Journal of Fusion Energy, Vol. 9, No. 4, 1990

"Cold Nuclear Fusion": A Hypothetical Model to Probe an Elusive Phenomenon

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The natural tendency of identical bosons to clump in ordinary space is ascribed to a "symmetry force," whose action is equivalent to the effects of the wavefunction for a collection of degenerate bosons. The symmetry force is hypothesized to produce clusters of deuterons in the lattice for a high enough stoichiometric ratio of deuterons to Pd atoms and to catalyze tunneling to achieve cold fusion. A semiempirical power law is derived as a function of the number of deuterons, N, in a representative cluster: for large enough N the fusion products are He^4 plus heat, while for small clusters the fusion rate is much lower and the Oppenheimer–Phillips process favors the production of tritium over neutrons. Pulsed production of heat and neutrons is suggested. Finally, three additional roles in physics for the symmetry force are hypothesized.

KEY WORDS: Cold nuclear fusion; "inclusion principle"; boson cluster model; symmetry force; tunneling.

1. INTRODUCTION

1.1. Cold Nuclear Fusion vs Hot Nuclear Fusion

Hot nuclear fusion between deuterons proceeds by brute force, with one deuteron in a high-temperature plasma having been given enough kinetic energy to go over the repulsive Coulomb barrier to reach the nuclear well of another deuteron. Cold nuclear fusion proceeds more subtly, with one deuteron undergoing the wave-mechanical process known as "tunneling" to reach the nuclear well of another deuteron. Thus, a successful model for cold nuclear fusion (hereafter: cold fusion) must, above all, account for the "catalyzing" agent that significantly enhances the probability of tunneling.

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1.2. "Boundary Conditions" for a Hypothetical Model

In addition to accounting for the mechanism enhancing tunneling through the Coulomb barrier, a hypothetical model should attempt to account for the following salient experimental features that have been reported:

(1) Production of excess heat on the order of about 10 W per cm^3 of palladium sample.[1] This is referred to as the "Pons-Fleischmann effect" (hereafer: P/F effect).
(2) "Anomalously" low neutron yields.[2]
(3) "Bursts" of neutrons.[3]
(4) "Anomalously" low γ-ray and X-ray yields.[2]
(5) Tritium production.[3]
(6) An inability to achieve the P/F effect.
(7) An inability to achieve any sort of "signature" of a nuclear reaction.

In what follows we present a hypothetical model to attempt to provide a conceptual framework in which to account for these experimental features. While our treatment is suggestive, it does not establish the validity of the P/F effect or even cold fusion at any level within a metal lattice. The model is intended to constitute a "jumping off point" for constructive dialogue and further theoretical and experimental work.

2. BOSON CLUMPING: THE "INCLUSION PRINCIPLE"

2.1. Bosons vs Fermions: Effects of Wavefunction Symmetry

Deuterium atoms (D's) entering the palladium metal lattice are stripped of their electrons to become deuterons (d's). (In this process of "chemisorption" the electrons become delocalized in the energy bands associated with the palladium metal lattice.) This transformation from fermions (D's) to bosons (d's) has potentially profound consequences due to the different symmetries of the wavefunctions: fermions have antisymmetric wavefunctions, while bosons are represented by symmetric wavefunctions. This difference in the symmetries of the wavefunctions is responsible for the radical difference in behavior of these two species of particles: identical fermions try to avoid each other, while identical bosons tend to clump together. The Pauli exclusion principle obeyed by electrons in an atom, molecule, or crystallite is a familiar example of the operation of the antisymmetry of the wavefunction for idential fermions. The counterpart for identical bosons is the "boson condensation" in phase space known as the Bose-Einstein condensation: this consequence of the fact that the wavefunction for identical bosons is symmetric is exemplified by the "superfluidity" of liquid He^4 below the lambda point (2.17 K). These opposite behaviors of fermions and bosons can be illustrated in elementary fashion by considering the well-known example of two identical particles in a one-dimensional box.

2.2. Example: Two Identical Particles in a Box

Because the two particles are identical, there are only two possible normalized wavefunctions, an antisymmetric one representing the case of two identical fermions in the box and a symmetric one representing the case of two identical bosons:

$$\psi_A = 2^{-(1/2)}[\psi_n(x_1)\psi_m(x_2) - \psi_n(x_2)\psi_m(x_1)] \quad \text{(fermions)} \quad (1)$$

$$\psi_S = 2^{-(1/2)}[\psi_n(x_1)\psi_m(x_2) + \psi_n(x_2)\psi_m(x_1)] \quad \text{(bosons)} \quad (2)$$

The n and m tags refer to different sets of quantum numbers, while x_1 and x_2 refer to the spatial locations in the box of particles one and two. From (1) we see that if $m=n$, the wave function goes to zero, illustrating the exclusion principle for the two fermions. However, even if $m \neq n$, but $x_1 = x_2$, the wavefunction in (1) also vanishes, illustrating the claim that two identical fermions try to avoid each other. In (2) if we let $m = n$ it becomes

$$\psi_S = 2^{(1/2)}]\psi_n(x_1)\psi_n(x_2)] \quad \text{("condensation in phase space")} \quad (3)$$

If a large number of identical bosons were so "condensed" in phase space, we would refer to it as a Bose-Einstein condensation, which is the bosonic counterpart of the exclusion principle. In another extreme case, we let $x_1 = x_2$ in (2) to give a condensation of the bosons in ordinary space: Note that we cannot also have that $n \neq m$, because the orthogonality of the separate functions for $n \neq m$ would lead to the vanishing of the normalization integral for Ψ_S. This other extreme case for (2) illustrates clumping in ordinary space:

$$\psi_S = 2^{(1/2)}[\psi_n^2(x_1)] \quad \text{("condensation in ordinary space")} \quad (4)$$

Equations (3) and (4) demonstrate, respectively, the clumping tendency of identical bosons in both phase space and ordinary space. Note that, when squared to give the probability density, both (3) and (4) are enhanced over the one particle case by a factor of

$$[2(1/2)]^2 = 2 \quad (5)$$

Clearly, (3) represents the case that physicists tend to be much more familiar with because of the association of the superfluidity of He^4 with the Bose-Einstein condensation. Equation (4), on the other hand, represents a less familiar case, that of the tendency of bosons to clump in ordinary space. If the P/F effect is valid, it is most likely a consequence of this clumping tendency of bosons in ordinary space. Indeed, one can say that, were it not for the repulsion due to the electric charge of the deuterons, (4) would imply the conversion to two deuterons in a box to a He^4 nucleus!

It should be noted that the simplicity of (4) is also regained by elegant many-body theory treatments employing the machinery of field operators and pair correlation functions. For example Baym,[4] in treating the "pair correlation function for noninteracting spin zero bosons" in his *Lectures on Quantum Mechanics,* writes, "In fact, the probability for finding the two bosons right on top of each other, $\mathbf{r} = \mathbf{r}'$, is twice the value for finding two at a large $\mathbf{r}$-$\mathbf{r}'$. . . ."

2.3. The "Inclusion Principle"

This tendency of identical bosons to clump in ordinary space, as well as phase space, deserves to be better known. In contrast to the exclusion principle for fermions, we associate this tendency of bosons to clump with a principle which we label the "inclusion principle." As a precise statement of this inclusion principle we can do no better than to borrow from the text of the well-known *Feynman Lectures:*[5] "What is the probability that a Bose particle will go into a particular state when there are already N present?. . . The probability of getting a boson, when there are already N, is (N+1) times stronger than if there were none before. The presence of the other particles increases the probability of getting one more."

Of course, again, it is the phase space condensation version of this that most physicists would claim familiarity with, because of the well-known Bose-Einstein condensation. However, researchers working with lasers tend to be familiar, also, with the clumping of photons in ordinary space. This clumping of photons in ordinary space was first demonstrated without the use of lasers in the experiment of Hanbury-Brown and Twiss[6] reported in *Nature* in 1956.

Finally, we note that the Feynman statement of our inclusion principle is demonstrated in its simplest case (*viz.,* that of going from an occupation number of one boson to that of two) for both clumping in phase space and in ordinary space by (5).

3. THE "SYMMETRY FORCE": A CONSEQUENCE OF THE WAVEFUNCTION

3.1. Symmetric and Antisymmetric Forms

The "antisocial" behavior of fermions and the "sociability" of bosons are natural consequences, respectively, of the antisymmetry and symmetry of their wavefunctions. An alternate, or equivalent, viewpoint attributes this to a "force" (some might say "pseudoforce"): thus, this "symmetry force" in its fermion (antisymmetric) form acts to keep electrons with parallel spins apart in the atom, so that the Pauli exclusion principle works. In the boson (symmetric) form, the symmetry force is associated with a binding energy that tends to clump bosons together. (Those who feel uncomfortable with any mention of "force" other than the standard four forces in textbooks can mentally substitute the term "wavefunction" every time they encounter the term "symmetry force" in our treatment, since it is actually the wavefunction which is producing the effect.)

3.2. Example: Lenard-Jones Potential

Kittel[7] writes the Lenard-Jones potential $U_{(r)}$ for the total potential energy of two atoms at a separation R as follows:

$$U(r) = 4\epsilon[(\sigma/R)^{12} - (\sigma/R)^{6}] \qquad (6)$$

The second term, going as R^{-6}, is the well-known induced dipole–dipole interaction, but the first term is an empirical term associated with the electron cloud overlap of the two atoms. We can associate this first term with a symmetry force (fermion form) having the following form, $F_S(R)$:

$$F_s(R) = -dU_{1st}/dR = +48\epsilon\sigma^{12}/R^{13} \qquad (7)$$

which, by its plus sign, is seen to be a repulsive force.

3.3. The Tight Cluster Model: The Symmetry Force

We assume at this stage that a globule (tight cluster) of bosons (deuterons) exists somewhere within the lattice of a palladium metal sample, with the prime candidate for its location being an interstitial lattice site (hereafter, IS) or vacancy in the crystal lattice. We now derive the form of that symmetry force, F_s, that is responsible for the formation of the cluster and for holding it together against the repulsive force of the deuteronic charge. Also, as we shall see, it is this force which catalyzes the tunneling reaction that is responsible for cold fusion within the metal. According to the inclusion principle, if the cluster consists of $N-1$ bosons already, the probability of adding the Nth is N times stronger than if there were none at all. So, at the edge of the cluster F_s can be written

$$F_s \propto N \qquad (8)$$

(For the region of space outside the cluster it would no doubt prove more convenient to work with the actual wavefunction.) Now the cluster is composed of degenerate deuterons. In this condensation these may be thought of as being roughly represented by hard spheres with a degeneracy radius $r_0 = 0.23$ Å, as portrayed in Fig. 1. [This radius may be inferred from the information on the molecular volume, V_M, given by Kittel:[8]

$$V_M = (4/3)\pi r_0^3 \times (6.023 \times 10^{23}) \quad (9)$$

Assuming the cluster has a constant density, the number N of d's (deuterons) is proportional to the volume of the globule, $(4/3)\pi R^3$. Employing this in (8) allows the symmetry force to be written

$$F_s = -\Omega R^3 \quad (10)$$

where Ω is a coupling constant to be determined, and the minus sign indicates an attractive force.

3.4. The Coupling Constant

As an estimate for the coupling constant Ω we assume that the two forces, Coulomb repulsive and the attractive symmetry force, are roughly balanced when there are but two d's present in the cluster. (The apparent arbitrariness of this choice of "normalization" is discussed later.)

$$\Omega R_0^3 = e^2/r_0^2 \quad (11)$$

(We ignore electronic contribution to the charge, since the cluster is a region of considerable electron depletion: The "protonizing" effect of palladium guarantees that the electrons have been to a large degree stripped off the d's and are now delocalized in the Pd conduction band. Of course, the cluster must be charge-neutralized on a somewhat larger scale. Thus, we would expect an electron cloud, probably of s-electrons, within a number of lattice spacings of the center of the cluster to provide this overall charge neutrality.) Because of the relative incompressibility of the spheres representing the d's,

$$(4/3)\pi R^3 = N(4/3)\pi r_0^3 \quad (12)$$

In particular, for only two deuterons present,

$$(4/3)\pi R_0^3 = 2(4/3)\pi r_0^3 \quad (13)$$

so that

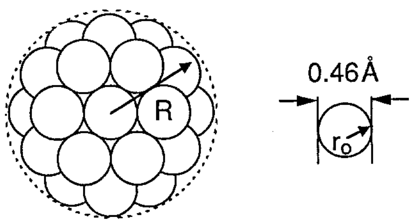

Fig. 1 Schematic for tight cluster of degenerate deuterons.

$$R_0^3 = 2r_0^3 \quad (14)$$

Substituting (14) into (11) yields

$$\Omega = e^2/2r_0^5 \quad (15)$$

Employing (15) in (10) the symmetry force becomes

$$F_s = -e^2R^3/2r_0^5 \quad (16)$$

Since we have not independently estimated the strength of the coupling constant Ω, the choice of normalization appears somewhat arbitrary. While this is a valid criticism, it should be noted that the "smoothed-out" repulsive electric field within the spherical cluster of deuterons is proportional to $+R$, the distance from the center of the cluster, while the attractive force associated with the symmetry force is proportional to $-R^3$, as seen from (16). Thus, it is certainly possible to have the force of attraction balance that of repulsion inside a hypothetical cluster at some distance R from its center. The larger this distance is in actuality, the greater would have to be the fluctuation in the number of deuterons in the region (e.g., interstitial site) to get a cluster started. We do not say how these fluctuations are produced. Presumably, however, they are associated with the tunneling of d's into an interstitial site where a cluster is forming via the 12 interstitial bonds between it and neighboring interstitial sites. No doubt this must be viewed as a wave mechanical phenomenon, in which the wavefunction has developed through time into a standing wave throughout the sample. Only then would there be considerable tunneling in opposite directions. (Initial formation via fluctuations actually favors vacancies over the IS's as cluster sites.)

It seems reasonable that the probability for large fluctuations might be enhanced by increasing the stoichiometric ratio of d's to Pd atoms in the sample. In this regard we note that research groups claiming to have observed excess heat claim also to have achieved a stoichiometric ratio of about one or greater, while those failing to observe this effect claim ratios of d's to Pd atoms of somewhat less than one, although enough to achieve a partial beta phase of Pd. [In the case of the "loose cluster model" considered later, the "cluster" is assumed to exist over a region containing a large number of interstitial sites (IS's), with an average of only two deuterons per site.]

4. THE SYMMETRY FORCE CATALYZATION OF COLD FUSION

4.1. Energy Associated with the Symmetry Force

Let us now consider how much energy the symmetry force can supply to a deuteron as it moves toward the center of the globule: The work is given by the integral of the symmetry force with respect to R:

$$\text{Work} = \int_R^0 F_S dR = \int_R^0 -\Omega R^3 dR = \Omega R^4/4 \qquad (17)$$

$$= e^2 R^4/8r_0^5 \qquad (18)$$

This work may be thought of as having gone into an equivalent amount of kinetic energy, E, of the particle. Alternatively, one can think of a potential energy,

$$V_s = \Omega R^4/4 \qquad (19)$$

that has been converted to kinetic energy by the time the particle has reached the center of the cluster. It is shown later that nuclear reaction rates favor cold fusion occurring at the center of the cluster.

4.2. Decreased Barrier Width for the Coulomb Barrier: Analogy to the "Muonization" of Deuterium

The energy in (18) and (19) can now be shown to lead to a decreased barrier width for the Coulomb barrier associated with the tunneling of one deuteron into the nuclear well of another deuteron at the center of the cluster. It is this decreased barrier width that enhances tunneling and, as we hypothesize, makes cold fusion possible within the lattice of palladium. Thus, on this viewpoint it is the symmetry force that is the catalyzing mechanism for cold fusion. (Equivalently, of course, it is the symmetric wavefunction associated with the degenerate bosons that does the catalyzing.) While the height of the Coulomb barrier is also somewhat altered, it is the decrease in the barrier width that is primarily responsible for the enhanced tunneling. In this respect, symmetry force catalyzation is somewhat analogous to the well-known cold fusion achieved in deuterium molecules by replacing the electrons by muons.

The new, and decreased, barrier width, r_1, for the Coulomb barrier for the tunneling of one deuteron into the nuclear well of another at the center of the cluster is then given by

$$E = e^2 R^4/8r_0^5 = e^2/r_1 \qquad (20)$$

Now, from (12) in terms of the number of particles N in the cluster,

$$R = N^{1/3} r_0 \qquad (21)$$

Substituting this into (20) yields the new barrier width

$$r_1 = 8r_0 N^{-4/3} \qquad (\text{for } N \text{ an integer} > 0) \qquad (22)$$

Figure 2 shows (not to scale) examples of barrier widths corresponding to different numbers of correlated deuterons, N. (This assumes a particle that was acted on by F_s all the way from the edge of the cluster to the center. To be sure, some tunneling in the cluster is catalyzed away from the center.) Note that, for $N = 133$, a deuteron reaching the center would been given enough kinetic energy via the symmetry force to achieve a separation distance (i.e., barrier width) equal to the Bohr radius of the muon in deuterium ("muonization" of deuterium). Such an N value would probably be reached by a cluster rarely, if at all. Also note from Fig. 2 that if an N value of 3100 deuterons could be reached in a cluster that cold fusion would go over into hot fusion since the barrier width would be reduced to the radius of the deuteron. It seems reasonable to say, then, that cold fusion never goes over into hot fusion in palladium based directly on this catalyzing mechanism in the tight cluster model.

We might ask why cold fusion effects are not observed in superfluid He^4 or in deuterium crystals. The answer is that, unlike the case of the deuterons in palladium, the repulsive effects (antisymmetric form of the symmetry force) of the electron clouds as exemplified by the first term in the Lenard-Jones potential (6,7) prevent further collapse.

Another question is this: most boson condensations, notably the superfluid phase of He^4 are known to be highly fragile. Thus, the latter condensation is destroyed by going above a temperature of about 2.17 K. So why would we expect such a condensation to occur for d's in palladium at 300K or higher? Our hypothesis here is that the periodicity of the wavefunction, which is asso-

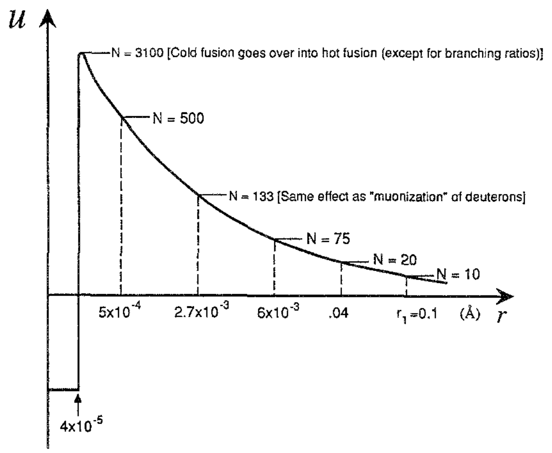

Fig. 2. Barrier widths, r_1, for a deuteron undergoing cold fusion at the center of a cluster corresponding to the number N of deuterons in the cluster.

ciated with the periodicity of the crystal lattice of Pd, acts to enhance the correlation effect produced by the thermal de Broglie wavelength of the d's. In this regard, deuteron long-range energy bands should be produced when the deuteron concentration is high enough. Also, note that the disruptive effects of lattice vibrations would be minimized by the relatively large mass of a d.

Finally, why do all of the bosons not end up in one large cluster within the lattice? We shall see that the fusion rate in a cluster depends critically upon N. This prevents an arbitrary buildup of N in the tight cluster. Also, it is important to realize that we have employed the symmetry force, (16), only inside the cluster or at its edge. In the region away from the cluster one should employ the wavefunction to obtain the distribution of bosons (d's).

4.3. The Nonviability of "Heavy Electrons" as Catalyzing Agents

Since the Pd crystal can be predicted to have some electrons of large effective mass" associated with its relatively narrow energy bands, some researchers will, no doubt, be tempted to hypothesize these as the catalytic agents via a "heavy-electron muonization" of the d's. The problem with this hypothesis is that the "heaviness" of the electron is the result to lattice effects. If the electron is now removed from the lattice and located between two d's to effect "muonization," it is no longer "heavy."

In the electron-depleted region of the deuteron cluster there may still be a few s-electrons (zero angular momentum) which ply back and forth through the center of the cluster in "cometary" fashion. However, unfortunately for the "heavy electron" hypothesis, the mass that they gain as they accelerate toward the center is only on the order of eV/c^2, rather than the necessary 100 MeV/c^2 or so required to achieve "muonization" of the d's.

5. EQUIVALENCE OF THE SYMMETRY FORCE APPROACH TO THAT EMPLOYING THE WAVEFUNCTION

We can see the equivalence of the treatment employing the wavefunction to that using the symmetry force by considering the symmetric wavefunction for N bosons at the center of an IS as shown in Fig. 3: the wavefunction shown is a reasonable approximation except near the very center of the IS where the Coulomb

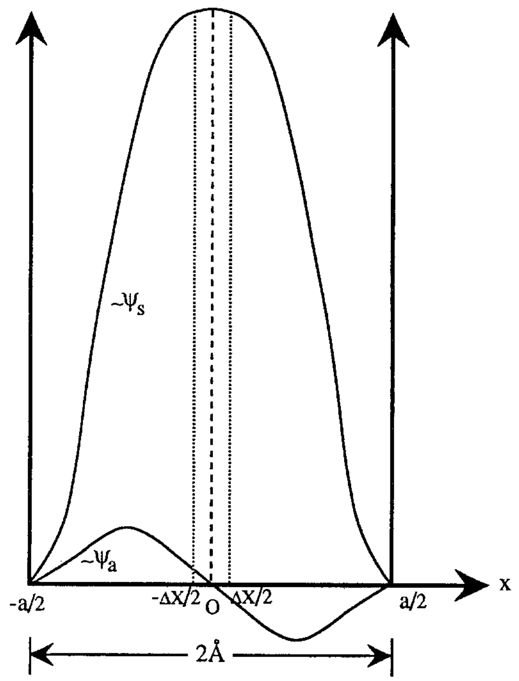

Fig. 3. Approximate schematic for symmetric wavefunction, Ψ_S, for N degenerate bosons in a cluster at an interstitial lattice site. Ψ_A, an antisymmetric wavefunction for identical fermions. (Not to scale.)

potential is extremely important. Thus, the actual wavefunction for the bosons within the periodic lattice should resemble the symmetric wavefunction in Fig. 3, with a slight "dimple" at its center. (Of course, we have assumed that a condensation of bosons has already occurred to give cluster formation.) The square of that wavefunction is employed to estimate N necessary for a given mean separation of the d's. (The mean separation of the d's is taken to be the barrier width.)

$$\psi^2_{\text{bosons}} = N\cos^2(\pi x/a) \tag{23}$$

Since we are working near the center of the IS we can approximate (23) by N: by conservation of area under the curves for the cases of N deuterons and 2 deuterons, respectively, and knowing that 0.23 Å is the mean separation for the case of two d's only present in the box, we can write for the mean separation $\Delta x = r_1$:

$$N\Delta x = 2(0.23 \text{ Å}) \tag{24}$$

Thus, for example, in the case of "equivalent muonization" with $r_1 = 0.27 \times 10^{-3}$ Å, N from (24) works out to about 170, as compared to the N value of 133 that we would obtain using (22). Note that, because our approximate wavefunction ignores the dimple in the wavefunction, we would expect that (24) based upon the approximation (23) would provide an overestimate of N as compared to the result from (22). Thus, we would anticipate an improvement as r_1 increases, i.e., smaller N in the cluster, where the "weight" of the "dimple" is not as significant: as an example, note from Fig. 2 that $N = 75$ is associated with an r_1 value [calculated from (22)] of 6×10^{-3}Å. Substituting this value into (24) yields an N value of 77, so that the symmetry force result and the result employing the approximate wave equation are in excellent agreement.

6. SEMIEMPIRICAL POWER FOR THE TIGHT CLUSTER MODEL

6.1. Transmissivity for the Coulomb Barrier Modified by the Symmetry Force

It is easy to show that the transmissivity for tunneling through the repulsive Coulomb barrier for a deuteron to reach the nuclear well (radius r_n) of another deuteron is given by[9]

$$T = \exp(-2G) \tag{25}$$

where

$$G = [(2m)^{1/2}/\hbar\,]\int_{r_n}^{r_1}(e^2/r - E)^{1/2}dr \tag{26}$$

r_n is the width of the nuclear well. r_1, the width of the barrier, is related to the energy, E, of the particle as it strikes the barrier by

$$E = e^2/r_1 \tag{27}$$

It is also easy to show that

$$G = (e^2\pi/2\hbar)(2m/E)^{1/2} \tag{28}$$

Now earlier it was shown that the effect of the symmetry force on a particle having reached the center of the cluster from the outer edge is just as if it has been given an energy which, from Eqs. (18) and (21) can be written

$$E = (e^2N^{4/3})/8r_0 \tag{29}$$

where r_o is the degeneracy radius of a deuteron in the cluster and, from Eq. (9), is approximately 0.23 Å. (We ignore an electrostatic contribution to E, since the smoothed-out repulsive electric field in the uniform density cluster goes only as $+R$, while the attractive symmetry force goes as $-R^3$.) Substituting (29) into (28) and employing (25) yields the transmissivity factor for the symmetry-force modified Coulomb potential:

$$T = \exp[(-4e\pi/\hbar)(mr_o N^{-4/3})^{1/2}] \tag{30}$$

$$\simeq \exp[(-501.3)N^{-2/3}] \tag{31}$$

Table I shows values of T (transmissivity), G, and barrier widths corresponding to respective N values. In addition, the "equivalent temperatures" that would be necessary to achieve these barrier widths if only two deuterons were present are listed.

6.2. Hypothesized Power Law: Representative Cluster Approach

To derive a power law we argue statistically in terms of a representative tight cluster having N deuterons. (The clusters are assumed to be essentially independent of each other.) In actuality, of course, there will be a distribution of different N values among the independent clusters. The number of pairs in the cluster than can tunnel is about $N(N\text{-}1)/2$, and the tunneling factor, or transmissivity, for tunneling at the center, where it is most probable, is given by T in (31). The energy released (to become heat) for each reaction involving the fusion of two d's to produce He^4 is given by about $E_1 = 24$ MeV, or 38.4×10^{-13} J. The frequency factor, ν, for collisions leading to a possible tunneling is taken to be roughly 10^{14}, which can be rationalized on the basis of either the approximate boson plasma frequency or the fact that the d's are initially particles with energies of about 1 eV inside a box (IS) approximately 2 Å wide. So, per cluster inside the lattice, the power is given by

$$P_1 = \nu[N(N-1)/2]\exp[(-501.3)N^{-2/3}]E_1 \tag{32}$$

Table I. Values of T, G, and Barrier Widths Corresponding to Respective N Values

N	r_1 (Å)	$2G$	T (transmissivity)	τ (equivalent temperature) (K)
10	0.1	108	0	1.3×10^6
20	0.03	68	2.8×10^{-30}	3.3×10^6
46	0.01	39	1.1×10^{-17}	10^7
75	6×10^{-3}	28	5.7×10^{-13}	2×10^7
125	3.0×10^{-3}	20	2×10^{-9}	3.7×10^7
133	2.7×10^{-3}	19	4.4×10^{-9}	4.1×10^7
220	1.4×10^{-3}	13.8	1.1×10^{-6}	8.0×10^7
650	3.3×10^{-4}	6.7	1.3×10^{-3}	3.4×10^8
1000	1.8×10^{-4}	5	6.6×10^{-3}	6.0×10^8
3100	4×10^{-5}	2.4	0.09	2.7×10^9

To get the total power we now multiply P_1 by the total number of independent clusters in the Pd sample: let n be the estimated average number of d's injected per interstitial site and N_t to the total number of interstitial sites in the sample (equal to the total number of Pd atoms). Then the total number of independent clusters is just

$$N_c = nN_t/N \simeq n[(M/106) \times 6.023 \times 10^{23}]/N \quad (33)$$

where M is the mass of the Pd sample in grams and 106 is the approximate molecular weight of Pd. Multiplying P_1 together with N_c to get the total sample power yields

$$P \simeq nMN\exp[(-501.3)N^{-2/3}] \times 10^{24}\ \mathrm{W} \quad (34)$$

where we have approximated N-1 by N. For 1 cm^3 of the sample we substitute 12 g for M:

$$P_{cm^3} \simeq 12nN\exp[(-501.3)N^{-2/3}] \times 10^{24}\ \mathrm{W} \quad (35)$$

So (35) constitutes a semiempirical power law for which we can find a best value of N if we are given n, the average number of d's injected per site, and the observed power per cubic centimeter of the sample, $P_{cm}3$. Table II gives the values of P_{cm^3} and the power per kilogram of sample for corresponding values of N.

6.3. Fit to Experimental Results

Fleischmann and Pons[1] claimed a power of 10 W per cm^3 of their palladium wire sample for an n value (estimated number of d's injected into the sample per site) of about 1.2. If the power in (35) is equated to 10 W, and 1.2 is substituted for n, an N value of about 25 gives a good fit. For the power estimated by Jones et al.[10] based on neutron emission, a best fit is obtained for (35) with an N value of about 13. [Note that a best fit based upon (35) is highly sensitive to the exponential tunneling factor, but less sensitive to a multiplicative factor in front of the exponential, such as the stoichiometric ratio n.]

Fleischmann and Pons claimed that the Pd cathode was "charged" with deuterium atoms for 3 months. So we explore what the N value would have to be to achieve a steady state employing their injection rate: for a steady state there must be as many d's injected per unit time as are used up in the fusion process:

$$nN_t v(N/2)\exp(-2G) = nN_t/\tau \quad (36)$$

where τ = 3 months = 3 × 30 × 24 ×3600 s. The best fit to (36) with the τ value given turns out to be about N = 30. (Note that it is independent of n, which seems reasonable, since we are not asking how long a time it takes to reach the steady state.) If N = 30 and n = 1.2 are now put back into the power equation (35), the steady-state power is calculated to be 6 KW/cm^3. Thus, in 3 s approximately enough heat to vaporize the wire could be generated (= 4 × 10^4 J) for this N value. In this connection, Fleischmann and Pons[1] reported one incident in which "a substantial part of the cathode fused (melting point, 1554°C) part of it vapourized and the cell and contents and a part of the fume cupboard housing the experiment were destroyed." So the N=30 value is consistent with this incident and, also, with their lack of an experiment demonstrating a steady-state power condition over a period of weeks or more.

Finally, while this treatment is suggestive, it must be emphasized that we have in no way proven that the P/F effect is viable. The purpose of the hypothetical model is to stimulate additional thinking and research.

Table II. Values of P_{cm^3} and the Power per Kilogram of Sample for Corresponding Values of N

N	P_{cm^3}	P (1 kg)
10	1.5×10^{-21} W	2×10^{-19} W
13	4.8×10^{-14} W	5×10^{-12} W
15	1.7×10^{-10} W	2×10^{-8} W
18	2.6×10^{-6} W	3×10^{-4} W
20	4.1×10^{-4} W	4×10^{-2} W
22	3.0×10^{-2} W	3 W
25	6.2 W	6×10^{2} W
27	1.3×10^{2} W	10 kW
29	1.8 kW	200 kW
30	6.1 kW	600 kW

7. NUCLEAR REACTIONS FOR THE TIGHT CLUSTER MODEL

7.1. Production of Helium 4 and Heat

Large clusters of degenerate deuterons should favor the production of He^4, since the intimate contact with the other bosons (d's) in the large cluster should make it extremely efficient for the compound He^4 nucleus, which is produced by one d tunneling through the modified Coulomb barrier to the nuclear well of another d, to de-excite by simply transferring its excitation energy of 24 MeV directly to the surrounding boson plasma via an electromagnetic interaction such as that of a dipole field. This would be essentially akin to a "giant resonance" de-excitation of a nucleus. Most of the resulting energy would end up in the Pd metal lattice.

This large energy release would produce a "meltdown" of the crystalline lattice in a volume centered on the cluster with a radius of the order of about 70 lattice spacings. No doubt the cluster itself would be destroyed in the "meltdown." With the high temperatures achieved locally in this process it is not inconceivable that some hot fusion would be promoted leading to the production of neutrons, tritium, protons, and He^3. "Bursts" of neutrons might be detectable. Local recrystallization of the lattice would attend cooling.

If the tight cluster model is valid, the production of He^4 is associated with the production of excess heat. In this regard, however, it is important that the He^4 be carefully searched for in the Pd sample: we would expect it to be trapped in crystal grains where cluster formation occurred. Thus, a search in which a milligram sample is taken from two diagonal corners of a Pd electrode and vaporized in a mass spectrometer is probably inadequate. Cross-section slices from different regions of the Pd electrode including the top, bottom, and center should be utilized in any rational detection scheme.

7.2. "Anomalous" Yields of Neutrons, Tritium, and Helium 3

Small clusters (i.e., small N), however, will preclude this efficient transfer of the excitation energy via a direct electromagnetic interaction between the nucleus and the boson plasma, so that the favored reaction products for two d's combining will tend to be the same as those of hot fusion; viz, (triton, proton) and (He^3, neutron). Note, however, from Table II that the rates of these reactions are relatively small, since the N value is small, as shown by (34) and (35). Thus, for small clusters (small N) there is very little heat produced.

Possible evidence in support of this comes from the discovery of spots of He^3 in laser-sliced segments of diamond[10] and the anomalously high ratios of He^3 to He^4 within thin metal foils.[10] In these cases we hypothesize that the paucity of available d's would lead to clusters small enough that cold nuclear fusion would proceed at a very low rate producing He^3 and tritium (t). (Recall, however, that tritium has a relatively short half-life of twelve years.) Support for tritium production is provided by enhanced atmospheric tritium associated with volcanic eruptions.[10]

7.3. Oppenheimer–Phillips Process

For the case of clusters of low N (i.e., $N < 20$) the relatively low speeds of approach of two d's in a cold fusion reaction should permit significant electric polarization leading to an orientation of approach with the neutrons in the d's closest to each other and the protons farthest away. This favors the formation of tritium via the well-known "Oppenheimer–Phillips process," in which one of the deuterons then strips away the neutron of the other to produce a triton and leave behind a proton. This would alter the hot fusion branching ratio of 1:1, and favor the production of tritium over neutrons. Note, however, that this process is precluded for the heat-producing reaction associated with large N clusters, since no researcher reporting excess heat has noted the large amounts of tritium that would otherwise be produced.

7.4. Possible Environmental Effects upon Branching Ratios

The environment of the nuclear reaction might also alter the branching ratio from that of hot fusion through a process that we label "symmetry favor." The probability of existence of particles near the center of the IS (center of the cluster) is strongly conditioned by the periodic wavefunction for indistinguishable particles: The symmetric wavefunction for a boson species peaks near the center, whereas that for fermions passes through zero at the center. While tritons and protons are fermions, they can quickly transform to bosons via charge neutralization (respectively, to tritium and hydrogen atoms) and, thus, partake of "symmetry favor." However, a He^3 nucleus and a neutron are "disfavored" in that charge neutralization leaves them as fermions. This symmetry favor effect, if it exists, would, however, not be expected to have as much influence on the branching ratio as the electric polarization effect leading to the Oppenheimer–Phillips process.

7.5. Time Evolution of the Tight Cluster

As a cluster builds up from low N values there would be nuclear reactions favoring the production of (t,p) over (He^3,n) due to the favored Oppenheimer–Phillips process. Small amounts of heat would be produced, since the transmissivity expressed in (31) is low for small N (Table II.) As the loading of the d's builds up, N increases and the rates of production of tritium, protons, He^3, and neutrons should rise. Eventually, however, N becomes large enough that the deexcitation of the compound He^4 nucleus via a direct electromagnetic interaction with the surrounding boson plasma becomes competitive and then dominates. The resultant meltdown and heating of the local region already indicated can "wipe out" other nearby clusters and drive additional "fuel" (d's) out of the region via a temperature gradient. After cooling, the growth of clusters can begin again. In this way there could be a sort of temperature "entrainment" effect of the clusters in a region. Thus, it appears that the production of heat and all other products could be "pulsed." Of course, for a large enough sample, since regions incorporating different grains are unlikely to be coherent, the production of heat might appear fairly steady over time.

We now examine some evidence for this scenario: at the May 8, 1989, session on cold nuclear fusion held by the Electrochemical Society in Los Angeles, several research groups[3,11] claimed to have observed "intermittancy" of neutron production ("bursts of neutrons"): neutron counts were observed to rise from background to a peak over several hours and then to fall back to background levels. The counts remained near background levels on the order of an hour or so and then the process repeated the cycle. Moreover, at the same meeting, Fleischmann and Pons reported a heating episode occurring over a period of several days for which they measured an excess heat for a Pd electrode in the megajoule range. Interestingly enough there were heat production "bursts," or spikes, with characteristic times of the order of several hours. Now if we assume that the rate of cluster evolution is roughly the same, even though the clusters are assumed to be noncoherent, the model can clearly account for both the neutron "bursts" and the heating "spikes." (This seems reasonable since the D's are being injected more or less uniformly around the surface of the cathode and considering the temperature entrainment effect already described.) Thus, based upon our hypothesized model, we predict that, in real time, a neutron burst peak would be followed by the growth of a heat spike (associated with He^4 production). The latter would be followed by a cooling period (no heat spike or neutron burst), and then the pattern would repeat. However, the amplitudes of the spikes should also decrease as the d's are used up and this was observed. Of course, it would be highly desirable to conduct an experiment in which both neutron bursts and heat spikes are observed.

7.6. "Anomalous" Yields of γ-Rays and X-Rays

Note that, even if created, γ-rays would find themselves within the interior of the "boson plasma" of deuterons provided by the collection of clusters within the Pd lattice. Employing a condensation radius of about 0.23 Å for a deuteron of the plasma yields a cutoff plasma frequency of roughly 6.4×10^{14} Hz with a corresponding cutoff energy of about 27 MeV: photons (i.e., γ-rays) with energies less than this would be unable to escape and would be degraded to heat. Even γ-rays with higher energies could be degraded to energies below 27 MeV by virtue of interactions such as the Compton scattering of a γ-ray by a deuteron. The net result is that most γ-rays formed would be essentially trapped within the plasma and give their energy up to it as heat. Some γ-rays formed near the surface might escape and be detectable. X-rays would also tend to be absorbed by the plasma. γ-rays emitted after the meltdown of a lattice region would encounter an even denser plasma.

8. THE LOOSE CLUSTER MODEL

In the loose cluster model, in contrast to the tight cluster model, the cluster encompasses a large number of interstitial sites, as opposed to one, but averages only two d's per interstitial site. (The loose cluster might, in fact, turn out to be an early stage in the time evolution of a tight cluster.) The wavefunction for the sample is a standing wave at this stage of charging with d's, so that tunneling through interstitial bonds by d's is not quite so unidirectional. The increased tunneling through the interstitial bonds might lead to some cold fusion between d's tunneling in opposite directions since the electronic charge of the bond may offer some "charge dressing" to lower the effective positive charge of the two d's. The Oppenheimer–Phillips process would probably still be important here.

9. THE SYMMETRY FORCE: ADDITIONAL HYPOTHESES

9.1. A "Multidimensional Revolution"?

It has been said that, if cold nuclear fusion as manifested by the P/F effect can be shown to be valid, this discovery would most likely be associated with a "multidimensional revolution" in science. Indeed, for that very reason, some have suggested that the P/F effect is unlikely to be valid. In this regard it is interesting to note that the concept of the "symmetry force" may have the potential for just such a multidimensional revolution: Thus, since the symmetry force has been hypothesized as the principal ingredient to permit our understanding in one area of physics, *viz.,* the catalysis of cold fusion, it is reasonable to speculate about its potential connection to other branches of knowledge. Here, we restrict ourselves to several hypotheses in physics.

9.2. The Aspect Experiment

In the area of quantum mechanics we hypothesize that the symmetry force is the missing ingredient required to understand why the results of the Bell's theorem[12]-elaborated, Bohm version[13] of the Einstein–Podolsky–Rosen paradox[14] experiment as conducted by Aspect et al.[15] are in agreement with standard quantum mechanics. In connection with their experiment, Aspect et al.[15] have shown that, if it is necessary to have signaling between two photons in order to produce polarization correlations in agreement with standard quantum mechanics, then the signals must be "superluminal" ("faster-than-light"). In this connection we speculate that the symmetry force is carried by de Broglie waves, since the latter are calculated to have a range of velocities from that of light on up to infinity. (Also, the role played by these hypothesized waves has been uncertain.) Thus, on this basis, the hypothesized "nonlocality" feature of our world potentially heralded by the Aspect experiment is accounted for by superluminal signaling via de Broglie waves. The Aspect experiment could serve to place a lower bound on the velocity of this signaling.

If the de Broglie waves are quantized, the resulting particles would be "tachyons" ("superluminal" particles, as opposed to "subluminal" particles, or "tardons"). If they simply carry "information," e.g., quantum state information, there seems to be no problem for the special theory of relativity. [Should they also carry energy, would the special theory have to be amended to apply only to particles of nonimaginary (i.e, real) rest mass? Would the "missing mass" problem be impacted by the existence of these particles? Could, for example, tachyons supply part, or all, of the "missing mass" required to gravitationally bind some globular star clusters and to "close the universe"?] The well-known objection to tachyons based on "causality violation" (recall that, at least in principle, tachyons allow signaling from the future back to the past) has been weakened by doubts as to how this would "play out" in a multidimensional universe anyway. The more serious quantum mechanical objection based upon considerations of the vacuum is obviated if these particles carry only information. (In this regard it is interesting to note that tachyons apparently arise in a rather natural way in "superstring models" for elementary particles. However, because of the quantum mechanical objection, they are "exorcized" from these superstring models by various techniques. The above considerations suggest that superstring researchers should reconsider the relation of tachyons to their models. To be sure, "superstring theory" is, itself, highly conjectural.)

9.3. Mechanism for the Pauli Exclusion Principle

We hypothesize that it is the symmetry force (fermion form) that provides the "mechanism" for the Pauli exclusion principle to operate. De Broglie waves (tachyons if the waves are quantized) would permit the signaling between two electrons in an atom, molecule, or crystallite (grain), which allows them to obey the Pauli exclusion principle. (In this connection it seems worthwhile to note that the symmetry force (fermi or boson form) explanation to account for the result of an experiment of the type performed by Aspect et al.[15] is akin to the explanation for the exclusion principle, but simply on a much larger scale than in the intraatomic case. That is, the correlation in the large-scale case would be expected to be statistically demonstrable but not necessarily equal to the virtually 100% correlation that would hold inside an atom, molecule, or crystallite (grain) in the case of the exclusion principle.

9.4. The "Horizon Problem" in Cosmology

Finally, the symmetry force might provide the missing ingredient in the so-called "horizon problem" in cosmology. Gribbin[16] states it as follows: "It looks as if the universe was born out of the fireball era in a perfectly smooth state, with exactly the same energy density (the same temperature) 'built in,' even in regions that were too far apart for any signal, restricted to travelling at the speed of light, ever to have passed between them. But what builds this uniformity of temperature into the Big Bang?" However, if the symmetry force is carried by de Broglie waves that can travel superluminally, it is apparent that this ingredient can explain the signaling riddle, and thus provide a solution to the "horizon problem."

10. CONCLUSION

In going from a hypothesis to explain the apparent puzzle of cold nuclear fusion to hypotheses which seek to account, respectively, for the results of the Aspect experiment (i.e., an experiment based upon the Bohm version of the Einstein–Podolsky–Rosen paradox), the operation of the exclusion principle, and the solution to the "horizon problem," we have traveled a considerable distance. However, the common denominator tying all of these together is the symmetry force, an effect of the wavefunction which we have hypothesized to be carried by de Broglie waves. For roughly 60 years, physicists and chemists have been calculating practical results with the help of "mathematical abstractions for reasonably localized parts of the wavefunction" without knowing fundamentally why this approach is so successful. A distinct possibility appears to be that a universal wavefunction operating via de Broglie waves is as real as anything in our universe.

ACKNOWLEDGMENTS

One of us (R.T.B.) is grateful to the College of Science and the Physics Department for five units of release time from teaching for research. We are especially grateful to Dr. Ray Shiflett, Dean of the College of Science, and to Dr. Ray Fleck, Director of Research, for their support and encouragement.

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