Nuclear Physics Approach

Hidden Results of the Ion Band State Theory

Scott R. Chubb and Talbot A. Chubb

Oakton International Corporation
5023 N. 38th Street
Arlington, VA 22207, U.S.A.

Abstract
Using the Ion Band State (IBS) theory[1,2] we predicted a number of important effects that were subsequently observed[3] in Cold Fusion anomalous heat experiments. Despite this fact, the theory has inspired controversy[4] and confusion[5]. By addressing[5,6] the skeptics[4], we have learned that both the success of the theory and the controversy it seems to provoke have a common origin: our application of conventional, mainstream, solid state, many-body physics ideas that are known[7] to describe the physics of hydrogen inside[7] and on the surface[7] of transition metals, to the PdD Cold Fusion problem. Our application of these mainstream ideas is inconsistent with the predominant paradigm[3,8] that is commonly applied to Cold Fusion because it uses important ideas that relate periodic order to coherence that are known to apply at low temperature (LT) in solids and to hydrogen-in-metal systems that are not consistent with the conventional high temperature (HT) models that have formed the basis of conventional thinking. Implicit in this alternative (LT) picture is the important result that symmetry provides a means of "hiding" the potential location of a particular nuclear reaction. As a consequence: 1. it becomes impossible to distinguish the locations of the associated (periodically distributed) nuclear interactions, and 2. the associated energy release is initiated through a coherent release of energy and charge at the crystal boundaries.

Introduction:
This paper describes fundamental ideas behind the Ion Band State (IBS) theory[1,2] and the associated Lattice Induced Nuclear Chemistry (LINC) model[2] for solid state nuclear reactions that explain Fleischmann-Pons (FP) Cold Fusion experiments. Both IBS theory and LINC follow from mainstream quantum mechanics as it applies to ordered, hydrogen-in-transition metal systems. This is made possible by the first, and most important of the "hidden results" of IBS theory: it is possible for hydrogen and deuterium nuclei to become so mobile within a periodically ordered transition metal lattice that they behave in a "wave-like", delocalized manner that resembles the way conduction electrons behave in metals. The reason this "hidden result" seems to be relevant to FP-Cold Fusion (as suggested by loading measurements) is because of a second "hidden result": fully-loaded PdD (defined by PdD_x, $x \rightarrow 1$) crystals that are sufficiently large not only provide a natural environment for D and H to occupy these "electron-like", ion band states, it is also plausible that once this occurs (through energy minimization), order-preserving, coherent D^+-D^+ overlap can occur with unanticipated results, including coherent forms of non-local energy release and charge transfer from the bulk to an unexpected location: outside the bulk region where the main nuclear overlap occurs.

Nuclear Physics Approach

IBS theory predicts that this scenario occurs only in a very specific situation, in which periodic order is present and energy is minimized by the occupation of these "electron-like" ion band states. Neither the theory or model has been widely accepted, possibly, because both seem to contradict the "conventional wisdom" that FP-Cold Fusion simply is impossible. It is also possible that this failure reflects a more serious difference: IBS theory and LINC apply rigorously in a limit (temperature T=0) that differs significantly from the higher temperature (HT) limit where the conventional picture applies. This has resulted in a serious clash between the intuitive pictures provided by IBS/LINC theory with conventional thinking because at T=0, rigorous quantum mechanics must be used, resulting in a number of IBS/LINC predictions of "Black-Box" like effects associated with our (and nature's) inability to identify how and where specific phenomena take place, which have no counter-part at high temperatures, where nuclear overlap and reactions may be described using a semi-classical limit, involving distinctly identifiable events that occur at specific loactions.

Although it is not clear that it would ever be possible to perform Cold Fusion experiments with $T \rightarrow 0$, pedagogically, there is value in examining this limit because it provides a distinct picture that illustrates the very different paradigms that follow from conventional wisdom and IBS/LINC theory. Also, in the low T limits of both IBS's and LINC, simplifications become possible that quantify rules and effects that are not immediately obvious, such as the requirements that periodic order be preserved in bulk regions during nuclear reactions, and in effects associated with ion-ion correlation. In an accompanying paper[1], we have provided an overview of a number of important results associated with the IBS theory[1,2] and the LINC model[2]. In particular, we discuss some experimental evidence for IBS occupation and the underlying behavior of IBS's. We also discuss the potential implications for Coulomb barrier penetration, and provide an overview of the assumptions of LINC. The focus of the present paper is the underlying microscopic theory of LINC, its relationship to the LT paradigm, and the relationship of this paradigm to the conventional HT paradigm.

Cold Fusion at Absolute Zero:

In the T=0 limit, no energy or momentum can be transferred into or away from a solid, and the solid really must be viewed as a "Black Box." Somewhat remarkably, when a solid also possesses perfect periodic order, it still is possible to maintain temperature T=0 conditions inside (or within a large portion of the interior of) a solid but to extract momentum and energy from the solid through resonant processes that couple to the bulk but do not alter the interior of the solid. In this context, the bulk still must be "viewed as a black box;" while the important interactions "appear" to be taking place in the surface regions. These processes, which are referred to as "UmKlapp"- or "U"-processes[6], play a fundamental role in heat conductivity in electron-band systems. For this reason, it is not entirely surprising that they would become important in the transport of heat in systems in which heat is initiated from H^+ and/or D^+ ions that occupy "electron-like" IBS's. Previously[6], we have discussed the governing equations, based on a statistical treatment, of transport phenomena and reaction possibilities that are associated with the manner in which these processes can affect IBS $^4He^{++}$- and D^+- occupations, at finite T. There[6], we suggested that these processes probably are dominant at room temperature. When T=0 within the bulk, in fact, these are the only processes that enter since they are the only processes that couple to the outside world. Then, the statistical Boltzmann equation treatment[6], can be replaced by a rigorous microscopic limit in which the only allowed changes in energy occur through a shift in the zero of kinetic energy of each ion band state relative to the zero of kinetic energy. This is because this mode of energy transfer merely shifts the energies of all IBS's relative to all of the remaining charged particles in the system and is equivalent to a constant uniform shift of the IBS chemical potential. Although such a change does alter the occupation of IBS's in the surface regions that surround the solid, in bulk regions, it does this through a coherent redistribution of charge, either by eliminating it from or adding it to each

unit cell by altering the occupation of the highest occupied band state.

The Fermi Golden rule calculations[2,6] that we have used to describe "coalescence fluctuations" are based on coupling of the IBS center-of-mass wave functions to these shifts in chemical potential. Previously, we have not fully described how these fluctuations physically couple to the outside world. This is because at finite T, a number of different energy dissipation paths (phonons, and other lattice excitations, etc) are available besides surface-dipole mediated processes. At T=0, the only available path preserves order. This occurs from coherent U- processes that transfer charge to the surface dipole by a constant change in the bulk potential.

In the T=0 limit, for sufficiently large crystals, the Coulombic barrier interaction that prevents normal D-D overlap is suppressed by a decrease in the amplitude of wave function cusps[1,6]. As a result potentially reactive nuclei have near-complete overlap. Then, nuclear and Electromagnetic (E.M.) interactions are constrained to be separable[2] provided IBS concentration is sufficiently low ($<\sim 10^{-4}$). A sufficient condition that maintains this limit in the bulk during potential nuclear reactions is that the possible nuclear reactions involve ground-state to ground-state transitions and occur in a manner that preserves both E.M./nuclear separability and periodic order. Then, the ion band state and nuclear wave functions possess "Born-Oppenheimer Separability" (BOS), and the nuclear portions of the wave function interact only through the strong force. This separability is required in the bulk region because it holds there initially and is needed to preserve an absolutely ordered, T=0, state.

Because all portions of the E.M. interaction (including the ion-ion corelation[1]) in the bulk are described using band states, the center of mass locations of potentially reactive nuclei become indistinguishable and delocalized. This is clearly very different than in the HT case, where a nuclear reaction always occurs at a single point. As a consequence, in the T=0 limit, effectively, four "hidden results" become possible that have no HT counterpart: 1. It is possible to "hide" the locations of the nuclear reactants and by-products as a result of periodic order and the "Black Box"- type of behavior that occurs at T=0. 2. It is possible for energy to be released through coherent processes in regions distinctly different from the locations where nuclear overlap occurs. 3. To maintain separability between nuclear and electromagnetic interactions, complete isospin conservation is required between initial and final states within the bulk. 4. As a consequence of the first three results, a "bosons in and bosons out" selection rule[2], in which each "boson" consists of an integer number of proton-neutron pairs, becomes rigorously valid.

Implicitly, we have applied the "Black Box-like" conditions of the T=0 limit in previous Fermi Golden Rule reaction rate calculations. Here, the transition rate is estimated from the following assumptions: 1. reversible fluctuations in mass occur at each bulk interior point. 2. Average energy of these fluctuations V ($\cong 2.38 \times 10^7/N_{cell}$; N_{cell}= number of bulk unit cells) couples to band states through a perturbing barrier height, inhibiting D^+_{IBS} (≡ IBS D^+) overlap with locations where energy is released (equivalent to lowering constant zero of kinetic energy K_o of each bulk D^+_{IBS} relative to the comparable K_o of the $^4He^{++}_{IBS}$ product). In the present work, we illustrate that these changes in K_o can be coupled at T=0 with the outside world through discontinuous changes in the wave-function at the boundaries of the solid (similar to those outlined[6] during ICCF5) that are consistent with an Umklapp-process that coherently alters the boundary, through a sudden, discontinuous change in K_o in regions where periodic order is lost, accompanied by a redistribution of positive and negative band state charge in the surface region.

These changes induce a breakdown of BOS, illustrating how energy transfer can couple to the outside world through surface region variations δK_o in the zero of kinetic energy K_o. δK_o equals the nuclear energy change resulting from $D_{nuc}+D_{nuc} \rightarrow {}^4He$. This change alters each nucleon wave

Nuclear Physics Approach

function by an amount $\delta\psi_{nuc} = -\partial\psi_{nuc}/\partial E \times N_{cell}V$. By construction, this energy is treated as a perturbation to the band state potential in the bulk, but in the surface region it is treated as a shift in the kinetic energy of each band state wave function. BOS breaks down through the implicit relationship, $\delta\psi_{nuc}(\mathbf{r}) = \partial\psi_{nuc}/\partial E \times \delta K_o$, where δK_o ($= -N_{cell}V$) is implicitly treated as a functional of the continuation of $\psi_{IBS}(\mathbf{r}')$ at points $\mathbf{r}'$ extending into the surface region. The implicit relationship between K_o and ψ_{IBS} is defined by an UmKlapp process involving a transfer $\Delta\mathbf{p}$ of momentum from the solid to the surface through a "resonant matching condition" requirement: Debroglie wavelength $\equiv h/\Delta\mathbf{p} = n^{-1}$ bulk lattice spacing, n=integer. This introduces discontinuous behavior in $\nabla\psi(\mathbf{r})$ in the surface region. Minimal transfer of kinetic energy to the outside world occurs when these discontinuities alter K_o only at the classical turning points of each band state wave function. From the definition of kinetic energy $K \equiv \hbar^2/(2m) \int d\mathbf{r}\, |\nabla\psi(\mathbf{r})|^2 / \int d\mathbf{r}'\, |\psi(\mathbf{r}')|^2$, it follows from the calculus of variations that

$$\delta K \equiv \frac{\hbar^2}{(2m)} \Big(\int_{\text{boundary}} d\mathbf{r}\ \Big[\delta\psi^* \frac{\partial\psi}{\partial n} + \frac{\partial\psi^*}{\partial n}\delta\psi\Big] - \int d\mathbf{r}\ \big[\delta\psi^*\nabla^2\psi + \nabla^2\psi^*\delta\psi\big] \Big)$$

$$- K \int d\mathbf{r}\ \big[\delta\psi^*\psi + \psi^*\delta\psi\big] \quad . \qquad (1)$$

Here, the first term is evaluated at all boundaries surrounding locations where possible discontinuities occur. The UmKlapp process occurs when $\delta\psi$ vanishes except in the surface region at classical turning points $\mathbf{r}_{tp}$ (defined by $\mathbf{r}$ such that $\nabla^2\psi(\mathbf{r}) = 0$), and is minimized absolutely when K_o is minimized absolutely. Denoting this minimal value by K_o, and, for simplicity, requiring that two-dimensional order be preserved in the x-y plane, we find

$$\frac{\delta K_o}{\delta\psi(\mathbf{r})} = \frac{\hbar^2}{(2m)} \Big(\sum_{z_b \in \text{boundary}} \delta(z - z_b) \frac{\partial\psi^*(\mathbf{r})}{\partial n} - K_o\psi^*(\mathbf{r}) \Big) \delta(\mathbf{r} - \mathbf{r}_{tp}) \, . \qquad (2)$$

By using Eq. 2, and the previous result $\delta\psi_{nuc}(\mathbf{r})/\delta\psi_{IBS}(\mathbf{r}') = \delta\psi_{nuc}/\delta E \times \delta K_o/\delta\psi_{IBS}(\mathbf{r}')$, we obtain the desired result, illustrating the breakdown of BOS that results from changes in IBS's through UmKlapp process induced changes in K_o in the surface region.

1. T. A. Chubb and S. R. Chubb, this proceedings.
2. S. R. and T. A. Chubb, Fus Tech, 24, 403, (1993). T. A. and S. R. Chubb, ibid, 20, 93, (1991). S. R. and T. A. Chubb, in AIP Conf. Proc. 228, 691, (eds. S. E. Jones et al, AIP (New York), 1991).
3. M. H. Miles et al., in Conf. Proc. Vol 33, 363, (eds. Bressani et al, Ital. Phys. Soc. (Bologna, 1991). M.C.H. McKubre et al., in Frontiers of Cold Fusion, 5, (ed. H. Ikegami, Univ. Acad Press (Tokyo, 1993)). K. Kunimatsu et al., ibid, 31.
4. D. Lindley, NATURE, 344, 376 (1989). Bressani et al, "Editorial Note to the Paper 'An Explanation of Cold Fusion...' by S.R. Chubb and T.A. Chubb", in Conf. Proc. Vol 33, 204, (eds. Bressani et al, Ital Phys Soc (Bologna, 1991)). V. A. Chechin et al., Int. J. Theor. Phys., 33, 636 (1994). M. Rabinowitz et al., Trans. Fusion Tech., 26, 3 (1994).
5. S.R. Chubb and T.A. Chubb, ICCF5 Book of Abstracts, p 409 (1995).
6. T.A. Chubb and S.R. Chubb, Proc. ICCF5, pp 315-326 (1995). S.R. Chubb and T.A. Chubb, Bull. Amer. Phys Soc, 41, 341 (1996).
7. R.C. Casella, Phys. Rev. B, 27, 5943 (1983). R. Niemenen, NATURE, 356, 289 (1992). M.J. Puska et al., Phys. Rev. Lett., 51, 1081 (1983).
8. A.J. Leggett and G. Baym, Phys. Rev. Lett, 63, 191 (1989).