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The dd Cold Fusion-Transmutation Connection

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Abstract

LENR theory must explain dd fusion, alpha-addition transmutations, radiationless nuclear reactions, and 3-body nuclear particle reactions. Reaction without radiation requires many-body D^{+}_{Bloch} periodicity in both location and internal structure dependencies. Electron scattering leads to mixed quantum states. The radiationless dd fusion reaction is $2\text{-}D^{+}_{Bloch} \rightarrow {}^{4}He^{++}_{Bloch}$. Overlap between ${}^{4}He^{++}_{Bloch}$ and surface Cs leads to alpha absorption. In the Iwamura et *al.* studies active deuterium is created by scattering at diffusion barriers.

Constraints on theory

Key characteristics of condensed matter cold fusion that have been challenging to explain are: 1) the overcoming of the Coulomb barrier, 2) the blocking of the decay modes that produce high energy particles, and 3) the conversion of nuclear energy into a heating of the environment. There is also an item 4. Experiments have shown that unexpected forms of "low energy nuclear reactions" (LENR) can occur in condensed matter, namely, the creation of various transmutation products. This paper speculatively assumes that these processes are part of the same physics scenario that is responsible for cold fusion. As Scott Chubb has stated [1], there is breaking of gauge symmetry, which means an ordering of deuteron wave-function phases. For dd fusion to occur, a subset of the deuterons in a metal must become self-organized into a coherent many-body deuteron system in which the deuterons act in concert like the atoms in a Bose-Einstein condensate. It may be that some of the teachings of Bose-Einstein condensates, particularly of Bose-Einstein condensates in optical lattices, can provide insight into conditions that enable cold fusion reactions to occur.

An intuitive fusion model

This paper is concerned with groups of deuterons in deuterided multi-crystalline Pd metal in which there are small domains with relatively regular periodic order, which are called crystallites. The resulting metal deuteride is assumed to have a composition PdD_x, where $0.5 < x < 1$.[2] We assume that each of the crystallites contains two

configurations of deuterons: a normal set of self-trapped interstitial D^+, and a second population of highly delocalized D^+ at a much smaller fraction y (y << 1). This second population consists of D^+_{Bloch} deuterons that are modeled in terms of a many-body D^+_{Bloch} wave function. The many-body D^+_{Bloch} wave function is assumed to have the translation symmetry of a Bravais lattice, i.e., the density associated with the wave function is invariant with respect to translation operations matching the displacements of a set of N_{cell} Bravais lattice vectors $\mathbf{R}_n$.[3] The array specified by $\mathbf{R}_n$ may have either 2-dimensional or 3-dimensional array symmetry. If it has 2 dimensional symmetry, the occupied volume is at least one atom layer thick. In both geometries a scalar field $\rho(\mathbf{r})$ is used to describe the D^+_{Bloch} charge density distribution.

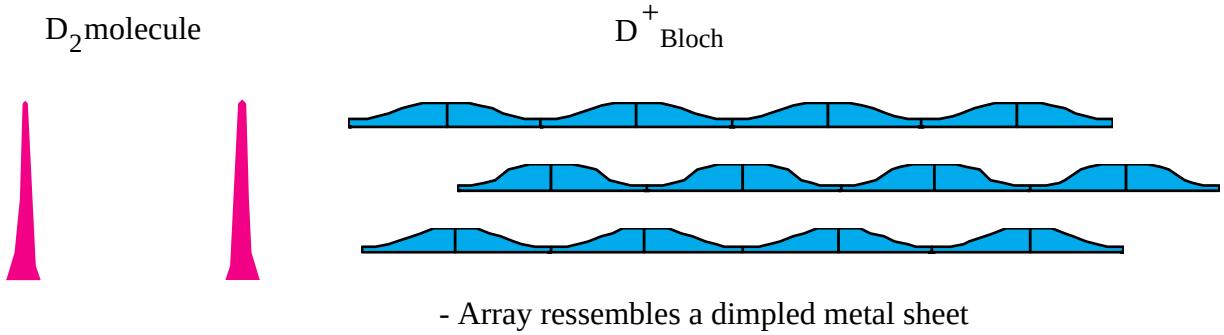


Fig. 1. **D_2 molecule:** Deuterons occupy side-by-side potential wells. Tunneling through a Coulomb barrier permits D^+-D^+ wave function overlap at the midpoint , which allows nuclear fusion. Reaction rate is too small to create detectable nuclear reaction. **D^+_{Bloch} :** The D^+_{Bloch} are in shallow potential wells within a metal lattice: High mobility spreads out each Bloch deuteron over a large set of communally occupied potential wells. A fraction of the charge of each Bloch-function deuteron is continuously present in each potential well all the time. Superposed wave functions overlap if the number of potential wells is sufficiently large.

Defining terms

By deuterons I mean a p-n nuclear pair, designated either by d or D^+. The metal crystallite provides a periodic lattice potential $V_{lat}(\mathbf{r})$ within which the deuterons reside. The Pd lattice provides 1 octahedral site potential well and 2 tetrahedral site potential wells per unit cell. The normal deuterons are known to occupy potential wells centered on random octahedral sites. It may be that the D^+_{Bloch} occupy the potential wells centered on the tetrahedral sites. The many-body wave function can be written in terms of products of single particle wave functions, each with the Bloch form $\phi(\mathbf{r}+\mathbf{R}_n) = e^{i\mathbf{k}\cdot\mathbf{R}_n}\,\phi(\mathbf{r})$.[3] A set of N_D D^+_{Bloch} deuterons is assumed to be neutralized by a many-body electron system confined to the same volume and containing N_D Bloch electrons. The N_D-D^+_{Bloch} wave function system combined with the N_D Bloch electron wave function system will be called a deuterium subsystem. The N_D-D^+_{Bloch} wave function system by itself will be called a deuteron subsystem. In any experiment the Pd metal will contain many distinct deuterium subsystems. The term subsystem comes

from Chernov et *al.*, who attributed their observations to a set of deuteron subsystems in each of which the deuterons are more closely coupled to each other than to the lattice in which they are embedded[4]. I interpret this close d-d coupling as meaning that the deuterons are "merged" with each other as expressed by deuteron coordinate exchange in the many-body deuteron wave function. The palladium lattice with its neutralizing electrons and the normal deuterons with their neutralizing electrons will be called the environment. The conduction electron system of the PdD_x lattice will be called the fermi sea. This definition of the fermi sea excludes the N_D Bloch electron subsystem that neutralizes the deuteron subsystem, only because the electron subsystem is assumed to have a smaller coherence length. The environment, together with all the deuterium subsystems, is assumed to contain no deuterium molecules, i.e., no side-by-side deuteron groupings. See Fig. 1. Also, the deuterium subsystems contain no D atoms, because there are no single electrons associated with a single D^+.

Defining terms in a wave equation, wave function model

It is asserted that the cold fusion and transmutation processes can be adequately modeled by quantum mechanics. The Shrodinger wave equation, wave function approach is used. In this formalism $\mathbf{H}\psi=E\psi$, where **H** is a differential operator, E is a constant, i.e., the system energy characterizing a stationary state, $|\psi|^2$ is a number density field, and $e|\psi|^2$ is a charge density field. As applied to modeling a deuteron subsystem containing N_D deuterons, ψ is a many-body wave function. The Hamiltonian can be written in terms of configuration coordinates $\mathbf{r}_1,\mathbf{r}_2, ...\mathbf{r}_{N_D}$ as

$$\mathbf{H} = \sum_{i=1}^{N_D} - \hbar^2/2m_D \ \nabla^2_{\mathbf{r}_i} + eV_{lat}(\mathbf{r}_i) + \sum_{i,j=1;\, i<j}^{N_D} U_{nuc}(|\mathbf{r}_i-\mathbf{r}_j|) + q^2/|\mathbf{r}_i-\mathbf{r}_j| \quad ,$$

where $V_{lat}(\mathbf{r}_i)$ is the electrostatic potential provided by the environment plus the N_D electrons of the deuterium subsystem, U_{nuc} is the nuclear potential energy seeking to bind 2 deuterons at fm separation, and q is an effective point charge in a screened 2-D^+ mutual Coulomb repulsion interaction. It will be shown that q is less than the electronic charge e when Double Bloch symmetry applies. Physical entities are identified by their wave functions. The nuclear interaction part of the process is treated as the decay of an excited state, rather than as a collision. A transition is a decay of a metastable state. A fluctuation is a reversing transition. The transfer of nuclear energy to the environment is treated as a scattering. A scattering changes a transition into a reaction, i.e., a reaction is a non-reversing transition. The potentially reactive state of the deuteron subsystem is viewed as a metastable state of a many-body D^+_{Bloch}. Each 2-D^+_{Bloch} pair in a nuclear Singlet spin configuration is potentially self-reactive and is metastable by 24 MeV relative to a $^4He^{++}_{Bloch}$ configuration with the same deuterons. The non-Singlet spin pairings are not directly reactive and fail to support direct dd nuclear fusion. It is assumed that the coupling between the nuclear configuration and each $V_{lat}(\mathbf{r}_i)$

interaction is sufficiently weak that the lattice interaction can be treated as independent of the nuclear configuration to a first approximation. This means that $\rho(\mathbf{r})$ is almost unchanged by a fusion reaction. The decay transition can be modeled by the Fermi Golden Rule of time-dependent perturbation theory[5]. Transition rates are calculated using the Fermi protocol.

$V_{lat}(r)$ determines geometry

The Hamiltonian $\mathbf{H}(\mathbf{r}_i)$ used to calculate the wave function of each single-particle D^+_{Bloch} uses the same lattice potential $V_{lat}(\mathbf{r}_i)$ for each of the Bloch deuterons. For a deuteron subsystem containing N_D D^+_{Bloch}, $\mathbf{H}(\mathbf{r}_i)$ uses a single $V_{lat}(\mathbf{r}_i)$ for each of N_D D^+_{Bloch} quasiparticles. The finite-lattice geometry of $V_{lat}(\mathbf{r}_i)$ leads to stationary states in the form of "bands" made up of N_{cell} closely spaced energy levels. This band energy structure plays almost no role in the nuclear reaction process. Since the D^+ are bosons, the N_D D^+_{Bloch} quasiparticles of the deuteron subsystem can all occupy the same lowest energy level in the lowest energy band. Also, the nuclear reaction is not expected to change the occupation distribution of the N_D-D^+_{Bloch} within the occupied band. For convenience, we model the deuteron subsystem with the assumption that all its D^+_{Bloch} occupy the lowest energy state of the lowest energy band, i.e., are in the electrostatic ground state. This N_D-D^+_{Bloch} ground state is defined as the E=0 reference state. The D^+_{Bloch} concentration y is assumed to be small enough that no y-dependent mean charge density correction is required, as in Ref. 2.

A 6-dimension problem

Consider a set of 2-D^+_{Bloch} within the N_D-D^+_{Bloch}. When viewed in the stationary state Bloch representation, the charge distribution $\rho(\mathbf{r})$ of a 2-D^+_{Bloch} deuteron pair occupies the same set of N_{well} potential wells as each single D^+_{Bloch}. To understand how dd fusion occurs one must recognize that a pair of Bloch-function deuterons in a many-body subsystem within a host metal, i.e., 2-D^+_{Bloch}, is a 6 degree-of-freedom system. A 3 degree-of-freedom wave function position factor $\phi(\mathbf{r})$ locates the 2-D^+_{Bloch} in/on the metal lattice. A second 3 degree-of-freedom factor $g(\mathbf{r}_{12})$ describes the pair's internal structure. (Similarly, a D_2 molecule occupying a cavity in a metal is also a 6 degree-of-freedom subsystem, with a 3 degree-of-freedom position factor describing the density distribution of the molecule within the cavity. A second 3 degree-of-freedom internal structure factor describes the molecule's rotation-vibration state). The nuclear interactions and the Coulomb repulsion interactions occur in the internal structure space $\mathbf{r}_{ij}$, where the $\mathbf{r}_{ij}$ specify the vector separations characterizing each of the deuteron pairings. The $\mathbf{H}(\mathbf{r}_{ij})$ used to calculate wave function factors $g(\mathbf{r}_{ij})$ include pair-interaction nuclear potential energies $U_{nuc}(\mathbf{r}_{ij})$ and pair interaction Coulomb repulsion potential energies $U_{coul}(\mathbf{r}_{ij}) = q^2/|\mathbf{r}_{ij}|$. $\mathbf{H}(\mathbf{r}_{ij})$ contains $N_D(N_D\text{-}1)/2$ nuclear potential energy terms, and an equal number of electrostatic $U_{coul}(\mathbf{r}_{ij})$ terms. The essential physics is contained in calculations for a single D^+_{Bloch} pair with designated vector separation coordinate $\mathbf{r}_{12}$.

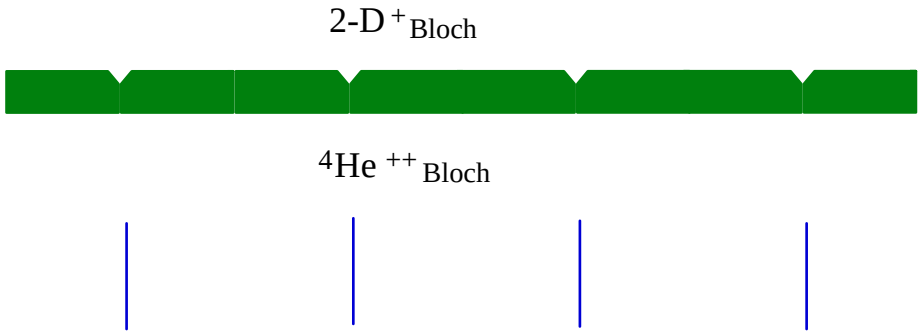


Fig. 2. **Changes in 2-D^+_{Bloch} wave function:** Change occurs in the internal structure of a 2-D^+_{Bloch} pairing. The location of the system is not affected. The charge of each superposed D^+_{Bloch} is spread out over a significant fraction of each shallow potential well within each unit cell. Charge density has a sharp minimum (cusp) at separation $\mathbf{r}_{12} = 0$ in internal separation space, and also at each equivalent lattice point in internal separation space. The cusps in $g(\mathbf{r}_{12})$ reduce, but do not eliminate, wave function overlap. For Singlet pairings in a many-body system, the nuclear potential contracts the 2-body wave function into nuclear dimension, transiently creating $^4He^{++}_{Bloch}$. Scattering of Fermi sea electrons creates a mixed quantum state $D^+_{Bloch} \rightarrow {}^4He^{++}_{Bloch}$, which transfers all the nuclear energy into the metal's Bloch-function many-body electron system.

Double Bloch symmetry: $\mathbf{U_{coul}(r_{ij}) \equiv e\, V_{coul}(r_{ij}) = (e^2/N_{well})/|r_{ij}|}$

For dd fusion to occur both $\phi(\mathbf{r})$ and $g(\mathbf{r}_{12})$ must be "commensurate Bloch functions". By commensurate we mean that both $\phi(\mathbf{r})$ and $g(\mathbf{r}_{12})$ are invariant with respect to translation operations matching the displacements of respective sets of N_{cell} Bravais lattice vectors $\mathbf{R}_n$ and $\mathbf{R}_{12n}$, and that Bravais lattices $\mathbf{R}_n$ and $\mathbf{R}_{12n}$ are congruent. This requirement is called "Double Bloch symmetry". Amplitudes must repeat over finite-element periodic vector spaces defined by lattice vectors $\mathbf{R}_n$ and $\mathbf{R}_{12n}$. (Double Bloch symmetry can be derived using the coordinate transformation from configuration space $\{\mathbf{r}_1,\mathbf{r}_2\}$ to "center-of-mass, separation space" $\{\mathbf{r},\mathbf{r}_{12}\}$, assuming total independence of the 2 Bloch deuterons including their lattice vectors. Alternatively, Double Bloch symmetry can be assumed as a theory postulate.) If Double Bloch symmetry is assumed, the amplitude of the 2-body wave function $\phi(\mathbf{r})$ is modulated by the amplitude of $g(\mathbf{r}_{12})$, i.e., $\Psi(\mathbf{r},\mathbf{r}_{12}) = \phi(\mathbf{r})g(\mathbf{r}_{12})$. Function $g(\mathbf{r}_{12})$ is called a dimming function. Its amplitude falls to a sharp minimum or cusp at $\mathbf{r}_{12} = 0$, and also at each of the $(N_{cell} - 1)$ equivalent lattice points $0 + \mathbf{R}_{12n}$. $U_{nuc}(\mathbf{r}_{12})$ and $U_{coul}(\mathbf{r}_{12})$ go to minimum and maximum values at the same N_{well} points. The nuclear interaction occurs in the $\mathbf{r}_{12}$ dependency of $U(\mathbf{r}_{12})$. The decay of the metastable state changes the 2-D^+_{Bloch} internal structure, contracting the $g(\mathbf{r}_{12})$ wave function factor into N_{well} nuclear size volumes, as shown in Fig. 2. The cusps in the initial-state configuration of $g(\mathbf{r}_{12})$, which describes the 2–D^+_{Bloch}

configuration, measure the degree of dd correlation avoidance prior to the sudden decrease in $g(\mathbf{r}_{12})$ "volume" shown in Fig. 2. They reduce initial-state dd wave function overlap as measured by $|\langle\Psi_{initial}|\Psi_{final}\rangle|^2$. Cusp depth depends on N_{well}. In each potential well $U_{coul}(\mathbf{r}_{12}) = (e/N_{well})^2/|\mathbf{r}_{12}|$. After summing over N_{well} one gets $U_{coul}(\mathbf{r}_{12}) = (e^2/N_{well})/|\mathbf{r}_{12}|$. In both initial and final states the deuterons are superposed. As a result there is no Coulomb barrier and no tunneling factor. In the limit of a large number of equivalent potential wells, the cusp depth $\rightarrow 0$, i.e., the cusp disappears. In this limit the deuteron pair behaves like 2 neutral particles. In all the decay transitions the nuclear product is a wavelike helium nucleus $^4He^{++}_{Bloch}$. It is the same 2 wavelike deuterons confined to N_{well} nuclear-well size volumes as existed before reaction. (Note that $N_{well} = 2\ N_{cell}$ for tetrahedral occupations) Before $g(\mathbf{r}_{12})$ contracts, the 2 deuterons are confined to the much larger N_{well} zero-point-motion volumes. Despite the major change in internal structure shown in Fig. 2, the D^+_{Bloch} charge distribution $2e|\phi(\mathbf{r})|^2$ in the lattice remains essentially unchanged. It remains as shown in Fig. 1.

$U_{nuc}(\mathbf{r}_{ij})$

The nuclear attraction potential energy $U_{nuc}(\mathbf{r}_{ij})$ between quasiparticles in a D^+_{Bloch} pair, designated 2-D^+_{Bloch}, plays the energizing role in the dd fusion reaction. The reaction is not sensitive to the detailed form of $U_{nuc}(\mathbf{r}_{ij})$. For example, $U_{nuc}(\mathbf{r}_{ij})$ can be approximated by a square-well potential of about 1 fm radius, and of a depth such that the lowest nuclear ground state, i.e., $^4He^{++}_{Bloch}$, lies at a level 24 MeV below that of the metastable 2–D^+_{Bloch}. This nuclear strong force potential applies only if the selected 2-D^+_{Bloch} pair has Singlet (0+) nuclear spin symmetry. Otherwise there is no attractive nuclear potential and $U_{nuc}(\mathbf{r}_{ij})$ is a constant. The existence of a potential energy well $U_{nuc}(\mathbf{r}_{ij})$ makes the deuteron subsystem metastable with respect to a set of energy levels 24 MeV lower than the electrostatic ground state. The decay rate to a single lower energy state is calculable using the $U_{nuc}(\mathbf{r}_{ij})$ combined with wave function overlap integrals between the initial and final states. In the final state the 2-D^+_{Bloch} has the internal structure of a $^4He^{++}_{Bloch}$ band state particle. However, the final-state charge distribution in the lattice $\rho(\mathbf{r})$ is determined by $V_{lat}(\mathbf{r})$. There is almost no difference in the $\rho(\mathbf{r})$ for initial state 2-D^+_{Bloch} as compared with the $\rho(\mathbf{r})$ for the final state $^4He^{++}_{Bloch}$. Only the internal structure is significantly changed. In the initial state the internal-structure separations between the D^+_{Bloch} are of lattice well dimension, whereas in the final state they are of nuclear dimension.

$U_{coul}(\mathbf{r}_{ij})$ in side-by-side vs. superposed pairs

The Coulomb repulsion potential $V_{coul}(\mathbf{r}_{ij}) \equiv U_{coul}(\mathbf{r}_{ij})/e$ between the 2 D^+_{Bloch} works against the fusion reaction in each Singlet 2-D^+_{Bloch} by reducing or preventing wave function overlap at nuclear dimension scale. In the D_2 molecule configuration (Fig.1) the effect of $U_{coul}(\mathbf{r}_{ij})$ is modeled by using a tunneling factor in a 2-D^+ wave function.[6] A potential barrier separates the fm-separation fusion product and the 0.15 nm-

separation molecule configurations. In the D_2 molecule the 2 deuterons have incoherent, uncorrelated wave functions. The side-by-side molecule geometry contrasts with that shown for the 2-D^+_{Bloch}. In the 2-D^+_{Bloch} configuration the 2 deuterons are superposed, i.e., each D^+_{Bloch} has the same spatial distribution over the same volume. The volume can be said to be "communally occupied". As a result there is no potential barrier between the D^+_{Bloch}. The quasiparticle wave functions have the possibility of wave function overlap. If their spatial distributions do overlap, their wave functions are coherent and correlated. If their spatial distributions do not overlap, then the model is unphysical. When the model applies, there is no electrostatic barrier between the two D^+ that requires tunneling. Instead, there is a correlation factor in the 2-D^+_{Bloch} wave function which reduces the 2-D^+_{Bloch} wave function amplitude at zero nuclear separation. In other words, correlation avoidance replaces Coulomb barrier. The correlation avoidance response to $U_{coul}(\mathbf{r}_{ij})$ is quantified in the internal structure of the 2-D^+_{Bloch} wave function, i.e., in the cusp structure of $g(\mathbf{r}_{12})$, as shown in the top sketch of Fig. 2. The correlation avoidance wave function applies only if $\rho(\mathbf{r})$ can be treated as essentially time-independent and only if there are multiple potential wells which divide $\rho(\mathbf{r})$ into local maxima. This is both the core conclusion and the key assumption of the Ion Band State Theory.

Wannier states describe superposed deuterons

The 1991 Ion Band State Theory[2] said that a D^+_{Bloch} system could be viewed as virtual states that might be viewed as forming superposed deuterons. It applied the Wannier state picture, which is defined in terms of an infinite lattice, to a finite lattice of N_{cell} unit cells. The nuclear reactive component was a many-body deuteron system, i.e., a quasiparticle subsystem embedded in the periodic environment provided by a metal crystal. It used the equivalence of each of N_{cell} unit cells in a metal crystal as an organizing principle. The paper tacitly assumed that if N_{cell} was sufficiently large, the Coulomb self-interaction between paired Bloch-function deuterons could be neglected. It calculated a nuclear transition rate based on the Fermi Golden Rule of time-dependent perturbation theory, using a many-body stationary state made up of coordinate exchange-symmetrized D^+_{Bloch}. In my words, it calculated a fusion transition rate using a Wannier expansion of the Bloch function stationary states to calculate the average number density of doubly occupied potential wells in the Wannier representation[3]. Double occupation fusions were treated as reversible fluctuations between 2 configurations, a double occupation in which 2 superposed deuterons are confined to a zero-point motion volume within a potential well provided by the lattice, and a double occupation in which the same deuterons are confined to the much smaller volume of a ^4He nucleus. The transitions were called fluctuations to emphasize their reversible character. Superposed deuterons were assumed because each double occupation is not a real occupation by a real D_2 molecule. Instead, it is a term in the Wannier expansion of the many-body Bloch-state deuteron system which communally occupies a set of potential wells. As Anderson said "In quantum mechanics there is

always a way, unless symmetry forbids, to get from one state to another. Thus, if we start from any one unsymmetric state, the system will make transitions to others, so only by adding up all the possible unsymmetric states in a symmetric way can we get a stationary state."[7] When this principle is applied to a lattice symmetric state, i.e. a Bloch-function state, it is OK to use the Wannier state expansion, but only in the full sum over states. A selected Wannier state at any given moment models a particular deuteron as present in a designated unit cell, but absent in all others.[8] In the time-independent sum over all Wannier states, each particle's charge is always fractionally present in each of the full set of communally-occupied potential wells.

Calculating a transition rate

Paper[2] did not treat either the Coulomb barrier problem or the transfer of energy to the lattice, but it did identify the nuclear reaction product as Bloch function $^4He^{++}_{Bloch}$.

The volumetric transition rate $\dot{n}$ as given in [2] is

$$\dot{n} = (16/3)^{3/2}\ 2\pi\ V_o^2/\hbar\quad v_{nuc}/v_{har}\ c_D^2\, c_{He}\ /v_{site}\ \rho_E$$

where $\dot{n}$ = transitions $cc^{-1}\, s^{-1}$, V_o is the energy difference between initial and final states (assumed to be 24 MeV), wave function overlap is measured by $v_{nuc}/v_{har} \equiv$ final/initial state volume ratio measured in $\mathbf{r}_{12}$ space, c_D and c_{He} are the initial and final state D^+_{Bloch}/Pd and He^{++}_{Bloch}/Pd concentration ratios, and v_{site} is the volume of a unit cell (assuming 1 potential well per unit cell). ρ_E is the density of final nuclear states to which the initial nuclear state can transfer. The density of states was calculated as the density of energy levels in an assumed dd nuclear well. This set of transiently occupied "final" states was not based on the known excited states of $^4He^{++}$. The presence of product helium increases the transition rate, as expressed by final state Bloch concentration c_{He}. This product-stimulation possibility is lost once the $^4He^{++}_{Bloch}$ transitions into localized atom form. The calculations showed that heating rates of the magnitude claimed by Fleischmann and Pons [9] are reasonable.

When correlation avoidance applies

The theory has continued to evolve. Subsequent study has shown that the N_D-D^+_{Bloch} wave function minimizes deuteron subsystem energy at sufficiently large N_{cell}. The side-by-side "molecule" configuration with its Coulomb barrier tunneling factor is replaced by N_D-D^+_{Bloch} with its correlation avoidance factors provided that N_{cell} exceeds $N_{cell,critical}$[8]. In other words $N_{cell,critical}$ is a the number of unit cells that must be exceeded for the cusp-form many-body wave function to apply. $N_{cell,critical}$ has been estimated from simplified modeling to be of the order of 1000 to 100000 unit cells. The substitution of many-body correlation for Coulomb barrier tunneling is in accord with the teachings of Julian Schwinger[10]. Schwinger said "In the very low energy cold

fusion, one deals essentially with a single state, described by a single-wave function, all parts of which are coherent. A separation into two independent, incoherent factors is not possible, and all considerations based on such a factorization are not relevant."

Single deuteron subsystems are the reacting entities

The original reaction rate calculations showed that the power produced in each coherent subsystem should be the same, independent of subsystem size, assuming a fixed D / Pd ratio. This means that the power density increases linearly with the number of coherent subsystems per unit volume, provided that the N_{cell} characterizing the coherent volumes exceeds $N_{cell,critical}$. This behavior translates into higher power density when more numerous deuteron subsystems are present. This logic is the source of the "small crystals are better" teaching.[8]

$V_{scat}(\mathbf{r},t)$ causes energy transfer, irreversibility

Fluctuations become reactions only if energy is transferred from a deuteron subsystem to the environment. The problem of energy transfer to the environment has been treated in a general context using 2 different pictures. At zero temperature one thinks in terms of momentum transfer from a recoiling coherent many-body system to the metal crystal, analogous to that which occurs with the Mossbauer effect.[11] Momentum transfer from the moving coherent subsystem to the hosting lattice causes incoherent phonon generation in a multi-crystal metal, which heats the lattice. The second picture is based on an intuitive model and envisions a piecemeal transfer of energy from the product Bloch helium nucleus $^4He^{++}_{Bloch}$ to the metal's electron fermi sea.[12] Both pictures require a scattering potential $V_{scat}(\mathbf{r},t)$ which couples the internal structure $g(\mathbf{r}_{12})$ of the many-body deuteron subsystem to the deuteron charge density distribution $e|\phi(\mathbf{r})|^2$ seen by the environment. In the intuitive model fluctuations between 2-D^+_{Bloch} and $^4He^{++}_{Bloch}$ instantaneously alter $V_{scat}(\mathbf{r},t)$ and scatter fermi sea electrons. When a 2-$D^+_{Bloch} \rightarrow He^{++}_{Bloch}$ transition occurs, it changes $g(\mathbf{r}_{12})$: the charge density distribution spread function $\rho(\mathbf{r})$ in each potential well suddenly narrows and the charge density gradient at the physical boundary of the deuteron subsystem suddenly steepens[12]. The change in charge density gradient alters any co-located environment E-field, such as can exist on the metal surface. The scatterings occur at the physical boundary of the deuteron subsystem. The changes in $V_{scat}(\mathbf{r},t)$ are caused by a change in the quantum of mass-and-charge of a Bloch deuteron pair as it transitions into and out of the Bloch helium form. The scattering of a single fermi-sea electron leaves the paired-deuteron$\leftrightarrow$helium nucleus in a mixed quantum state, i.e., a superposition of 2 time-independent states. The 2-$D^+_{Bloch} \leftrightarrow He^{++}_{Bloch}$ mixed state is neither a Bloch deuteron pair nor a Bloch helium nucleus. It is a superposition of 2 energy eigenstates states and fluctuates between them[13, 5]. Each eigenstate can be occupied only transiently. The mixed state becomes a stationary state only after a stepwise transfer of the full 23.8 MeV of nuclear energy to the metal's electrons.

Symmetry blocks energetic particles

The lack of energetic neutrons, protons, gamma rays, etc. is a result of system symmetry. The blocking of the high energy particle decay modes, such as dominate both hot fusion and muon-catalyzed fusion, is implicit in a requirement that there be no departure from periodic symmetry during the reaction process. The wave function of an energetic decay particle cannot match onto the periodic symmetry of an excited He^{++}_{Bloch} final state. The nuclear reaction occurs coherently in N_{well} locations in the separate unit cells occupied by $\phi(\mathbf{r})$, and at N_{well} cusp points in internal structure space $\mathbf{r}_{12}$. In my words, an energetic particle's deBroglie wavelength is too small relative to the lattice constant for matching onto $\phi(\mathbf{r})$ to occur since there is no collapse of $\phi(\mathbf{r})$. A nuclear decay particle is a single localized entity. It cannot map onto a set of N_{well} volumes. Because periodic symmetry is preserved, the release of energetic particles cannot be part of the primary Fleischmann-Pons cold fusion reaction process.

Creating a deuterium subsystem

To create a deuterium subsystem, one can make use of one or more of the procedures developed by cold fusion experimenters. Of special interest for this paper is the apparent role of non-equilibrium deuteron flows in creating conditions for cold fusion, as demonstrated by McKubre et *al.*[14] and by the conditions for transmutation identified by Iwamura et *al.*[15]. Iwamura et *al.* introduced thin diffusion barriers within a permeation membrane to create active deuterium. Other important observations include: the change in metal deuteride properties at elevated D/Pd ratio as documented in Italian experiments[16], the usefulness of fine metal powders as shown by Arata and Zhang[17], the importance of metal integrity and near surface location as shown by Storms[18] and the observations of helium release in electrolysis offgasses as shown by Miles[19]

Single D^{+}_{Bloch}-Cs nucleus wave function

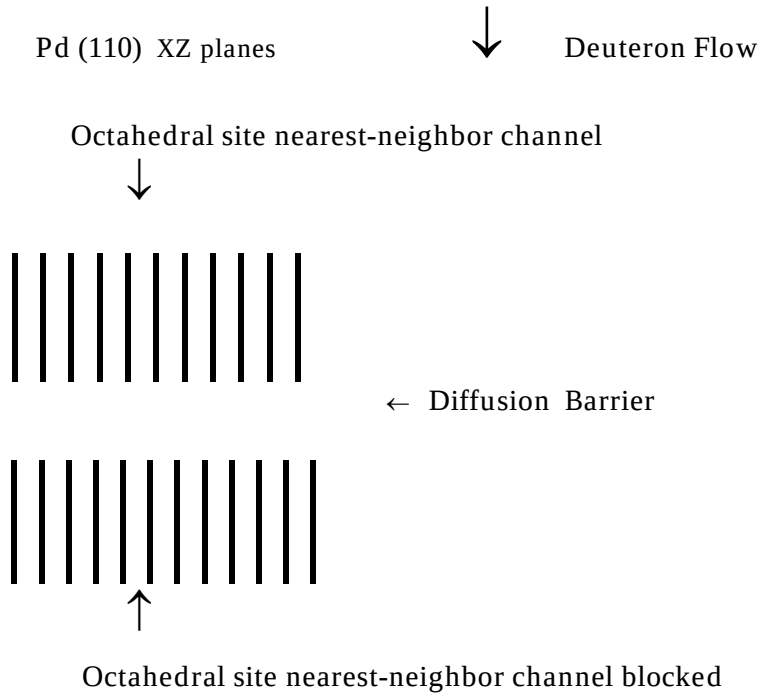
Low energy transmutations seem understandable as follows: To have a hydrogen-induced transmutation reaction there must be an overcoming of the Coulomb barrier between the nucleus of a feedstock atom serving as a "target" and a reacting Bloch-function deuteron or proton. As in cold fusion there must be a correlation-avoidance form of wave function. Reaction can only occur if the charge of a reacting proton or deuteron is split into many separate potential wells, thereby reducing its charge in any single potential well. It must be configured like a "Bloch" function in which the charge present in any single unit cell of its occupation volume is below some critical value. This requires coherence over a volume exceeding $N_{cell,critical}$, where the $N_{cell,critical}$ for transmutations is expected to exceed that of the $N_{cell,critical}$ for d-d fusion. This larger N_{cell} requirement is an expectation based on the larger point charge (>1) of an off-lattice transmutation "target" nucleus[20]. If this condition is met, it becomes possible for the off-lattice transmutation "target" atomic nucleus and the deuteron or proton many-body system to share a common small volume of space, i.e., they have mutual overlap. The

Coulomb barrier becomes replaced with a coherence avoidance factor in the combined Bloch-function-hydrogen wave function plus the localized transmutation "target" nucleus. The "target" nucleus and the hydrogen Bloch system then become a common nuclear system, which allows transfer of nuclear matter between the coherent hydrogen system and transmutation feedstock nucleus if not blocked by spin and electron considerations. This process appears to be what occurs in the Iwamura et *al.* experiments, where feedstock surface cesium atoms pick up the equivalent of 2 helium nuclei from a many-body deuteron system so as to become product praseodymium atoms. Exothermic reaction energy is transferred to the metal lattice by the mixed quantum state process of cold fusion.

Alpha-addition transmutations

Let us now consider 2 aspects of the Iwamura et *al.* work First, it showed that LENR reactions can be made to occur on the surface of Pd metal at a 1-bar D_2 pressure. The equilibrium D / Pd ratio at 1-bar pressure is much lower than that at which cold fusion workers have been able to produce observable excess heat. The Iwamura team accomplished this feat by using a permeation flow of deuterium through a Pd metal membrane, and requiring that this permeation flow overcome a set of thin diffusion barriers embedded inside the pure metal membrane. They used five 2-nm thick layers of CaO to obstruct diffusion flow. Their permeation flow was from 1 bar entrance pressure into a much lower pressure, using active pumping to maintain vacuum in the gas removal volume. The flow was at 70 ^{o}C. One question is: why should obstructed deuterium permeation flow within a metal create the conditions needed for nuclear reactions involving "impurity" surface atoms of Cs or Sr, either of which functions as a successful feedstock transmutation target? My answer is that given above, most likely a $^{4}He^{++}_{Bloch}$ system is created that overlaps with the surface target atoms. The other question is: how does the Iwamura protocol produce the 2-D^{+}_{Bloch} matter that generates the $^{4}He^{++}_{Bloch}$?

Iwamura et *al.* deuteron diffusion across thin diffusion barrier



- When octahedral channels are blocked, some deuterons jump to the tetrahedral shallow-well network, which provides an alternate flow path

Fig. 3. **Mitsubishi process creates D^{+}_{Bloch}:** Deuterium permeation flow encounters a diffusion-inhibiting barrier. Up-stream density is larger than downstream density, creating a larger lattice spacing upstream than downstream. Diffusing deuterons scatter out of deeper octahedral sites into shallower tetrahedral sites. The spreading out of the deuterons in the shallower network of tetrahedral site forms D^{+}_{Bloch}. Overlap between D^{+}_{Bloch} and a Cs nucleus merges the quantum systems, allowing exothermic transfer of fusion product $^{4}He^{++}_{Bloch}$ into the Cs nucleus.

Two component deuteron flow

One way of envisioning what could be happening is the following: Think of the membrane as containing 2 species of deuterium, i.e., normal atom-like interstitial deuterium and communal D^{+}_{Bloch} band state deuterium. The diffusing D moves through the membrane in response to a concentration gradient by normal hopping- or tunneling-atom diffusion. This diffusion is largely blocked at the CaO layers, which results in a larger concentration of deuterium on the higher pressure upstream side of each layer and a lower concentration on each downstream side, as shown in Fig. 3. This discontinuity in concentration means that there are larger unit cells on the upstream side of each CaO barrier than on the downstream side. Hence, there is a discontinuity in lattice structure at

each barrier as shown in Fig. 3, and a strong gradient in concentration across each barrier. The selected thickness of the CaO layers allows inhibited diffusion to occur. Assume that the total permeation flow has 2 components, the normal diffusion gradient flow and a D^+_{Bloch} ion current flow. The D^+_{Bloch} is a many-body system that contributes to permeation by current flow in a manner analogous to the flow of an electrical current. The D^+_{Bloch} current flow is driven by a difference in D^+_{Bloch} chemical potential. The 5 CaO diffusion barriers within the Iwamura et *al.* structure separate the D^+_{Bloch} into 6 separate, independent many-body systems. Low resistance D^+_{Bloch} flow occurs within each of the 6 Pd regions, but at the CaO barriers there is an interface that can be expected to split the D^+_{Bloch} flow into transmission, reflection, and scattering components. Transmitted D^+_{Bloch} flow contributes to permeation. Reflected D^+_{Bloch} contributes a negative permeation component. Scattering of D^+_{Bloch} might be expected to remove carriers from the many-body system, converting band state deuterons into normal interstitials. The scattering component is the interesting component. Now, consider the normal diffusion contribution to permeation flow. If we consider that microscopic reversibility is likely to apply, it means that the incoherent incident normal diffusion flow would be expected to undergo a reverse scattering similar to that encountered by the D^+_{Bloch} flow. This reverse scattering means that some of the diffusing deuterons change into the coherent D^+_{Bloch} configuration. So I propose that a scattering of particle-like deuterons into D^+_{Bloch} deuterons occurs at the diffusion-inhibiting barriers used by the Iwamura et *al.* in their obstructed permeation flow.

Other speculations

It will be argued separately that the postulated D^+_{Bloch} current flow is carried by deuterons in Pd tetrahedral sites instead of in the normally occupied octahedral sites.[21] Also, there are other unanswered questions. The nature of the Iwamura et *al.* transmutations is unexpected. Surface cesium atoms seem to add 2 helium nuclei (near-zero energy alpha particles) to become surface praseodymium atoms. Why are $^4He^{++}_{Bloch}$ helium nuclei absorbed rather than D^+_{Bloch}? The answer to this may lie in the S=0, J=0 nuclear configuration of the helium nucleus. (There is a problem with $^{133}Cs \rightarrow {}^{141}Pr$. ^{133}Cs has I = 7/2. ^{141}Pr has I = 5/2. Maybe an excited state is produced.) But why does a double alpha particle absorption seem to be preferred? My speculation is that maybe there is a slight difference between a $^4He^{++}_{Bloch}$ and an α_{Bloch}, even though both have the same quantum of mass-and-charge. My guess is that having coordinate exchange between two deuterons is not exactly the same as having coordinate exchange between 2 neutrons and also between 2 protons. Having an additional reaction 2-$^4He^{++}_{Bloch} \rightarrow {}^8Be^{4+}_{Bloch}$ might speed up the nuclear matter addition process. Note, however, that the $^{24}Mg \rightarrow {}^{28}Si$ reaction fits a single alpha addition picture.[22]

Regarding 3-body reactions, an excess of 3-body products is observed in D^+ ion beam studies using metal deuteride targets. Assuming a pre-existing D^+_{Bloch} system, D^+ impacts onto double-occupancy Wannier states could occur. The double occupancy

Wannier states could function as real states because of impact-induced wave function collapse.

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