

Many-Centers Nuclei

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— ABSTRACT —

The goal of this paper is to convince nuclear physicists that cold fusion is not blocked by the Coulomb barrier of molecular physics. When periodicity dominates the environment seen by a test particle, the controlling physics changes. The test particle assumes the properties of a Bloch state. When the test particle is an electron, the Coulomb repulsion between paired Bloch state electrons with $0+$ symmetry effectively vanishes, leading to fermi sea behavior in metals, and to quasiparticle electronics in semiconductors. When the test particle is a deuteron, the Coulomb repulsion between paired Bloch state deuterons with $0+$ symmetry is replaced by anti-correlation, allowing dd fusion in an exothermic $0+ \rightarrow 0+$ reaction.

INTRODUCTION

This paper argues that deuterons in quasiparticle configuration can fuse to form ${}^4\text{He}$ in a symmetry-preserving many-centers nuclear reaction. Nuclear physics is a complex subject. It is not just the high energy impact physics of the atomic bomb, and not just the impact physics of beam scattering experiments. The physics of Fleischmann-Pons (F-P) cold fusion¹ is not the physics of plasma fusion, and not the physics of the sun, where energetic impacts between hot ions result in a real but low rate of nuclear reaction. Instead, it is the quantum physics of an electron traffic jam.

The motion of electrons in a metal are blocked like cars in an interstate traffic jam. However, instead of a few thousand cars stacked together in zero motion, electrons are faced with billions of metal atoms blocking their motion in all three dimensions. Nonetheless, electrical currents flow. The “electrons” that conduct electricity in wires and make modern electronics possible have configured themselves into a geometry that conforms with the crystal lattice. In this new configuration they are called quasiparticles and have Bloch-function wave functions. Metal physics is made possible by quantum-of-mass malleability. Understanding this malleability is a first step towards understanding radiationless cold fusion.² This gentler physics is important. It promises cold fusion energy for heating our houses and powering our cars.

The most troublesome obstacle to understanding how radiationless cold fusion works is the Coulomb barrier. Many people think that the repulsive force between charged-particle pairs must inevitably keep them from making mutual physical contact. This view is incorrect, markedly so for electrons. The view that paired deuterons can never make mutual contact is difficult to dispel. Paired deuterons must make mutual contact if dd fusion is to occur. Nuclear contact is guaranteed if the wave functions of paired deuterons mutually overlap each other. Overlap is ensured if a two-deuteron wave function has a positive value at zero separation. In single-center nuclear physics overlap transiently occurs in high energy dd collisions, and would continuously occur if neutron star densities could be achieved by deuterons dissolved in a metal. However, we know that high density fusion is not part of F-P fusion, since pure F-P cold fusion is radiationless. Muon-catalyzed cold fusion is a form of high density fusion.³ It produces copious radiation which is not seen in F-

P fusion.

This paper explains how dd overlap can occur if deuterons achieve a geometric form resembling that of electrons in a metal, as postulated in the Ion Band State model.⁴⁻⁶ The challenge is to make it clear that the mutual dd overlap picture is consistent with known physics.

APPLICABLE QUANTUM MECHANICS

The Physics Argument Against Wave Function Overlap

It is well known that the Coulomb barrier prevents dd fusion in normal D_2 molecules. In the D_2 molecule the two deuterons share a common potential well provided by a zero-spin pair of electrons. In the molecule the repulsion between these side-by-side $\text{D}+$ ions splits the potential well and keeps each deuteron in its own separate well. Quantum mechanics allows tunneling through the barrier between deuterons. However, the barrier is so high that quantum tunneling is infinitesimal on the time scale of the Universe. Leggett and Baym⁷ showed that having side-by-side point-particle deuterons in a solid does not alter this conclusion. Furthermore, attempts to lower the barrier height by creating abnormally high electron charge density in the region covering the two deuterons is not possible at metal density. Pauli exclusion (Part 1 of the Pauli principle) says that electrons “fill up space,” which limits the electron density to values too low to be helpful. Attempts to overcome the barrier by high-energy kinetic vibrations or other motion involving neighboring deuterons in a solid is also unphysical at solid phase temperatures. There is a strong basis in physics for the skepticism that nuclear physicists and other competent scientists feel towards the possibility of cold fusion.

However, the Leggett and Baym argument against F-P cold fusion is negated by caveats included in their paper. They state that they specifically exclude “an exotic mechanism relying on coherence between fusion processes involving different deuteron pairs.” This is a fancy way of saying that they are excluding the deuteron Bloch states and related physics which allow F-P cold fusion to occur. Instead, they carefully examine the tunneling process of molecular quantum mechanics that applies to side-by-side cold fusion, but which does not apply to a many-centers environment. They

specifically exclude the Bloch 0+ geometry that makes F-P fusion possible.

Nuclear Physics Requires Quantum Mechanics

Nuclear physics, like the microphysics of atoms and molecules, is understandable only in terms of quantum mechanics. Nuclear physics started with scattering experiments, where energetic protons and alpha particles scattered off target nuclei. These bullet-like studies involved directed particles hitting nuclei at various miss distances, parameterized by an impact parameter. Sometimes no scattering occurred, sometimes simple elastic scattering collisions occurred, sometimes an unstable composite nucleus was formed. Often a transient composite nuclear product decayed, creating a transmuted nucleus. When the impact parameter was zero, no angular momentum was imparted to the product nucleus. At positive impact parameter, a transient nucleus was created with orbital angular momentum added to the original nucleus. In this impact nuclear physics, input and target are modeled in a moving coordinate system in which the center-of-mass of the target and bombarding particle are at rest. At separation distances substantially greater than nuclear dimension both target and bombarding particle are modeled as converging collinear traveling plane waves, in accord with the dictates of quantum mechanics. After collision both recoiling target and scattered particles are modeled as diverging plane waves. At the instant of collision, if a transmutation occurs, there is a compound nucleus which exists transiently at a single high-mass-density center, *i.e.* at the center-of-mass of the two-particle system.

The Coulomb repulsion between converging incoming charged "particle" and initial charged nucleus is described by a classical single-center point-particle potential-energy-density function proportional to $1/r$. This potential energy density function is part of the total energy density function used in a Schrodinger-type wave equation. Wave function solutions to the wave equation are sought using a set of functions whose sum expresses incoming and outgoing plane waves. The Coulomb repulsion between input and target "particles" greatly reduces the cross section for nuclear reaction. The factor that expresses the extent to which the Coulomb repulsion reduces reaction cross section has become known as the Gamow factor.⁸

Quantum Mechanics as an Abstract Science

The title of this paper is "Many-Centers Nuclei." The title needs to be interpreted abstractly, just as the motions dictated by quantum mechanics need to be visualized abstractly. F-P cold fusion is a quantum mechanics phenomenon. Quantum mechanical motions are not compatible with the behavior of solid objects as described by classical physics. But they correctly describe the microscopic world. Here we work with the simplest "non-relativistic" quantum mechanics of Planck, Heisenberg, Bohr, and Schrodinger, and not the more general relativistic quantum electrodynamics. When we look at the motions of diatomic molecules, the abstract picture provided by quantum mechanics is that of a dumbbell simultaneously tumbling about two mutually orthogonal axes at different frequencies. This is not the motion of a classical dumbbell as described by Newtonian mechanics. Instead it describes simultaneous tumble motion about two orthogonal axes and expresses kinetic energy

simultaneously present in two different degree-of-freedom excitation states. "Visualizing" a dumbbell simultaneously tumbling about two orthogonal axes at different rates is the type of abstract thinking one must accept. It seems to violate common sense, yet it nonetheless describes microsystem reality. It is necessary to use this abstract way of thinking to understand why F-P cold fusion can take place.

Quantum Mechanics as an Axiom-Defined Protocol

Quantum mechanics is generally taught as an axiom-defined protocol that models microsystems in a manner that agrees with experiment. Students of quantum mechanics are challenged to organize their thinking to conform to the reality which experiment and the axioms of quantum mechanics impose. Quantum mechanics teaches that the microscopic world is subject to limitations in system behavior as expressed in the Heisenberg uncertainty relations involving position and momentum, and energy and time. Position is uncertain when momentum is well defined. Energy is uncertain when time is accurately defined. The energy-time uncertainty says that conservation of energy can be violated for short intervals of time. In practice, states violating conservation of energy for short time intervals exist and are called virtual states.⁹ The state of a system is determined by its history and environment, as described by a wave function. The uncertainty principle limits the precision of this description. Degrees-of-freedom and symmetries play essential roles in this somewhat abstract quantum world. In the simplest quantum mechanics, this abstract behavior is expressed in the wave function of a stationary state, where the wave function implicitly contains a full description of the steady-state system being studied. The wave function in turn is determined by the wave equation. The equation and its solution, coupled together, equally define a system modeled to conform to a specified environment. The quantum world is sometimes simpler than that imposed by the unending detail needed to rigorously describe the macroscopic Newton-Maxwell world. The quantum world is what agrees with experiments testing microscopic world behavior.

So what are the axioms that guide stationary state quantum mechanics? First, the connection between environment and embedded system are modeled by a combined wave equation + wave function. The modeling includes rules by which the wave equation is written, plus constraints which must be imposed on wave-function solutions. A stationary state wave equation equates an expression for total system energy expressed in terms of momentum and position with an allowed constant value E . Momentum and position are treated as mathematical operators. The momentum variable is expressed as a differential operator which operates on the system wave function. The solution mathematics is that of eigenfunctions and eigenstates. For stable bound systems, solutions of the wave equation exist only for a set of discrete energy values E_i , which are the so-called eigenvalues. The lowest energy eigenvalue is the energy of the system ground state, and the corresponding wave function describes the ground state spatial density distribution to the extent that physics allows. The mathematics of eigenfunctions says that among a family of functions that obey the symmetry constraints imposed by environment geometry, the trial function that gives the lowest expectation value for system energy $\langle E \rangle$ when substituted into the wave equation is the best

approximation to the system ground state. Variational physics selects the best ground-state wave function.¹⁰

Reaction physics requires either a two-particle or multi-particle wave function. The main constraint on multi-particle wave functions is the Pauli principle, as applied to wave functions containing two or more “particles.” It applies to paired particles, or pairings of particles, but only when the particles are both of the same type, *e.g.*, “indistinguishable” electrons. As concerns this paper, it says that a zero orbital angular momentum many-body wave function, written as the product of single particle wave functions with half integer spin (like electrons), must be an anti-symmetric product of spatial and spin functions. The Pauli principle is best thought of as a two part constraint. Part 1, called the Pauli exclusion principle, says that if spin factors don’t cancel, the spatial part of the wave function must be anti-symmetric; Part 2, called a requirement for coordinate exchange symmetry, says that if spin factors do cancel, the spatial wave function must be symmetric. In essence, Pauli 1 says spin 1/2 particles take up space unless spin-paired with an indistinguishable partner. Pauli 2 says that when a spin 1/2 particle is spin-paired with an indistinguishable partner, it can share space with its partner, but the paired entity must be spatially symmetric.

2-body Wave Functions: Equivalence of 0+ and ¹S₀ Symmetry

The constraint to which spin-zero wave functions must conform is a requirement for coordinate exchange symmetry (Pauli 2) that the wave function must satisfy. The existence of this constraint tells us something fundamental about the nature of matter. It says that the spin-zero two-particle entity is a spatially symmetric entity in the quantum mechanics sense. This type of pair symmetry is called “positive parity” and designated 0+. For zero angular momentum systems, it describes the same symmetry that atomic physics designates ¹S₀. (The atomic physics designation means: innermost shell, Singlet state with zero orbital angular momentum, and zero spin.) Nuclear physicists use the designation 0+.

The exchange symmetry constraint plays a role in current nuclear physics. A 2006 nuclear physics paper by Negret *et al.*¹¹ describes an impact deuteron beam study in which a high energy impacting deuteron d is converted into a product high energy ²He nucleus, which in turn converts into two protons in an entangled ¹S₀ state. The primary reaction involving ²He is designated ¹⁴N(d,²He)¹⁴C. The ²He nucleus has 0+ symmetry, which is conserved throughout the measurement process up to the detection of the two separating protons. Heyde’s 1994 nuclear physics textbook designates these 0+ → 0+ reactions as E₀ reactions.¹² The Negret *et al.* study is important to this many-centers paper because it demonstrates the equivalence of 0+ and ¹S₀ symmetries, and because it shows that symmetry is preserved during a density change from nuclear density to laboratory vacuum.

NO ee COULOMB BARRIER IN THE HELIUM ATOM

2-body Wave Functions, Hartree Wave Functions, and Configuration Coordinates

Quantum mechanics atomic physics began with a modeling of the hydrogen atom, which is a single electron in the central Coulomb field of a much heavier nucleus. This is a single-center problem. The calculated wave function is that of a

single particle in a spherically symmetric potential well of 1/r potential. The Schrodinger formulation of this problem was an outstanding success. This atomic model appealed to Bohr more than the earlier, less visual modeling by Heisenberg.

The next axiom-based step in theory development involved consideration of the helium atom, with its two electrons. A standard approach to modeling uses a two-electron wave function,

$$\Psi(\mathbf{r}_1, \mathbf{r}_2) = \phi_1(\mathbf{r}_1) \phi_2(\mathbf{r}_2) , \quad (1)$$

where $\Psi(\mathbf{r}_1, \mathbf{r}_2)$ is a six degree-of-freedom function, and $\phi_1(\mathbf{r}_1)$ and $\phi_2(\mathbf{r}_2)$ are independent three degree-of-freedom wave functions.¹³ This representation of $\Psi(\mathbf{r}_1, \mathbf{r}_2)$ is called the “configuration coordinate” representation.¹⁴

Use of a 1/r potential is inadequate in that it does not include the effect of the distributed charge density of electron₂ on the potential seen by electron₁. In a step toward greater realism, the central field seen by electron₁ was assumed to be not just the central field of the helium nucleus, but a field that included the effect of the average distribution of charge density of electron₂. This average potential also has a spherical distribution. Similarly, electron₂ was assumed to see the same modified potential as encountered by electron₁. More generally, a many-body wave function built from one-electron wave functions in which each one-electron function sees a potential modified by the average charge distribution provided by all the other electrons, is called a Hartree function.¹³

Fundamentally, Equation 1 is inadequate as applied to ground state helium because it neglects the 0+ symmetry requirement that is required for spin-zero paired electrons in a common state, in accord with coordinate exchange symmetry (Pauli 2). No sum over Hartree functions can replace this requirement. In order to meet the axiom-dictated requirement for a zero-spin pair, $\Psi(\mathbf{r}_1, \mathbf{r}_2)$ must have a form equivalent to

$$\Psi(\mathbf{r}_1, \mathbf{r}_2) = 1/\sqrt{2} [\phi_1(\mathbf{r}_1) \phi_2(\mathbf{r}_2) + \phi_1(\mathbf{r}_2) \phi_2(\mathbf{r}_1)] . \quad (2)$$

Equation 2 defines coordinate exchange symmetry as applied to two-particle spin-zero systems.¹³ Only a sum over functions, each of which has coordinate exchange symmetry, can approximate a realistic helium ground state.

Hylleraas was the first person to successfully model the two-electron helium ground state problem. He used elliptical coordinates. His success was made possible by his requiring that his two-electron wave function have coordinate exchange symmetry, as expressed in Equation 2. He used energy-minimizing variational physics to obtain solutions of ever increasing accuracy, eventually achieving a wave function that calculated the ground state energy to an accuracy of better than five significant figures. None of his trial functions has the mathematical form of a Coulomb barrier separating two side-by-side electrons. Instead, each two-electron trial wave function has a positive amplitude at zero electron-electron separation. The amplitude is smaller when the electrons are envisaged as sitting on top of each other than when sitting on opposite sides of the helium nucleus. This behavior expresses electron-electron anti-correlation. *There is no Coulomb barrier.* The Hylleraas wave function solution means that if the electrons had the nuclear properties of

deuterons, they would fused.¹⁴

Center-of-Mass, Separation Coordinates and 0+ Symmetry

One way of guaranteeing coordinate exchange symmetry and 0+ geometry is to write Ψ in terms of center-of-mass, separation coordinates $\{\mathbf{r}_{cm}, \mathbf{r}_{12}\}$, where

$$\Psi(\mathbf{r}_{cm}, \mathbf{r}_{12}) = \phi(\mathbf{r}_{cm}) g(\mathbf{r}_{12}) \quad (3)$$

and

$$\mathbf{r}_{cm} = \frac{\mathbf{r}_1 + \mathbf{r}_2}{2}; \quad \mathbf{r}_{12} = \mathbf{r}_1 - \mathbf{r}_2,$$

and \mathbf{r}_1 and \mathbf{r}_2 are the position vectors of the configuration coordinate representation.¹⁵ A requirement for 0+ symmetry seems to be essential in modeling F-P fusion.

AVOIDING THE dd COULOMB BARRIER USING A MANY-CENTERS GEOMETRY (quasiparticles)

Electron Quasiparticles

Electrons flowing from an electrolyte into the anode of a discharging battery are subject to a profound change in geometry. Once they enter the anode metal they are subject to a crystalline environment that imposes periodicity on each electron quantum-of-mass. The metal crystals consist of repeating structural elements (unit cells) that repeat almost indefinitely in each direction. The idealized treatment that became the foundation of solid state physics assumed an infinite array of unit cells to simplify calculations. Conduction electrons in a metal were modeled as subject to a wave equation with an unending periodic potential. The wave function solutions expressed unending periodicity. Such functions are called Bloch functions, named after Felix Bloch. In Bloch's modeling all unit cells can be considered equivalent.¹⁵ This means that when electrons are embedded in a metal, the conduction electrons see no preferred site in which to locate a single center-of-mass-density maximum.

Instead, they see an infinite number sites in which to form equivalent local density maxima, all of equal weight. *One cannot specify a preferred center-of-mass.* Figure 1 illustrates a surface array of repeating unit cells. The conduction electrons in an idealized metal conform to arrays of this type and have a many-centers geometry.

Calculations based on the Bloch model were amazingly successful in describing the properties of real metals. Even though the periodic boundary conditions employed in such calculations are topologically impossible, in practice, metals were found to behave in accord with these idealized calculations throughout a piece of bulk metal to within about two layers of the metal surface. The many-body electron calculations included the requirement that coordinate exchange symmetry be applied between all pairs of Bloch state electrons not isolated by Pauli exclusion (Pauli 1). The coordinate exchange operation mixed each entering electron with all its partners within the same volume, so as to form a many-body electron system that came to be called a fermi sea. In the process the electrons lost their individual identity. The configuration change was called second quantization. The quanta-of-mass making up the fermi sea were called quasiparticles. Each electron quasiparticle had the same charge and mass as the single-center electron that entered the metal from the battery. The modern day physics of metals and semiconductors is based on the physics of Bloch electron quasiparticles.

Finite Crystal Bloch Systems as a Many-Centers Geometry

When the idealized periodic crystal lattice is replaced by a real lattice of finite dimension, the physics changes. Embedded electrons become bounded within finite volumes. The periodic boundary conditions of the infinite lattice become replaced by mirroring boundaries that contain the electrons enclosed within the crystal. The effect of this change is small for very large crystals, but becomes increasingly important as the size of the crystal decreases. Quantum dot theory calculates effects resulting from having a relatively small number of unit cells in the crystal.

Even what is considered a small crystallite has a thousand or more equivalent unit cells. For such a crystallite there are a thousand or more equivalent centers-of-mass. The Ion Band State Theory of cold fusion is based on deuteron quasiparticles.⁴ The nuclear physics that applies to deuteron quasiparticles embedded in such a system is fundamentally different from that which applies to localized deuterons, each of which has its own identifiable single center-of-mass. This difference distinguishes the nuclear physics applicable F-P cold fusion from that which applies to plasma fusion and that which applies to beam studies using deuteride targets.

When the variational physics that solved the two-electron helium atom problem is applied to deuteron quasiparticles embedded in a metal, *there is no Coulomb barrier in the dd wave function solution if the number of occupied potential wells $N_{well} > \sim 1,000$.*²¹

Deuteron Quasiparticles in PdD_x

Most cold fusion research has made use of the metal Pd, which is a transition metal that easily absorbs hydrogen and has only a weak affinity for oxygen.

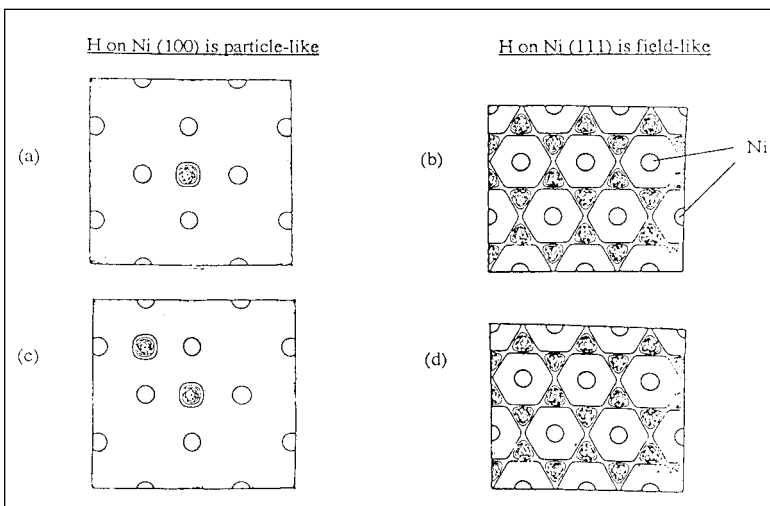


Figure 1. Based on calculations of charge density distributions of H+ on Ni surfaces by R. Nieminen.²¹ 1a shows a single-center single H+ ion on Ni (100). The site expands in response to ion occupation (self-trapping expansion not illustrated).¹⁶ 1b shows a many-centers distribution of a single H+ ion with quasiparticle geometry (Bloch state) on Ni (111). 1c shows geometry of two single-center H+ ions in nearby sites on Ni (100). 1d shows a many-centers distribution of two quasiparticle H+ ions on Ni (111).^{14,21} The 1b and 1d distributions are identical, which expresses wave function overlap.

These attributes have made it a favored metal in the development of metal hydride physics. In its pure form Pd is malleable. When Pd absorbs deuterium, its lattice distorts locally to accommodate the electron that provides neutralization of the charge associated with each absorbed interstitial hydrogen or deuterium ion.¹⁶ The process is called self-trapping. This lattice distortion impairs periodic symmetry. The distortion gives each interstitial deuteron a single-center geometry. It is considered located in specifiable unit cell. These localized interstitial deuterons are the target nuclei in dd beam impact studies using a metal deuteride target.

Under reversible equilibrium conditions at standard T and P, the composition of the palladium deuteride is about PdD_{0.65}. The deuteron fraction can be increased by use of non-equilibrium chemistry. As more deuterium is added, the PdD_x becomes increasingly brittle. As the value of x approaches 1, the periodicity of the metal deuteride lattice becomes relatively regular. At PdD_{1+δ}, where δ is a small number, the periodic lattice meets the array symmetry requirements for a many-centers geometry. The teachings of Jaksch *et al.* and Weiner *et al.* then apply.^{18,19} In accord with these teachings, almost all of the 1 + δ deuterons form a Mott insulator, and the δ-fraction forms a superfluid with Bloch function symmetry. The δ-fraction are deuteron quasiparticles. They are the reacting deuterons in dd many-center nuclear fusion reactions.

Many-Centers Geometry Reduces Coulomb Repulsion Work

The wave function physics applied to quasiparticle systems embedded in crystallites preserves periodic order. It describes a different response to the Coulomb repulsion between quasiparticle pairs than that which applies to single center-of-mass particles. The e²/|r₁₂| repulsion of a single center-of-mass two-quasiparticle system gets replaced with a sum over the repulsions contributed by each of the many-centers local mass-density maxima. The Hamiltonian for a quasiparticle system with N_{well} mass-density maxima is given below. A nuclear term is included because at sufficiently large N_{well} the reduction in dd Coulomb repulsion is large enough for system energy minimization to dictate two-deuteron wave function overlap in an anti-correlation form of wave function.¹⁵ The Hamiltonian operator is

$$\begin{aligned} \mathbf{H}(\mathbf{r}_{\text{cm}}, \mathbf{r}_{12}) \cong & \left\{ -\frac{\hbar^2}{4m_d} \nabla^2 + (2e) U_{\text{lattice}}(\mathbf{r}_{\text{cm}}, N_{\text{well}}) \right\} + \\ & \left\{ -\frac{\hbar^2}{m_d} \nabla_{12}^2 + \sum_{\substack{j=1 \\ \text{coherent} \\ \text{volume}}}^{N_{\text{well}}} e^2 / (N_{\text{well}}^2 |(\mathbf{r}_{12} + \mathbf{R}_{12j})|) + E_{\text{nuc}}(\mathbf{r}_{12}) \right\} \end{aligned} \quad (4)$$

where \mathbf{R}_{12j} is a Bravais lattice vector pointing to Bloch unit cell_j.¹⁶ The operator equation is

$$\mathbf{H}(\mathbf{r}_{\text{cm}}, \mathbf{r}_{12}) \Psi(\mathbf{r}_{\text{cm}}, \mathbf{r}_{12}) = E_i \Psi(\mathbf{r}_{\text{cm}}, \mathbf{r}_{12}),$$

where E_i is a constant which designates the energy of eigenstate_i.

The nuclear potential E_{nuc}(r₁₂) appearing in the Hamiltonian describes a coupling between the quasiparticle nucleus and the value N_{well} which parameterizes the many-centers geometry.

The behavior of embedded quasiparticles subject to a periodic potential applies to protons and deuterons when

such particles have been catalyzed to convert to Bloch geometric form.¹⁷ The physics of Bloch deuterons in a metal is the basis of the Ion Band State Theory of cold fusion.⁴⁻⁶ The reduction in dd repulsion between embedded deuterons parallels that which occurs with spin-zero electron pairs in a metal. The difference between the behavior of the nuclear potential and the electromagnetic potential is due to the contact nature of the nuclear interaction, which contrasts with the need to volume integrate over an electrostatic field to obtain the electromagnetic potential. The anti-correlation form of quasiparticle wave function opens up a new area in deuterium-based nuclear physics, just as it opened up metal electron physics during the mid-twentieth century.

F-P Fusion as a 0+ → 0+ Reaction

When paired Bloch deuterons are embedded in crystallites above a critical size, energy minimization says that they must have a Pauli-2 anti-correlation form wave function, like that of the electrons in the He atom ground state.¹⁴ This allows the strong force nuclear potential to pull pairs of quasi-particle deuterons together when spin considerations do not block the process. The converging process is called "coalescence."¹⁸ It is the reverse of the ²He expansion process described by Negret *et al.*¹¹ Spin-zero paired Bloch deuterons then stepwise coalesce into a nuclear-dimension size configuration in an exothermic process. Energy removal from the product quasiparticle nucleus preserves Bloch symmetry, and involves electromagnetic coupling to the lattice. In resonant energy transfers from a 0+ symmetry pair state, creation of excitons replaces the K-electron internal conversion of single-center nuclear physics. In addition, a coupling of nuclear-lattice phonons to metal-lattice phonons can occur.² Emission of energetic particles is blocked.

Quasiparticle nuclei can be greatly affected by their hosting lattice. During any nuclear fusion event energy is expended in pulling feedstock nuclei together to nucleus size. Coherent partitioning reduces this work energy, compared with what is required for a system with a single mass-density center. The reduction in expended work makes the Bloch geometry nucleus more stable than it would otherwise be. In other words: *The embedding environment lowers the ground state energy of a quasiparticle nucleus in a many-centers geometry.* This does not happen with a conventional single-center geometry nucleus. The amount of energy reduction depends in part on the diameter of the product nucleus, and in part on the value of N_{well}. For spin-zero deuteron pairs, the dd-pairing work reduction at large N_{well} is in 100-keV range. The same physics applies for a spin-zero proton pair, *i.e.* ²He. However, the energy reduction for a 0+ quasiparticle proton pair is in the MeV range, because of the much smaller size of an 0+ pp pair within the nucleus as compared with a nuclear dimension 0+ dd pair. It may be that the nuclear density Bloch configuration spin-zero proton pair, *i.e.* the ²He_{Bloch} nucleus, is stable, whereas the single-center ²He nucleus is unstable. An increase in stability applies to most, if not all the many-centered nuclei. This new regime of nuclear physics remains to be explored.

SUMMARY

As discussed in Chubb,² the quantum-of-mass of a test particle can have a non-point-particle geometry. When embedded in the periodic environment provided by a metal crystal

lattice, deuterons in a set of communicating potential wells can convert to a quasiparticle Bloch-function periodic geometry in which each such particle is coherently partitioned into entangled fractions. The particle density distribution describing these fractions has a local mass density maximum located in each of the equivalent potential wells provided by the metal lattice. Each local mass density maximum is an equivalent center-of-mass. The result is the creation of a new many-centers form of nucleus. In the wave function describing the set of fractions, the separate fragments of the wave function have related phase factors, *i.e.* the fragments are coherently entangled. The single-center quantum-of-mass equivalent nucleus is recovered analytically by summing over the entangled fragments. The coherent partitioning process does not change the internal structure of the quantum-of-mass, but it does reduce the effective Coulomb repulsion associated with this internal structure. This same entanglement physics describes Bose atom condensates in optical lattices.^{19,20} It underpins a new area of nuclear physics in which nuclear stability is affected by the degree of partitioning as measured by the number of occupied "equivalent" potential wells N_{well} .

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