Chubb, T. *LENR: Superfluids, Self-Trapping and Non-Self-Trapping States*. in *Tenth International Conference on Cold Fusion*. 2003. Cambridge, MA: LENR-CANR.org. This paper was presented at the 10th International Conference on Cold Fusion. It may be different from the version published by World Scientific, Inc (2003) in the official Proceedings of the conference.

LENR: Superfluids, Self-Trapping and Non-Self-Trapping States

Talbot A. Chubb
Research Systems, Inc.
5023 N. 38th St.
Arlington, VA 22207
USA

Abstract

LENR ion band state models involve deuteron many-body systems resembling superfluids. The physics of atom Bose-Einstein condensates in optical lattices teaches that superfluid behavior occurs when the potential barriers between adjacent potential wells permit high tunneling rates and the well potentials are shallow. These superfluids have fractional occupation of individual wells. Well periodic symmetry is not affected by the presence of the atoms. This behavior suggests that deuterons in a lattice should be in non-self-trapping sites, which may indicate that D^+_{Bloch} occupies the Pd tetrahedral sites.

In a companion paper in this Proceedings[1], a deuteron many-body Bloch system, designated N_D-D^+_{Bloch}, is proposed as the nuclear active form of matter in both Fleischmann and Pons radiationless cold fusion[2] and in Iwamura et *al*. alpha-addition Cs transmutation reactions[3]. Each N_D-D^+_{Bloch} is pictured as a low density array of N_D Bloch-function deuterons neutralized by an equal number of lattice-arrayed electrons, so as to jointly form a deuterium subsystem. A number of deuterium subsystems are assumed to exist in a multi-crystallite metal. It is assumed that $N_D/N_{well} << 1$, where N_{well} is the number of potential wells in the crystallite. Referring to their cold fusion experiments Chernov et *al*. state: "The experimental results testify: - H atoms occupy regular positions in the crystal lattice, form their own H subsystem - In this subsystem H atoms are connected with each other a much stronger than with atoms of the matrix."[4] Here, H atoms refer to either protons or deuterons. I think that the abnormally close connection between deuterons (or protons) is a result of coordinate exchange symmetry. The properties of each N_D-D^+_{Bloch} resemble those of a superfluid embedded in an array of potential wells. There is a communal occupation of N_{well} potential wells within each crystallite with only a fraction of each D^+_{Bloch} particle present in each potential well of the occupied crystallite. This fractional occupation geometry seems similar to the superfluid phase of recently studied Bose-Einstein Condensates in optical lattices[5,6]. It seems appropriate to examine current work on

Bose condensates in optical lattices to see if such studies can provide insight to the LENR active state.

Let us consider the creation and manipulation of a coherent atom system as carried out by Greiner et *al.*[6]. Greiner et *al.* created a coherent population of ^{87}Rb atoms by transferring laser-cooled Rb atoms in the (F=2, M_F =2) state into a cigar-shaped magnetic trapping potential characterized by trapping frequencies of ν_{radial} = 240 Hz and ν_{axial} = 24 Hz. They used forced radio-frequency evaporation to create Bose-Einstein condensates with up to 2 x 10^5 atoms and no discernible thermal component. The success of this procedure illustrates a principle that seems to say that many-body coherence becomes established in a bound system of indistinguishable particles when the participating particles are in the same vibration state. Their large deBroglie wavelengths cause their wave functions to overlap. As indistinguishable particles, they then become subject to coordinate exchange symmetry. The wave functions of the particles then have either a single in-common wave-function phase or an ordered phase that is determined by physical position. The principle that an ordering of many-body phase occurs when the wave functions of the associated particles overlap presumably applies to the LENR case.

Greiner et *al.* next imposed a laser-created optical lattice onto the coherent population, thereby partitioning the mass density of the Bose-Einstein condensate among more than 1.5 x 10^5 potential wells. Coherency was shown to be maintained as long as the potential wells created by the lattice were not too deep. The resulting Bose-Einstein system was a superfluid in which the atoms were partitioned, with only a fraction of each indistinguishable atom present in each potential well. In such a system the atom fraction in any selected potential well is not precisely determinable in the quantum mechanical sense, only the atom sum over the set of potential wells is measurable. In other words, the particle fraction in any given unit cell fluctuates, i.e., is not constant. In contrast, the difference in wave function phase between selected cells is measurable, i.e., is sharply defined. The uncertainty in mass-in-any-given-potential well together with the measurability of wave function phase difference is an expression of the Planck uncertainty principle as applied to an essentially Bloch many-body configuration of atoms.

Greiner et *al.* next increased the depth of the potential wells making up the optical lattice. They observed the transition of their many-body superfluid system into a particle-like configuration in which adjacent unit cells are occupied by whole atoms, while the phase difference between adjacent particles becomes indeterminable. This uniform whole atom configuration is called a Mott insulator. The Mott insulator configuration is not a coherent many-body state. However, they found that the transition between the superfluid state and the Mott insulator state was reversible if one did not stay in the deep-well configuration "too long", indicating a persistence of superfluid-atom entanglement. Modeling studies by Jaksch et *al.* preceded the Greiner

et al. experiments. Both the Greiner et *al.* and Jaksch et *al.* studies show that shallow potential wells are required for superfluid behavior.

Radiationless deuterium cold fusion seems to require that one create a N_D-D^+_{Bloch} superfluid state in which a fraction of each deuteron in a many-body deuteron subsystem continuously occupies each of N_{well} potential wells. In the Bose-Einstein optical lattice study this condition is maintained for cold atoms if the potential barriers separating adjacent unit cells are low in the sense that a relatively high, quantifiable tunneling rate exists between adjacent unit cells. In practice, this means shallow potential wells. In the Bose-Einstein optical lattice case the superfluid state is periodic and has the same array geometry as the optical lattice. Once the periodicity and orientation of the condensate is established, its center-of-mass location is positioned so as to minimize total system energy. It is important to note that the addition of individual rubidium atoms cause no local distortion of the optical lattice. This lack of adjustment by the lattice means that there is no self-trapping of rubidium atoms, i.e., there is no impairment of trap-array periodic symmetry. Since cold fusion experiments seem to need a superfluid type state, one seeks conditions where some of the deuterons in a metal deuteride are in a similar, non-self-trapping configuration with shallow barriers between adjacent potential wells. In the palladium deuteride system this could mean that a small number of deuterons come to occupy the relatively shallow tetrahedral sites in the metal's fcc crystals. In this scenario the tetrahedral-site deuterons would become the N_D-D^+_{Bloch} superfluid. Alternatively, the N_D-D^+_{Bloch} component could occupy the fringes of octahedral sites, while the central volume of some of the sites remain occupied by normal self-trapped interstitial deuterons.

When a metal absorbs hydrogen, a hydrogen ion entering the metal lattice at an interstitial site becomes shielded by a neutralizing electron. In the normal process, the lattice expands around the occupied site to accommodate the added volume required for the neutralizing electron[7]. This localized expansion of the lattice occurs because it lowers the energy of the total system. The process is called self-trapping. Self-trapping makes the trapping volume larger and deeper than it would otherwise be. With respect to palladium deuteride there are 2 other factors that affect palladium deuteride formation. First, in palladium's fcc lattice there are 2 tetrahedral sites per unit cell and 1 octahedral site per unit cell. Second, whereas self-trapping increases the strain energy work done on the metal lattice if the deuterium/metal ratio is less than about 0.5, it reduces the lattice strain energy if the deuterium/metal ratio is greater than about 0.5. The localized distortion of the lattice accompanying the presence of a normal deuterium ion in Pd contrasts with the uniform spacing that characterizes the Bose-Einstein optical lattice scenario. Self-trapping preserves the particle-like character of an interstitial D^+; a non-self-trapping occupation supports the wave-like character of a D^+_{Bloch}. The condition required for cold fusion is that some of the D^+ ions go into a Bloch configuration in a process that creates D^+_{Bloch} and avoids a localized distortion of the lattice.

We introduce new notation. It seems useful to distinguish between self-trapped deuterons, ${}_{st}D^+$ and non-self-trapped deuterons, ${}_{nst}D^+$. Both types of deuterons may co-exist within the same metal deuteride crystal. For example, in Fleischmann and Pons cold fusion the reactive crystal might be described by the formula $Pd\ {}^{O}_{st}D^{+}_{0.8}\ {}^{T}_{nst}D^{+}_{.001}$. The notation describes palladium deuteride PdD_{x+y} with a self-trapped D/Pd fraction x = 0.8 occupying octahedral sites, and a non-self-trapped D/Pd fraction y = 0.001 occupying tetrahedral sites. The nuclearly active component presumably is the non-self-trapped population. An alternate configuration, in which both self-trapped and non-self-trapped sets of deuterons occupy octahedral sites, would be $Pd\ {}^{O}_{st}D^{+}_{0.8}\ {}^{O}_{nst}D^{+}_{.001}$. If both sets of deuterons are in octahedral sites, the wavelike configuration deuterons would likely avoid the center part of the octahedral potential wells. Jaksch et *al.* in their modeling paper on Bose-Einstein condensates in optical lattices show in their Figure 3 a combined superfluid + Mott insulator system where both components occupy the same set of potential wells. The superfluid matter avoids the center part of the potential wells, while the centers are filled by the whole-atom (Mott insulator) component. Cold fusion transition rate calculations suggest that the fraction of band-state non-self-trapped deuterons needed to provided observable excess heat could be less than 0.001.[8] The proposed notation could be extended to include H as well as D. Maybe heat is sometimes produced in mixed hydrides of the form $Pd\ {}^{O}_{st}H^{+}_{0.6}\ {}^{O}_{st}D^{+}_{0.2}\ {}^{T}_{nst}D^{+}_{.001}$.

References:

[1] T. Chubb, "The dd Cold Fusion-Transmutation Connection", *Proc. ICCF10*.

[2] M. Fleischmann and S. Pons, "Electrochemical Induced Nuclear Fusion of Deuterium", *J. Electroanal. Chem.*, **261**, 301 (1989). Hawkins, M. was added to the list of authors.

[3] Y. Iwamura. M. Sakano, and T. Itoh, "Elemental Analysis of Pd Complexes: Effects of D_2 Gas Permeation" *Jpn. J. of Appl. Phys. A*, **41**, 4642 (2002)

[4] I. P. Chernov, Y. P. Cherndantzev, A.M. Lider, and G. V. Garanin, "Excess Heat Released upon Hydrogen Isotopes Electrolytical Saturation into Metals Covered by Porous Film", *Proc. 8th Russian Conf. on Cold Nuclear Transmutation of Chemical Elements*, 133 (2001).

[5] D. Jaksch, C. Bruder, J. I. Cirac, C. W. Gardiner, and P. Zoller, "Cold Bosonic-Atoms in Optical Lattices", *Phys. Rev. Lett.*., **81**, 3108 (1998).

[6] M. Greiner, O. Mandel, T. Esslinger, T. W. Hansch, and I. Bloch, *Nature* 4**15**, 39 (2002).

[7] Y. Fukai, *The Metal -Hydrogen System* (Springer-Verlag, Berlin, 1993), pp. 185, 189-197.

[8]. T. A. Chubb and S. R. Chubb, "Cold Fusion as an Interaction between Ion Band States", *Fusion Technol*., **20**, 93 (1991).