion processes and two topics related to complexity theory: (1) cellular automata and (2) recursion relations of the form $x_{n+1} = \lambda f(x_n)$. The connection with cellular automata is that the occupation numbers at time $t + 1$ for D (or H) at a lattice site depend on the values at time t at the site and its neighbors. The working out of the exact dependence has been left for future work. For the recurrence relations, the author describes the population model that led to the *logistic equation*, $x_{n+1} = bx_n(1 - x_n)$. Radically different types of behavior, chaotic and non-chaotic, can be obtained by varying b

Such results are applicable to a wide variety of nonlinear dynamical systems. Precise details of the connection with cold-fusion phenomena are left for future work.

Can the methods of Control Theory modeling assist in the design of CMNS experiments?

Mitchell **Swartz** (20) considers phenomenological relations involving various performance parameters of CMNS systems, such as excess heat production and production of helium or tritium. He argues that these relations (referred to as Optimal Operating-Point [OOP] Manifolds) are best presented as functions of electrical input power and that these relations describe many (or most) CMNS systems, provided one distinguishes three regions: surface, subsurface, and deep bulk (the last also including Y. Arata's zirconium / Pd black systems). The author relates OOP manifolds to an equation (eq. 1 in the paper) then relates deuteron fluxes to drift rates (due to applied field) and thermal diffusion rates. On the basis of the equation, he recommends use of low currents, high voltages, and pure D_2O without additives such as LiD.

Robert **Bass** & Mitchell **Swartz** (3) confront Bass's work on system identification ("Empirical System Identification") described in his ICCF-1 paper, with Swartz's work on OOP Manifolds, mentioned just above. Models of various sizes were estimated, and the system output values calculated from them were compared with measured values. On the basis of the results, the authors hold out the possibility of designing a feedback controller for lattice-assisted nuclear reaction (LANR) systems that would yield a substantial improvement in output power.

Mitchell **Swartz** & Lawrence **Forsley** (21) examine results reported by Irving Dardik and others at Energetics Technologies, in which LANR systems were driven by a complex waveform consisting of a sinusoid modulated by another sinusoid, which was modulated in its turn by yet another sinusoid. The authors propose as an explanation for the reported substantial energy gains that the waveform had the effect of driving the system, for at least part of its duty cycle, through its optimal operating point (OOP, mentioned above).

Does CMNS compel us to take a quantum-theoretic view of CMNS?

The paper by **Scott Chubb** (5) is a largely philosophical work that takes as its thesis that the real barrier to progress in Condensed-Matter Nuclear Science (CMNS) is not the physical Coulomb barrier but the conceptual barrier presented by quantum mechanics. We are introduced to the epistemological perplexities of quantum theory and the challenges to our notions of causality presented by Wheeler and Feynman's absorber theory. Towards its end, the paper makes contact with the "Ion Band Theory," which has been developed in many previous publications by the author and Talbot Chubb. Deuterium ions in the lattice are treated as occupying nonlocal states similar to the states occupied by conduction electrons in conventional solid-state theory. Resonant conditions are important, and boundary effects come into play.

Explanation of fusion (with or without high-energy emissions)

Several of the papers involve the notion of *screening*—accumulation of negative charge (electrons) at locations between two nuclei so that the resulting attractive forces partially offset the repulsion between the positive charges of the nuclei. A few circumvent the Coulomb barrier by introducing neutrons into the interaction, neutrons not being subject to electrostatic repulsive forces. Both these ideas are highly intuitive—they are easy to picture in the mind's eye. Many of the papers, however, invoke notions more remote from everyday experience. We find mention of cooperative effects, nonlocality, quasiparticles, resonance, and condensates. The discussion becomes ineluctably quantum-theoretic.

The Ion Band Theory (mentioned above in connection with Scott Chubb's paper) is also the subject of the paper by **Talbot Chubb** (6), who discusses a two- (rather than three-) dimensional version of the theory suitable for treating interfaces, such as that between a ZrO_2 crystal face and a Pd nanocrystal.

The paper by Ben **Breed** (4) studies "heavy electrons," electron pseudo-particle states with high *effective mass*, a well established concept in solid-state physics. Breed points out that while the states are nonlocal in the sense of extending over many lattice cells, they can nevertheless concentrate charge near the lattice sites, or at points midway between, and thus provide a mechanism for screening to suppress the Coulomb barrier. To explain the lack of high-energy emissions, he invokes resonant modes that can bring *four* deuterons close together. Though such multi-particle interactions are virtually impossible in particle-beam experiments, we are told that they are not uncommon in a solid-state environment. Not all four deuterons are required to participate in fusion. However, the additional particles expand the possibilities of sharing energy and momentum while respecting conservation laws.

Four-deuteron interactions are also considered in the paper by Akito **Takahashi** (22) though details differ greatly. Takahashi posits the formation of a "tetrahedral symmetric condensate," involving a cluster of four deuterons with the symmetry of a tetrahedron, an example of what he calls "Platonic symmetry." (The tetrahedron and the octahedron, also mentioned, are regular polyhedra, instances of the classical Platonic solids.) Applying a one-dimensional Langevin equation to the internuclear distance, the author concludes that, once formed, such a cluster, while preserving its symmetry, will with near certainty undergo catastrophic collapse to very small dimensions, fusing to an excited $^8Be^*$ state. Takahashi expects this to yield two 24 MeV alpha particles, though details await further work. The energy is predicted to be expressed as kinetic energy of the alphas rather than as gamma radiation.

The paper by Jacques **Dufour** *et al.* (8) concerns a hypothesized new force, derived from a Yukawa-like potential with a greater range than the usual nuclear scale: picometers rather than femtometers. The authors explore some consequences of the existence of the potential, including possible bound states between Pd and D or D and D at a picometer scale, and possible promotion of fusion reactions. They propose an experimental program to test the existence of and to study the potential.

Cheng-ming **Fou** (9) considers a pair of deuterons contained in a void of atomic dimensions in an otherwise homogeneous solid. He proposes mechanisms, namely neutron exchange and electrostatic fields, that could generate attractive forces between the deuterons, partially offsetting the Coulomb barrier. The author makes the point that knowing what the fields are in the metal environment is an important consideration, and through a simple model calculation, he attempts to find a tractable way of estimating them.

Fulvio **Frisone** (10) studies plasma oscillations of palladium *d*-shell electrons, Pd ions, and deuterons in D-loaded Pd, in an extension of work by Giuliano Preparata. He finds negative charge condensation near D^+ ions, providing a screening potential. However, calculated fusion rates are said to be insufficient to explain substantial heat production in Fleischmann–Pons experiments. The author contemplates further work, exploring the contributions of deformations, micro-cracks, and impurities.

Yeong E. **Kim** (15) proposes that mobile deuterons in a micro- or nano-scale grain of Pd can form a Bose-Einstein condensate. He cites work of Dirac and Bogolyubov to assert that for large occupation number of the ground state, the bosons act independently and largely ignore the Coulomb barrier. He presents selection rules, which suggest that, in contrast to free space, $d + d \rightarrow \alpha$ should dominate, not $d + d \rightarrow p + t$ or $d + d \rightarrow n + {}^3He$. The resulting 24 MeV is said to be taken up by the condensate and shared by the remaining deuterons.

K. P. **Sinha** and A. **Meulenberg** (19) propose a mechanism for screening involving: presence of d-d pairs in linear defects in the Pd lattice; interactions of optical-mode phonons with ions and electrons; consequent formation of local electron pairs; then formation of D^- and D^+ ions and hence resonant D^+-D^- pairs. The local electron pairs have been discussed elsewhere by one of the authors in connection with high-temperature superconductors.

The paper by Dimiter **Alexandrov** (2) is one of three in this section that deal in some way with neutrons as participants in nuclear reactions in solids. The focus of this paper is "heavy electrons." The author considers disordered nitride semiconductors such as $In_xGa_{1-x}N$ and performs band-structure calculations that lead to values (some quite large) for the effective electron mass. He considers conditions under which the enhanced mass can permit an inverse beta-decay reaction: $e + p \rightarrow n + \nu$, as also proposed under other conditions by A. Widom and L. Larson (ref. [3] of the paper). The resulting neutrons can induce various unspecified nuclear reactions. Application of this work to metallic hydrides, such as PdD, is not yet clear and is left to future work.

Robert **Godes** (11) proposes a mechanism to explain FPE devices built by his company, and perhaps other systems. Direct D+D fusion is avoided by an indirect path involving cold neutrons. An assumed Hamiltonian leads to neutron production through inverse beta-decay. Hydrogen isotopes build up to ^4H by neutron capture, followed by $^4H \rightarrow {}^4He + e + \bar{\nu}$.

Xing Z. **Li** *et al.* (18) present a three-parameter empirical formula for cross sections of several processes involving D, T, or ^3He. It shows better fits to data than a much used five-parameter formula. They argue that the form of the formula supports a "selective resonant tunneling" model for the processes and, on the basis of channel-width matching, that the absorption process at low energy must be narrow, long-lived, and therefore a weak-interaction process. They conclude that selective resonant tunneling explains the occurrence of excess heat without high-energy neutron or gamma emission. As a candidate reaction they mention "K-capture of an electron by a deuteron, followed by decay of a triton.” This is written as p + d + $e^- \rightarrow T + \nu$ followed by $T \rightarrow {}^3He + e^- + \bar{\nu}$, though “K-capture of an electron by a deuteron” would seem to hint at the transitory existence of a dineutron, ^2n, during the first reaction.

This brings us to the paper by Peter **Hagelstein** and Irfan **Chaudhary** (12). Though screening is addressed, the main thrust of the paper is how a large quantum of energy, on the order of 24 MeV, can get distributed to the lattice as a very large number of quanta of vibrational modes, each on the order of a small fraction of an eV. The authors have studied models of a two-level system with a large transition energy (such as D_2 and ^4He separated by 24 MeV) coupled to a low-energy harmonic oscillator, representing phonon modes. (These are reminiscent of multi-spin spin-boson models that occur in other contexts.) Because the coupling is weak due to the Gamow factor associated with the Coulomb barrier, they are led to consider (1) a loss term to suppress destructive interferences and (2) a second two-level system strongly coupled to the oscillator. Candidates for the second two-level system are discussed. This work is one part of a very ambitious program to model the FPE in detail from established basic principles. It takes place within a general framework described in the paper by Hagelstein *et al.* (14) already discussed above.

Transmutation

In previous work, V. **Adamenko** and V. I. **Vysotskii** (1) reported observations that suggested transmutations such as $^{27}Al + {}^{12}C \rightarrow {}^{39}K$ in high-current electron-beam experiments. They hypothesized that such reactions were promoted by magnetic monopoles. In this paper, they make inferences about the properties of the monopoles and discuss possible mechanisms for their creation.

The paper by Norman D. **Cook** (7) considers a lattice model of nuclear structure, an alternative to the usual shell, liquid-drop, cluster, and other models. The lattice model has previously been applied to explaining the asymmetric fission of uranium. It is applied here to observations of palladium cathodes by T. Mizuno suggesting transmutations of the form Pd + D → (fission products) for various isotopes of Pd.

The “water tree” in the title of the paper by Hideo **Kozima** and Hiroshi **Date** (17) is a micron-scale defect, filled with electrolyte, which forms in polyethylene subjected to intense electric fields and has been implicated in failures of polyethylene-insulated power lines. The authors propose an explanation for observations by T. Kumazawa *et al.* that suggest various transmutations associated with the formation of water trees. The explanation is based on the authors’ “neutron-drop model,” developed in earlier work, which hypothesized the existence of a “dense neutron liquid at boundary / surface regions of . . . crystals” that contains “neutron drops,” denoted ${}^A{}_Z\Delta$, having Z protons, Z electrons, and $(A - Z)$ neutrons. The transmutations in question could be attributed to absorption by a nucleus of a neutron, with or without subsequent beta-decay, or to absorption of a ${}^4{}_2\Delta$ or an ${}^8{}_4\Delta$.

Finally, it should be noted that not all theoretical concepts for LENR were represented at ICCF-14. Hence this section, whilc relatively comprehensive, is necessarily incomplete.

Theory Papers

1. V. Adamenko & V.I. Vysotskii, *The possible mechanism of creation of light magnetic monopoles in strong magnetic field of a laboratory system*
2. D. Alexandrov, *Heavy Electrons in Nano-Structure Clusters of Disordered Solids*
3. R. W. Bass & M. Swartz, *Empirical System Identification (ESID) and Optimal Control of Lattice-Assisted Nuclear Reactors*
4. B.R. Breed, *Can Established Physical Principles Explain Solid-State Fusion?*
5. S.R. Chubb, *Resonant Electromagnetic-Dynamics Explains the Fleischmann-Pons Effect*
6. T.A. Chubb, *Interface Model of Cold Fusion*
7. N. Cook, *Toward an Explanation of Transmutation Products on Palladium Cathodes*
8. J. Dufour et al., *An Experimental Device to Test the YPCP ("Yukawa Pico Chemistry and Physics") Model: Implications for the CF-LENR Field*
9. C. Fou, *Investigation of Deuteron-Deuteron Cold Fusion in a Cavity*
10. F. Frisone, *"The Coulomb Barrier not Static in QED," A correction to the Theory by Preparata on the Phenomenon of Cold Fusion and Theoretical hypothesis*
11. R. Godes, *Quantum Fusion Hypothesis*
12. P.L. Hagelstein & I. Chaudhary, *Excitation transfer and energy exchange processes for modeling the Fleischmann-Pons excess heat effect*
13. P.L. Hagelstein, M.E. Melich, & R. Johnson, *Input To Theory From Experiment In The Fleischmann-Pons Effect*
14. P.L. Hagelstein et al., *A Theoretical Formulation for Problems in Condensed Matter Nuclear Science*
15. Y.E. Kim, *Theory of Low-Energy Deuterium Fusion in Micro/Nano-Scale Metal Grains and Particles*
16. H. Kozima, *Complexity in the Cold Fusion Phenomenon*
17. H. Kozima and H. Date, *Nuclear Transmutations in Polyethylene (XLPE) Films and Water Tree Generation in Them*
18. X.Z. Li et al., *Exploring a Self-Sustaining Heater without Strong Nuclear Radiation*
19. K.P. Sinha & A. Meulenberg, *A model for enhanced fusion reaction in a solid matrix of metal deuterides*
20. M. Swartz, *Optimal Operating Point Manifolds in Active, Loaded Palladium Linked to Three Distinct Physical Regions*
21. M. R. Swartz & L. P. G. Forsley, *Analysis of "Superwave-as-Transitory-OOP-Peak" Hypothesis*
22. Takahashi, *Dynamic Mechanism of TSC Condensation Motion*