Chubb, T.A. *I. Bloch Ions*. in *Eleventh International Conference on Condensed Matter Nuclear Science*. 2004. Marseille, France.

I. Bloch Ions

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ABSTRACT

A Bloch ion has periodic symmetry and is distributed in space in a lattice array form. Its spatial density distribution is neutralized within each unit cell by a metal's electrons. The wave function repeats coherently modulo a Bravais lattice vector. Paired Bloch deuterons partitioned over a sufficiently large number of unit cells become superposed and coherently mixed by coordinate exchange. A Hamiltonian describing paired deuterons 2-D^+_{Bloch} is presented, and its nuclear self-interaction and coupling with the lattice are described.

INTRODUCTION

This paper is the first of a group of 3 papers that argues the view that LENR processes share a common physics. Conclusions are summarized at the end of Paper III.

Wave function coherence plus a partitioning of nuclear charge appear to be a requirement for LENR, including Fleischmann and Pons (F-P) cold fusion. Bloch ion wave functions[1] have the required characteristics. The D^+_{Bloch} ion is compared with the D_2 molecule in Fig. 1. The deuterons in the molecule have coordinate-exchange-symmetry[2] and share a common potential well provided by spin-paired electrons. Drawings compare a D_2 molecule trapped in a harmonic well with a 2-D^+_{Bloch} wave function trapped in multiple potential wells furnished by a metal lattice. The center of the D_2 molecule is distributed as a Gaussian within the harmonic well (not shown). The molecule's double-peaked structure exists in "separation space". It is pictured in Fig. 1a, and is the site of vibration,rotation excitations. The lattice-conforming structure of the 2-D^+_{Bloch} wave function exists in "center-of-mass" space, i.e., lattice space, and closely resembles that of the Bloch-state electrons in a metal. Both are characterized by coherent partitioning of charge density over multiple potential wells. Their wave function phases are ordered with respect to position, and can only change in concert. The partitioned coherence of Bloch electrons gives the metal its high conductivity. Both types of Bloch particles are described by periodic symmetry that occurs in response to the periodic order of a hosting metal atom lattice. The 2-D^+_{Bloch} wave function also exists in "separation space". In "separation space" it has important resemblance to the spin-paired 2-electron orbital that neutralizes the He nucleus in the atom ground state. Both paired particles are subject to coordinate exchange symmetry, but differ in that the 2-D^+_{Bloch} has a local maximum in each of multiple potential wells, whereas the He atom's spin-paired 2-electron density has a single maximum in a single potential well. Both are expressed by 2-particle wave functions describing anti-correlated superposed charged particles, instead of side-by-side charged particles kept separate by a Coulomb barrier.

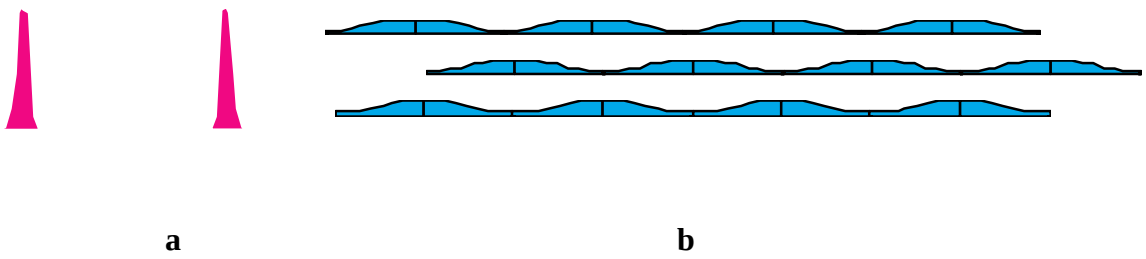

Fig. 1a. Density distribution of D_2 molecule in separation space $\{\mathbf{r}_{12}\}$. If D_2 molecule is bound inside harmonic-well potential cavity, its ground state spatial distribution in physical space $\{\mathbf{r}\}$ is a Gaussian (not shown). The double peak structure shown in 1a exists in $\{\mathbf{r}_{12}\}$ and is subject to vibration,rotation excitations. Fig. 1b. Density distribution of D^+_{Bloch} in physical space $\{\mathbf{r}\}$. The D^+_{Bloch} ion charge is dressed by electron charge contributed by the lattice. The dressing process creates N_{well} potential wells. For $N_{well} > N_{well,critical}$, the 2-$D^+_{Bloch}$ ion charge distribution is the same as that of the single-deuteron D^+_{Bloch} charge, since the two deuterons in 2-D^+_{Bloch} are superposed, and not side-by-side.

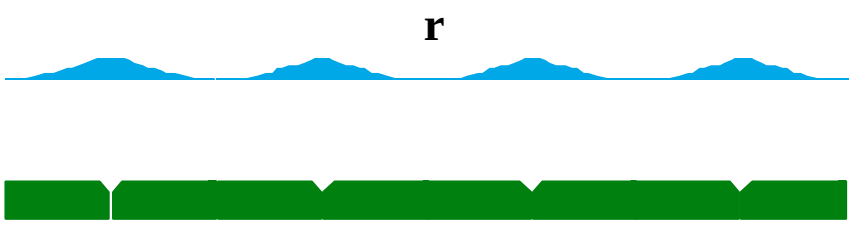

Fig. 2. The 2-D^+_{Bloch} wave function is a 6 degree-of-freedom wave function, which can be written as $\Psi(\mathbf{r},\mathbf{r}_{12}) = \psi(\mathbf{r})\, g(\mathbf{r}_{12})$ when the interaction between the dressed lattice potential $U(\mathbf{r})$ in physical space $\{\mathbf{r}\}$ and the form of the density distribution in separation space$\{\mathbf{r}_{12}\}$ can be neglected. In accord with double Bloch symmetry, both $\psi(\mathbf{r})$ and $g(\mathbf{r}_{12})$ are independent Bloch functions, describing a distribution modulo a Bravais lattice vector. $|\psi(\mathbf{r})|^2$ is a physical density distribution. $|g(\mathbf{r}_{12})|^2$ describes a normalized amplitude modulation function which decreases the amplitude of the 2-body wave function at $\mathbf{r}_{12}=0$ modulo a Bravais lattice vector. $g(\mathbf{r}_{12})|^2$ expresses dd anti-correlation. There is no Coulomb barrier. This superposed-deuteron functional form minimizes system energy when $N_{well} > N_{well,critical}$.

QUANTUM DELOCALIZED SURFACE STATES

Three papers concerned with atom surface science provide a background for cold fusion theory: Puska et al. (1983)[3] titled "Quantum Motion of Chemisorbed Hydrogen on Ni Surfaces", Puska and Nieminen (1985)[4] titled "Hydrogen Chemisorbed on Nickel Surfaces: A Wave-Mechanical Treatment of Proton Motion", and Astaldi et al. (1991)[5] titled "Vibrational Spectra of Atomic H and D on Cu(110): Evidence for H Quantum Delocalization". These papers show that hydrogen nuclei can be prepared in a coherently partitioned form on a metal surface. Such a coherently partitioned nucleus is dressed by metal surface electrons so as to form a neutralized species conforming to a template provided by the underlying metal. The nucleus sees itself as the positively charged part of a coherently partitioned surface atom, coherent in that it has an ordered wave-function phase. These coherently partitioned nuclei were prepared by scattering low energy electrons off ordinary chemisorbed ground state atoms. The partitioned nuclei were formed as excited surface states with 2-dimensional periodic symmetry, and had band-broadened energy levels, i.e., they occupied an ion band state. In contrast, the calculated energy levels for the as-adsorbed ground-state chemisorbed atoms were sharply defined (zero band width), except for H on Ni(111), where calculation described a narrow energy band with width ~ 0.004 eV.[4]

COHERENT PARTITIONING AND DOUBLE BLOCH SYMMETRY

Since it is now known that protons and deuterons can be prepared in the form of coherently partitioned surface states, it seems reasonable to consider whether partitioned deuterons might be responsible for cold fusion. A similar configuration would be deuterons in a coherently partitioned interface state, such as might exist within a water-metal interface. It seems reasonable to ask whether some of the chemisorbed deuterium "atoms" at the interface between a polarizable electrolyte like water and a transition metal like Ni or Pd might exist in a coherently partitioned deuteron form. It would seem that the dressing (electron screening) of such deuterons would be more complete when the non-metal side of an ion's surface charge distribution makes contact with a high dielectric constant medium like water, as opposed to vacuum. It may be that under some conditions the interface ground state has the partitioned configuration.

However, the main question to be answered is: Does a pairing of spin-paired coherently partitioned deuterons (deuteron $d \equiv D^+$ ion) result in a lower mutual Coulomb repulsion force between dd partners than would exist for the same pair in a non-partitioned state? Based on a system energy minimization study[6], this is a distinct possibility, provided that the number of coherent pieces N_{well} exceeds a critical number called $N_{well,critical}$. (N_{well} is the number of potential wells provided by the lattice. A 3-dimensional fcc crystallite having N_{cell} unit cells has $N_{well} = N_{cell}$ octahedral sites and $N_{well} = 2\ N_{cell}$ tetrahedral sites.) The applicability of the energy-minimizing calculation depends on which of 2 quantum mechanics protocols for constructing a center-of-mass,separation 2-particle wave function applies when one models a coherently-partitioned pair subject to coordinate exchange symmetry. The idealized wave function for a coherently partitioned surface particle on a periodic lattice is a Bloch wave, which describes a density distribution within a unit cell, modulo a Bravais lattice vector. There is an ambiguity as to what the proper protocol is for combining 2 independent Bloch functions in configuration space into a 2-particle wave function in center-of-mass,separation space. If independent Bravais lattice vectors are used in the protocol, (as opposed to using the same lattice vector for both ions) the 2-particle repulsion potential decreases with the number of partitions, as designated by N_{well}. The resulting symmetry is called "double Bloch symmetry".

DOUBLE BLOCH SYMMETRY

The 2-D^+_{Bloch} double ion, like the D_2 molecule trapped in a harmonic well, has six degrees of freedom. It is best expressed in "center-of-mass, separation" coordinates $\{\mathbf{r},\mathbf{r}_{12}\}$, where the $\mathbf{r}$ dependency describes a density distribution in the lattice and the $\mathbf{r}_{12}$ dependency describes an internal structure, as shown in Fig. 2. The distinguishability of the two D^+_{Bloch} deuterons prior to coordinate exchange is formally expressed by starting with independent Bloch functions in configuration coordinates $\{\mathbf{r}_1,\mathbf{r}_2\}$. If independent Bravais lattice vectors apply, the coordinate transformation to $\{\mathbf{r},\mathbf{r}_{12}\}$ results in a double Bloch symmetry, in which both $\mathbf{r}$ and $\mathbf{r}_{12}$ dependencies are independent Bloch functions. At sufficiently large N_{well}, the $\mathbf{r}_{12}$ dependency expresses superposed single-particle wave functions with an anti-correlation behavior, in which the 2-particle wave function has reduced magnitude near $\mathbf{r}_{12}= 0$ modulo $\mathbf{R}_{12_{ij}}$, where $\mathbf{R}_{12_{ij}}$ is a lattice vector in $\mathbf{r}_{12}$ space. N_{well} is the number of potential wells within which each ion is divided, as shown in Fig.3. As N_{well} increases, the degree of anti-correlation, described by cusps, decreases while wave function overlap increases. In the limit of large N_{well}, the cusp amplitude $\rightarrow 0$, and there is no anti-correlation. With decreasing N_{well}, the amplitude of the cusps increases, as shown in Fig. 3. At $N_{well} = N_{well,critical}$, the cusps reduce the wave function amplitude to zero at N_{well} points, and double Bloch symmetry no longer applies. The wave function reverts to side-by-side molecule form. However, for all $N_{well} > N_{well,critical}$ spin-zero paired-deuterons with symmetric coordinate exchange symmetry (+ parity) have no Coulomb barrier to a coalescence type of fusion.[6]

BLOCH SENSITIVE NUCLEUS AND BLOCH ION FUSION

In accord with double Bloch symmetry, this paper assumes that there is a reduction in the Coulomb potential between a pair of coherently partitioned ions proportional to $1/N_{well}$. At large N_{well} this reduction is sufficient to allow: nucleus-nucleus contact, coordinate exchange symmetry[2], and nuclear reaction. Coherent partitioning reduces the e^2/r_{12} work required to bring 2 deuterons into nucleus-nucleus contact. Contact allows nuclear reaction. The immediate nuclear product is a nucleus whose ground state energy decreases with increasing partitioning. Such a nucleus is called a Bloch-sensitive nucleus. Bloch sensitivity couples the nucleus ground state energy level to the occupied area on the lattice surface, as measured by N_{well}. Fluctuations in occupied area perturb the lattice, do work, and transfer energy from the product nucleus to the metal lattice. They also cause the Bloch-sensitive

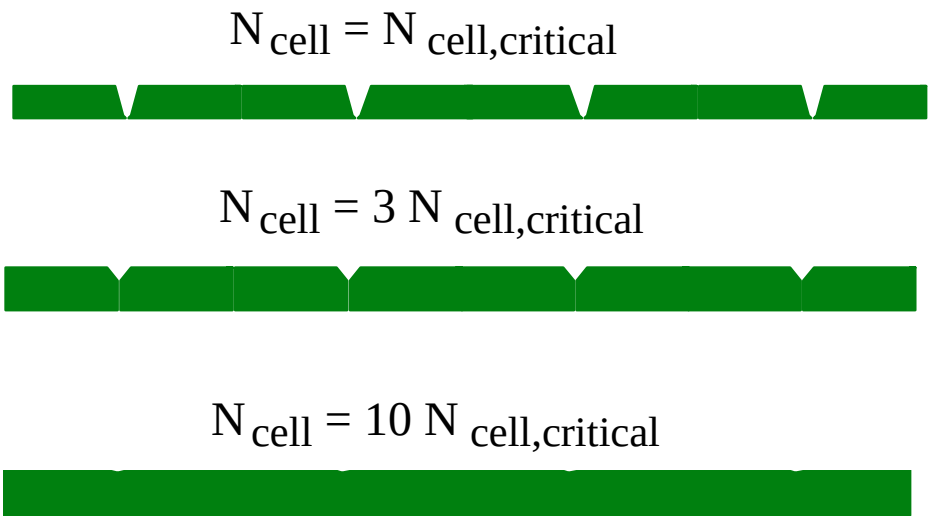

Fig. 3. Anti-correlation wave function $g(\mathbf{r}_{12})$ for 3 values of N_{well}. The minimum that occurs at each $\mathbf{r}_{12} = 0$ modulo a Bravais lattice vector is called a cusp because the minimum point is a point at which there is a discontinuity in deuteron momentum (the direction reverses). $g(\mathbf{r}_{12})$ is called a cusp function. For $N_{well} < N_{well,minimum}$, the cusp depth extends below zero, with the result that the wave function solution becomes invalid. The 2-deuteron system reverts to molecule form.

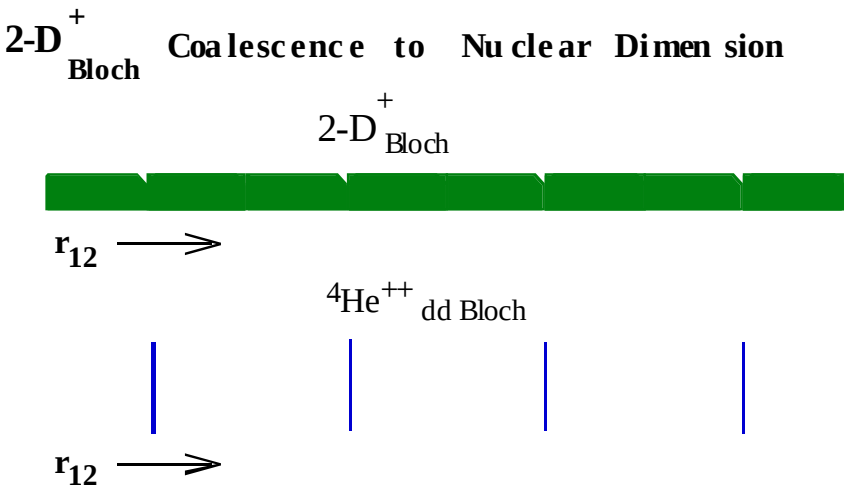

Fig. 4. When cold fusion occurs, the cusp function transitions from a normalized anti-correlation function that preserves the dd spatial separation spread-width at a value matching potential well diameter, modulo a Bravais lattice vector, into a form where separation spread-width equals a nucleus diameter, modulo a Bravais lattice vector. The shrinkage is called coalescence. During energy transfer, the 2-deuteron system can be in a mixed quantum state in which the fraction of time spent in the coalesced form increases until it becomes the metastable final state $^4He^{++}$dd Bloch. A subsequent mixed quantum state transition involving fluctuations in N_{well} changes $^4He^{++}$dd Bloch into $^4He^{++}$Bloch, which is the partitioned alpha particle form.

nucleus to become mobile, expand, and migrate so as to minimize total system energy by becoming partitioned into a maximally large effective number of potential wells, as described in Paper II. Interestingly, this behavior is needed to explain Iwamura's observations of 2-alpha-addition transmutations involving protruding surface atoms. Also, there is a second cold-fusion related process demanding explanation. Electrolysis-associated MeV particle showers originating in some sort of source suspended in electrolysis off-gases have been repeatedly observed by Oriani using CR-39 particle detectors. Coherently partitioned nuclei provide the essential starting point for understanding these showers, as described in Paper III.

BLOCH ION HAMILTONIAN

A first approximation to the Hamiltonian $\boldsymbol{H}_1$ describing a spin-zero positive-parity 2-deuteron model of the F-P cold fusion process describes the coordinate-exchanged dd pair as a 6 degree-of-freedom double ion in which the dependency on lattice space (physical space) $\{\mathbf{r}\}$ is separable from the dependency on internal space (separation space) $\{\mathbf{r}_{12}\}$. This Hamiltonian includes no explicit coupling between the nuclear configuration and the hosting metal lattice. The dressed double-deuteron is treated as a subsystem of the hosting crystallite.

$$\boldsymbol{H}_1(\mathbf{r},\mathbf{r}_{12}) \cong \left\{-\frac{\hbar^2}{4m_d}\nabla^2 + (2e)\,U_{lattice}(\mathbf{r}, N_{well})\right\} +$$

$$\left\{-\frac{\hbar^2}{m_d}\nabla_{12}^2 + \sum_{\substack{j=1 \\ \text{coherent} \\ \text{volume}}}^{N_{well}} e^2/(N_{well}^2\,|(\mathbf{r}_{12} + \mathbf{R}_{12j})|) + E_{nuc}(\mathbf{r}_{12})\right\} \quad . \quad (1)$$

Here the first bracket is the Schrodinger Hamiltonian for a mass-4, charge-2 ion in the external potential field of a metal lattice. The coordinate-exchanged double-deuteron is treated as a single particle of mass = 2 m_d. $U_{lattice}(\mathbf{r}, N_{well})$ describes a dressed lattice potential in which the double-deuteron is embedded. In this paper, the lattice potential is assumed to be periodic over an interface layer volume one layer thick covering an array area containing N_{well} potential wells. Dressing is an implicit coupling between the 2-ion system and the lattice, since there are no potential wells unless the lattice electron charge redistributes itself so as to lower the energy of the combined lattice+ion system. The second bracket is the Schrodinger Hamiltonian for two mass-2, charge-1 particles relative to their center of mass. The Hamiltonian calculates kinetic energy using the reduced mass of the 2 equal-mass deuterons, which is $m_d/2$. The second term within the bracket calculates the dd Coulomb repulsion work in accord with double Bloch symmetry. The interaction potential is calculated for the work done in each unit cell as the coherently partitioned charge fractions are brought together so as to reduce the $\mathbf{r}_{12}$ separation. Coherency requires that the work done in each unit cell be summed so as to give the total work involved in reducing $|\mathbf{r}_{12}|$. The summed work = $e^2/(N_{well}\,|\mathbf{r}_{12}|)$. The nuclear potential term $E_{nuc}(\mathbf{r}_{12})$, which is negative, reflects the contact nature of the strong interaction. It contributes (negatively) to subsystem energy once the separation $|\mathbf{r}_{12}|$ is reduced to twice the deuteron radius. At this point the Coulomb+nuclear force is attractive for a spin-zero double-deuteron (which has symmetric coordinate-exchange symmetry)[2], and there is no barrier to fusion into a coalesced coordinate-exchanged dd nuclear configuration.

A second approximation to the Hamiltonian adds the effect of having a Bloch-sensitive nucleus final state. The coalesced double deuteron is a Bloch-sensitive nucleus. The work done in bringing 2 deuterons to nuclear contact depends on the degree of partitioning, as designated by N_{well}. This means that the energy level of the coalesced product nucleus is a function of N_{well}. The second approximation Hamiltonian $\boldsymbol{H}_2$ is

$$\boldsymbol{H}_2(\mathbf{r},\mathbf{r}_{12}) \cong \{-\frac{\hbar^2}{4m_d}\nabla^2 + (2e)\,U_{lattice}(\mathbf{r}, N_{well})\} +$$

$$\{-\frac{\hbar^2}{m_d}\nabla_{12}^2 + \sum_{\substack{j=1 \\ \text{coherent} \\ \text{volume}}}^{N_{well}} e^2/(N_{well}^2\,|(\mathbf{r}_{12} + \mathbf{R}_{12_j})|)\} + E_{nuc}(\mathbf{r}_{12}, N_{well}(\mathbf{r}))\,. \quad (2)$$

This Hamiltonian couples the $\mathbf{r}$ and $\mathbf{r}_{12}$ dependencies. It provides an explicit coupling between the hosting lattice and the double-deuteron nuclear configuration.

INTERMEDIARY BLOCH-SENSITIVE NUCLEUS

The immediate (direct) coalesced double-deuteron nuclear product does not have the alpha particle nuclear configuration. The alpha particle configuration involves the attraction between spin-paired coordinate-exchanged protons and spin-paired coordinate-exchanged neutrons, rather than the attraction between spin-zero coordinate-exchanged deuterons. The F-P fusion reaction can be viewed as a 2-step reaction. The first step starts with a spin-zero double-deuteron 2-D^+_{Bloch} and ends with a spin-zero coalesced double-deuteron $^4He^{++}_{dd\ Bloch}$ intermediate state. There is no change in coordinate exchange. The second step is a change from the coalesced $^4He^{++}_{dd\ Bloch}$ intermediate state to the Bloch alpha configuration $^4He^{++}_{Bloch}$, in which the 2 protons are coupled by coordinate exchange and the 2 neutrons are coupled by coordinate exchange. The $^4He^{++}_{dd\ Bloch}$ designates an intermediary Bloch-sensitive nucleus, while final product $^4He^{++}_{Bloch}$ is not Bloch sensitive.

The last term in $\boldsymbol{H}_2$ describes an explicit coupling between the intermediary nuclear state and the lattice. The lattice parameter N_{well} in $\{\mathbf{r}\}$ affects the Gibbs free energy of the nucleus $^4He^{++}_{dd\ Bloch}$. Reversibility requires that the structure of the nuclear state in $\{\mathbf{r}_{12}\}$ affects the lattice potential $U_{lattice}(\mathbf{r}, N_{well})$ in$\{\mathbf{r}\}$. The last term in $\boldsymbol{H}_2$ is the Bloch-sensitive nuclear strong force term

$$E_{nuc}(\mathbf{r}_{12}, N_{well}(\mathbf{r})) = E_{nuc,strong}(\mathbf{r}_{12}) - \int_{|\mathbf{r}_{sc}|}^{2r_d} \frac{e^2}{|\mathbf{r}_{12}|\,N_{well}}\, d\,|\mathbf{r}_{12}|\ ,$$

where $\mathbf{r}_{sc}$ is the screening radius and r_d is twice the nuclear radius of the deuteron. The integration limit $|\mathbf{r}_{sc}|$ expresses imperfect dressing caused by the mismatch between the deBroglie wavelength of the electron and the deBroglie wavelength of the deuteron. It is a lattice parameter whose value is determined by energy minimization of the combined double-deuteron Bloch function and the many-body lattice system. For the non-ideal case (e.g.,

imperfect lattice) not all potential wells will have the same weight, so N_{well} should be considered an effective number of potential wells, and not necessarily an integer. The integral is the work required to bring the coherently partitioned nucleus into nucleus-nucleus contact. The subscript "nuc,strong" emphasizes that the weak force plays no role in the cold fusion nuclear interaction.

COUPLING TO THE LATTICE

The coupling mechanism between $\{\mathbf{r}\}$ and $\{\mathbf{r}_{12}\}$ involves the parameter N_{well}, which determines the surface area of the double-deuteron subsystem. In other words, N_{well} determines the circumference of the planar double-deuteron nucleus. Without the nucleus-lattice coupling in $\{\mathbf{r},\mathbf{r}_{12}\}$ the circumferential boundary is determined by electrostatics involving the initial hosting crystallite, which is part of the multi-crystallite hosting metal. When the double-deuteron is in coalesced form (fusion product form), the Gibbs free energy of the hosted Bloch-sensitive nucleus decreases with increasing N_{well}. This decrease in free energy powers an increase in the area of the locally-periodically-ordered portion of the metal's surface layer, in a manner that matches the periodicity of the central portion of the periodically ordered sub-region, where the $^4He^{++}{}_{dd\ Bloch}$ was formed. During nucleus expansion, work is done on the multi-crystallite metal lattice, while the combined lattice-nucleus system goes to a lower energy level.

Ignoring the possible role of resonance, it seems likely that the dd cold fusion reaction is not a simple single-step transition. During energy transfer to the lattice, the double-deuteron may exist transiently in a mixed quantum state $2\ D^+{}_{Bloch} \leftrightarrow {}^4He^{++}{}_{dd\ Bloch}$. The mixed quantum state fluctuates between the initial eigenstate $2\ D^+{}_{Bloch}$ and a coalesced virtual state $^4He^{++}{}_{dd\ Bloch}$. (A virtual state can violate conservation of energy by $|\Delta E|$ for time Δt such that $|\Delta E|\ \Delta t \sim \hbar$.) Fluctuations in effective N_{well} scatter lattice electrons or generate phonons at the subsystem boundary, which is measured as the locus of classical turning points. Energy transfers result in the metastable state designated $^4He^{++}{}_{dd\ Bloch}$. Completion of the fusion reaction requires a second step. The second reaction step transitions $^4He^{++}{}_{dd\ Bloch}$ into the Bloch form of the partitioned alpha ground state $^4He^{++}{}_{Bloch}$ ($^4He^{++}{}_{Bloch} \equiv alpha_{Bloch}$). This second step is also not a single-step transition. It involves a second mixed quantum state $^4He^{++}{}_{dd\ Bloch} \leftrightarrow {}^4He^{++}{}_{Bloch}$, which fluctuates between the Bloch coalesced double deuteron and the Bloch alpha configuration. Again, fluctuations in effective N_{well} scatter lattice electrons or generate phonons at the "N_{well}" boundary. Since the Bloch alpha product is not directly formed by forcing 2 deuterons together, the $^4He^{++}{}_{Bloch}$ ($\equiv alpha_{Bloch}$) is not a Bloch-sensitive nucleus. Its energy level is independent of the Coulomb work carried out in the initial forced coalescence of the spin-zero dd pair. As a result, the ground state energy level of $^4He^{++}{}_{Bloch}$ is the same as that of the ordinary doubly-ionized helium ion $^4He^{++}$. Hence $^4He^{++}{}_{Bloch}$ is not Bloch-sensitive.

Summarizing the above picture, and remembering that $d \equiv D^+ \equiv {}^2D^+$, the F-P reaction is

$$2\ D^+{}_{Bloch} \leftrightarrow {}^4He^{++}{}_{dd\ Bloch} \leftrightarrow {}^4He^{++}{}_{Bloch} \equiv alpha_{Bloch} \quad , \qquad (3)$$

where reversibility is converted to irreversibility by energy transfers to the metal lattice at the dd subsystem boundary. The symbol $\leftrightarrow$ signifies fluctuations occurring while in a mixed quantum state, which can be treated as a virtual state. The $^4He^{++}{}_{dd\ Bloch}$ state is a Bloch-sensitive state, whereas the initial and final states are ordinary stationary states of Schrodinger quantum mechanics.

REACTION RATE CALCULATION

Let us now consider the F-P reaction rate problem. The reaction rate physics that makes F-P fusion possible recognizes that nuclear force is a contact force. The reaction rate calculation is based on the Fermi Golden Rule for calculating time-dependent perturbation of a stationary state configuration. Wave function overlap is required for fusion to occur. The reacting deuterons must share some common volume of space, and the initial state wave function must also share a common volume of space with the final state wave function. The condition that normally prevents this from happening is a zone of exclusion, caused by inadequate electron screening. The inadequate screening prevents deuteron(1) from contacting deuteron(2). This zone of exclusion vanishes if the charge repulsion between the 2 deuterons is sufficiently reduced. This reduction occurs if one or both of the deuterons is coherently partitioned into a sufficiently large number of pieces. The second overlap requirement, namely, the sharing of space between the initial and final states, introduces a very small number into the reaction rate calculation. This small number is about 10^{-15}. It is the volume ratio between the volume of the product nucleus and the volume of the pre-coalesced 2-deuteron system. This small overlap occurs in $\{\mathbf{r}_{12}\}$. The overlap in $\{\mathbf{r}\}$ is unity, due to coordinate exchange, which in the large N_{well} configuration considered, causes the 2 Bloch deuterons to "sit on top of each other". The reaction takes place at N_{well} locations in $\{\mathbf{r}_{12}\}$, and at the continuum of points which contribute deuteron density in $\{\mathbf{r}\}$. The small volume ratio in $\{\mathbf{r}_{12}\}$ is what keeps the nuclear reaction rate small and what makes the F-P fusion process intrinsically relatively safe. The Fermi Golden Rule equation includes a summation over final states. As applied to the nuclear reaction step, there could be a single final nucleus state. However, a modeling of Oriani's observations of anomalous cold-fusion related MeV-energy particle showers suggests that there could be a large density of nucleus final states, describing a range of vibrationally excited nuclear excitations.[7,8]

The reaction rate calculations apply to spin-zero double-deuteron pairings, and to deuterons in both 2-dimensional and 3-dimensional symmetry Bloch configurations. The feedstock reactive component is best thought of in terms of a multiply-occupied ion-band state, i.e., as a many-body Bloch system in which individual D^+ quasiparticles are simultaneously partnered with all the other D^+ quasiparticles in a reactive subsystem.[1] The spin-zero pairings are 1/3 of the total pairings.[2] (There is another 1/3 of total pairings that has symmetric coordinate-exchange symmetry and non-zero spin, and a final 1/3 which has anti-symmetric coordinate exchange symmetry, so that amplitude $\rightarrow 0$ as $\mathbf{r}_{12} \rightarrow 0$.)

In this picture the reaction rate per subsystem for large and small subsystems is the same at equal Bloch-deuteron concentration D^+_{Bloch}/Pd. The subsystem reaction rate varies with concentration as $(D^+_{Bloch}/Pd)^2$. In F-P cold fusion most of the deuterons in PdD_x are non-Bloch deuterons and are not part of the reactive subsystem. Because small and large subsystems have equal reaction rate at the same D^+_{Bloch}/Pd as long as $N_{well} >> N_{well,critical}$, this picture leads to the recommendation that "small crystals are better". Crude calculations assuming

3-dimensional periodic symmetry, such as might exist in PdD_x at large loading where $x \sim 1$, indicate that the reaction rate can provide cold fusion power in the observed range.

ROLE OF RESONANCE

X-Z Li has pointed out that resonance (no change in system energy) can play a major role in cold fusion reactions.[9] The existence of Bloch-sensitive nuclei, whose energy level varies with the degree of partitioning as measured by N_{well}, makes the occurrence of resonance a likely phenomenon in cases where a non-partitioned reaction product would be moderately endothermic. This situation seems to apply to the fusion of Bloch alpha-particles, as addressed in Paper III. An increase in N_{well} makes the reaction increasingly exothermic. If the endothermicity of the non-partitioned reaction is not too high, at some value of N_{well} the heat of reaction passes through zero. Since lattice imperfections affect the effective N_{well}, and since the effective N_{well} need not be integer, a relatively precise matching of the resonance condition seems possible, in part due to the many internal nuclear vibration,rotation excited states[8] that may be present.

Li 's resonance picture was developed to explain tunneling through a Coulomb barrier for deuterons in a side-by-side molecule-like geometry. In this paper we are discussing the coherently-partitioned Bloch configuration where deuterons are superposed and there is no Coulomb barrier. A coherently-partitioned configuration is required for the existence of Bloch-sensitive nuclei. When there is no Coulomb barrier, the resonance can be broad and is better thought of as a Feshbach resonance. In a Feshbach resonance a transition occurs between equal-energy states with different configurations, such as occurs when an atom Bose condensate switches into a molecule-like Bose condensate form.[10]

The occurrence of nuclear resonance would mean that an initial nuclear reaction could occur without need for "instantaneous" energy transfer to the lattice. During resonant nuclear fusion transitions, an energy transfer process acting on a non-nuclear slower time scale could make the initial interaction irreversible. As a result, potential impediments to fusion due to a difference in the time scales of the nuclear part of the reaction relative to that of an electromagnetically-coupled energy transfer step are avoided. In accord with the 2-step process applied to the deuteron fusion case, slower sequential electromagnetic-time-scale energy transfer fluctuations of a mixed quantum state can transition the deuteron subsystem into the partitioned metastable form $^4He^{++}_{dd\ Bloch}$. The energy transfer process partially stabilizes the intermediary $^4He^{++}_{dd\ Bloch}$ Bloch-sensitive nucleus. Similar energy transfer fluctuations can transition $^4He^{++}_{dd\ Bloch}$ into $^4He^{++}_{Bloch}$ at the electromagnetic rate. These slower transfers of energy, which involve mixed quantum states, occur in response to fluctuations in N_{well}, completing the transition from $^4He^{++}_{dd\ Bloch}$ to $^4He^{++}_{Bloch}$.

ALTERNATIVE PICTURE BASED ON FESHBACH RESONANCE

There is an alternative modeling of the role of Feshbach resonance in F-P cold fusion. The energy level of the intermediate fusion state $^4He^{++}_{dd\ Bloch}$ is subject to large predissociation broadening, because of the near identity of its structure with that of the "un-coalesced" (dissociated) state $2\text{-}D^+_{Bloch}$. If the life time of the $^4He^{++}_{dd\ Bloch}$ state is 10^{-22} s, the broadening extends the wings of the resonance peak so as to include the energy levels of both the un-coalesced initial state $2\text{-}D^+_{Bloch}$ and the coalesced final state $^4He^{++}_{Bloch}$ state, even

though these states are separated by 24 MeV. Predissociation broadening of a nuclear energy level has proved important in modeling Oriani showers, as discussed in Paper III. Fluctuations in the energy level of the intermediate state $^{4}He^{++}_{dd\ Bloch}$ means fluctuations in the double-deuteron's value of N_{well}, which means fluctuations in the circumference boundary of the 2-deuteron subsystem, which means fluctuations are imposed on the hosting lattice. The fluctuations span a large range of time scales. The slower fluctuations (possibly as groups of fast fluctuations) can be expected to scatter electrons or generate phonons at the circumferential boundary, resulting in energy transfer. The situation is the reverse of that encountered in the Oriani shower problem, where Brownian-motion type energy transfers play a key role. As the energy transfer process proceeds, the resonance peak moves toward the energy level of $^{4}He^{++}_{Bloch}$. Since the process is enabled by a Feshbach resonance, the change in structure from spin-paired deuteron to alpha configuration is allowed.

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