Roles of Approximate Symmetry and Finite Size in the Quantum Electrodynamics of d+d→^{4}He in Condensed Matter Nuclear Science

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Abstract

Resonant electromagnetic interaction (EMI) in finite solids not only can be used to explain conventional, electron energy band theory (which explains charge and heat transport in solids), but also how, through finite size effects, it is possible to create many of the kinds of effects envisioned by Giuliano Preparata. Through a generalization of conventional energy band theory, it is also possible to explain how resonant EMI, as a function of time, can cause coherent effects, in which momentum can be transferred from external regions of a lattice to its center-of-mass. As a consequence, virtual processes can cause large changes in momentum between two, indistinguishable particles, without either particle acquiring large momentum or velocity. With increasing time, these changes can occur over shorter and shorter length scales, through ("Bloch") oscillations of the charged particles within the lattice, leading not only to possible deuteron (d)-d nuclear dimension overlap, but, as a result of resonant EMI, to forms of overlap that are consistent with those that occur through quantum electro-dynamic (QED) effects in the conventional d+d→^{4}He+γ reaction. The resulting theory predicts that the orientation of the external fields in the SPAWAR protocol has direct bearing on the emission of high-energy particles. Resonant EMI also implies that nano-scale solids, of a particular size, provide an optimal environment for initiating Low Energy Nuclear Reactions (LENR) in the PdD system.

Introduction

In this paper, important facts about the importance of electromagnetic interaction (EMI) in the conventional deuteron (d)+d→^{4}He+γ reaction are reviewed that are not widely appreciated. These facts reveal that as opposed to a static Coulomb barrier, the "barrier," in this reaction, involves important time- and spatially- dependent effects that require that for the reaction to take place, the incident d's that are involved must be prepared, far from the reaction, in a particular way, through EMI, that occurs infrequently in thermonuclear fusion. As a consequence, the reaction occurs infrequently, relative to the dominant reactions, in hot fusion, not because of the large energy release (which is commonly believed by most nuclear physicists to be the reason the reaction does not occur frequently) but because it involves important EMI effects that are conventionally ignored that occur infrequently at high temperatures.

In the next section, the associated facts about EMI in this reaction are discussed. In this section, a rationale is also presented that justifies the idea that a generalization of this kind of "QED" barrier can be applied in solids, involving resonant forms of interaction, associated with approximate translation symmetry. Elsewhere[1], it is argued that these forms of reaction can convert the γ-ray that occurs in the conventional situation, through generalized forms of parametric down conversion processes, into many, lower frequency photons in smaller, finite solids, and can cause electromagnetic emission to completely disappear, and the associated energy and momentum to be dispersed through radiation-less processes, in larger solids. The motivation for both arguments is: 1. Because time-dependent EMI effects can cause particles separated by macroscopic distances to interact with each other, the presence of this alternative "barrier" suggests that coupling can occur between many different "particles," located at positions that are separated by considerably larger distances than in the dominant ($d+d\rightarrow{}^3He+n$ and $d+d\rightarrow t+p$; p=proton, n=neutron, t=triton=^3H) hot fusion reactions, where a static, Coulomb barrier, at close separation, can be used; and 2. In situations that are consistent with the palladium-deuteride experiments, many particles are allowed to "move" rigidly (i.e., when the particles are capable of moving without the relative position of any of them relative to the others being altered, while the location of their center-of-mass is allowed to change); and 3. As a consequence of approximate periodic order, the associated forms of overlap can result in highly non-linear coupling through EMI that can lead to new (potentially massive) forms of parametric down conversion processes (as discussed elsewhere[1]).

In this section of the present paper, I argue that resonant EMI effects not only can explain how Low Energy Nuclear Reactions (LENR), involving $d+d\rightarrow{}^4He+23.8$ MeV, can take place, but these effects are based on an assumption that changes in the time-dependent interaction potential, associated with EMI, as opposed to the changes in the time-dependent strong force, are responsible for the effect. This assumption, in turn, is consistent with the situation in the $d+d\rightarrow{}^4He+\gamma$ reaction, and the observation that the associated "QED" barrier, associated with this reaction, is different from the Coulomb barrier that applies in conventional fusion. Because of an approximate symmetry associated with rigid translations, it is possible to explain the commonly observed $d+d\rightarrow{}^4He+23.8$ MeV reaction, through a form of resonant EMI, and the fact that it occurs without high energy particle emission.

In the following section, some new results associated with applying a generalization of conventional energy band theory are summarized. The generalization, which is explained in detail elsewhere[1, 2], involves including finite size effects in a more precise way than they are included in the conventional theory, in which a model has been used that involves infinitely repeating, periodically ordered unit cells. The generalization is based on an approximate form of resonant EMI that applies to the ground state (GS) and the lowest energy excitations of the GS, which are associated with the kinds of rigid forms of translation, alluded to above.

Here, a situation involving approximate forms of palladium (Pd)-deuterium (D) compounds is discussed and generalized, associated with a "hypothetical" limit (approaching stochiometric palladium-deuteride, PdD), defined by PdD_x, $x \rightarrow 1$, that we suggested earlier in the ion band state theory of cold fusion could initiate excess heat effects[3]. In particular, in the present paper, a more realistic model is introduced, based on the assumption that in finite lattices, involving real boundaries, dynamical effects can evolve that can explain a number of the known effects and be used to make new predictions. As opposed to the "quasi-particle" formulation (which was presented previously), inferred from an argument based on energy minimization, leading to the possible occupation of a potentially unstable, initial state, from which cold fusion could be initiated[3,4,5], a new, dynamical picture is identified, in which a nuclear transition can take place, in which all of the particles in a particular region, possessing approximate periodic (translational) symmetry, can accelerate, rigidly, (i.e., without altering any of the inter-particle separations), relative to regions that do not possess this approximate symmetry. The resulting picture, in general terms, involves, long wave-length, rigid oscillations, of charged deuterons, and applies in sufficiently large crystals, in a semi-classical limit, through effects that are strikingly similar to the oscillations suggested by Giuliano Preparata[6]. An important distinction is the resonant coupling picture, presented here, includes effects, involving deuteron-deuteron exchange, and electron-electron exchange, that are not included in Preparata's model. The present, resonant EMI model also includes finite size effects that he does not include, except in very general terms. A common point in both theories involves the importance of boundaries. In his model, these enter through the idea of fixed fluctuations in what he refers to as the vacuum zero. He also estimates these fluctuations. In the finite-size QED model, presented here, this concept is generalized, based on the idea that the associated fluctuations, in principle, can be arbitrary, and their magnitude and their coupling to potential reactions are determined by the allowable forms of overlap that are consistent with externally applied fields and the sizes of the potential crystal lattices where the potential reactions are initiated.

Importance of the QED (as Opposed to the Coulomb) Barrier in $d+d \rightarrow \alpha+\gamma$

By assumption, within the conventional picture of nuclear fusion, a static Coulomb barrier is used to explain how same-charged, heavy hydrogen nuclei (deuterons-d's) can have appreciable overlap. In this conventional picture, d's initially approach each other with such a high velocity that their momenta do not change appreciably, except when their separation approaches nuclear scale, where they are allowed to interact dynamically entirely through the strong force, and the EMI can be treated, entirely statically (through the semi-classical, Coulomb barrier model), based on the standard (WKB), Gamow-Teller tunneling formula. Fig. 1 shows a schematic diagram of how the most frequently observed reactions occur. In the figure, two proton-neutron pairs collide at a point, where the two pairs can be viewed as forming an “excited state” of a helium-4 nucleus, in which the dynamical changes are dominated by the strong force. In this limit, the distinction between protons (p’s) and neutrons (n’s), at the point of nuclear contact, effectively (except through differences in kinetic energy, associated with changes in mass that do not relate to time-dependent EMI effects), is inconsequential, and the normal, intuitive picture that nuclear physicists have applies: The most frequent reactions occur when the amount of nuclear energy that is released is minimized.

Based on this intuitively appealing idea, most nuclear physicists assume that the least common reaction ($d+d \rightarrow \alpha+\gamma$) occurs infrequently because the energy release (23.8 MeV) is considerably (7 to 8 times) larger than it is in the remaining reactions. In fact, this picture is not right. Important details about time-dependent, EMI effects, which are responsible for the fact that the $d+d \rightarrow \alpha + \gamma$ reaction occurs rarely (a fact that was not appreciated even by Schwinger and Preparata[6]), have been ignored. In Fig. 2, a second schematic diagram is used to illustrate this fact.

In particular, the fact that EMI plays a central role is this reaction is known because although $d+d \rightarrow \alpha+\gamma$ rarely occurs, the reverse reaction (the photo-dissociation process: $\gamma+\alpha \rightarrow d+d$) has been studied in detail. As discussed elsewhere [1], it is known, implicitly, as a consequence, as opposed to the conventional picture, involving a static Coulomb barrier, and the common, intuitive idea that the large energy release that is involved is responsible for the reaction occurring infrequently, an alternative model applies: Selection rules exist and a well-defined electro-magnetic transition is involved in the photo-dissociation process. The analysis shows quite conclusively that the reaction can be explained as resulting from a well-characterized (quadrupolar) transition, in which the total spin of the final state d’s vanishes and that it is necessary to include the effects of EMI (and the requirement that the d’s obey Bose Einstein statistics) on length and time-scales that are far from the location of the photo-dissociation process. Because in QED, the rate of any transition is proportional to the absolute square of the associated transition matrix element, by construction, the theory requires that a transition rate forward in time be equal to the comparable rate for a transition backward in time. As a consequence, the common intuition, that this reaction does not occur frequently because of the large energy release, is wrong.

An important point has and continues to be the role of time-dependent effects in QED phenomena. The potential relationship of these EMI effects in potential nuclear fusion reactions, and in LENR, involving $d+d \rightarrow {}^4He$ is not widely appreciated because it is widely believed that the charge-neutral, strong force potential provides the time dependent dynamics associated with the reaction.

An important reason for this is that, as outlined above, the importance of the effect of QED in $d+d \rightarrow \alpha+\gamma$ is not widely appreciated because this reaction, superficially, appears to be dominated by strong force effects since it conserves isospin and also because it is believed, as a consequence, it occurs infrequently because the energy from the reaction is so much larger than the comparable reaction energies associated with the other reactions. The possible importance of QED in the LENR situation, and the possibility that approximate symmetry in this situation might be important, in solids, has not been widely considered probably because the conventional theory, of periodically ordered solids, that is commonly used, involves a semi-classical limit that does not include the possibility that, effectively, many channels for de-excitation can become possible through resonant phenomena in which an approximately ordered lattice is allowed to move and accelerate, rigidly. In this situation, in principle, all of the charged particles in a particular region can "move" together at once, in such a way that the separation between any two particles does not change.

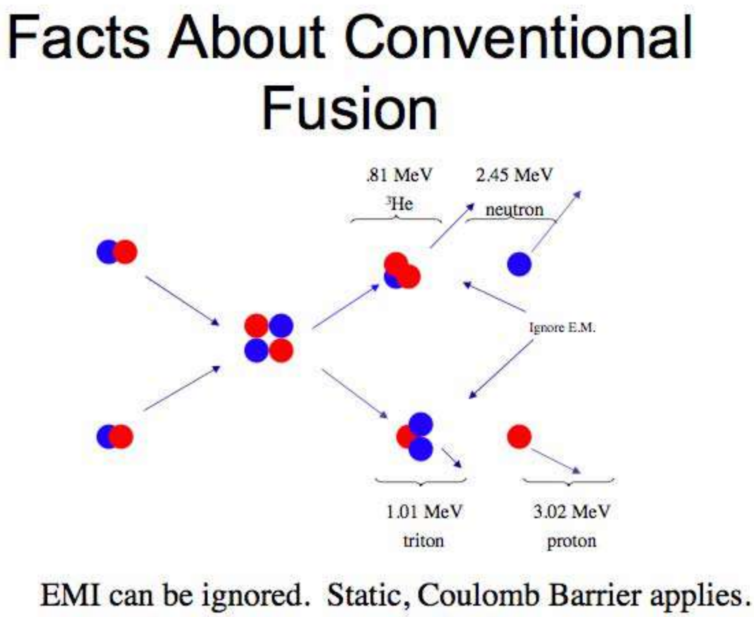

Figure 1. Schematic diagram of dominant Hot Fusion Reactions; on the left-side two deuterons, pictured as two proton-neutron pairs (each pair has a single proton—shown as a red sphere—and a single neutron—shown as a blue sphere) come together with high velocity, where conventionally, they are viewed as forming an excited state of a helium-4 nucleus, which is pictured as four nucleons (two red spheres and two blue spheres), near the center of the figure. As shown in the figure and explained in the text, in these reactions, the time dependence in the electromagnetic interaction (EMI) can be

In fact, collisions between charged particles at the "boundaries" of such a region with "particles" outside the region introduce forms of coupling that limit the extent and lifetime of these forms of "rigid-body" motion. In fact, because it is never possible to identify where the "boundary" of such a region occurs, implicitly, the lowest energy excitations that result from these forms of approximate symmetry occur through resonant

EMI processes, in which momentum and energy are conserved globally, and the perturbations (resulting from collisions) that result involve situations in which the net flux of each kind of particle into and away from the "ordered" region vanishes. Possible coupling between different configurations involving different center-of-mass velocities (and momenta) necessarily can result in forms of approximate degeneracy, and (as a consequence) many alternative forms of partial excitation and de-excitation can take place.

In free space, comparable forms of coupling are not present. As summarized elsewhere[1], in a finite solid, not only through these kinds of effects, can the "single γ ray" be converted into many (lower frequency) photons, but through the Zener/ionic breakdown model summarized here (and elsewhere [7,8, 1]), the phenomenon can occur through a time-dependent process, involving a form of coherent tunneling, in which the necessary changes in momentum for triggering the reaction can increase in magnitude with time.

"Secret Reaction" ($d+d \rightarrow {}^4He+\gamma$) Has QED (as opposed to Coulomb) Barrier

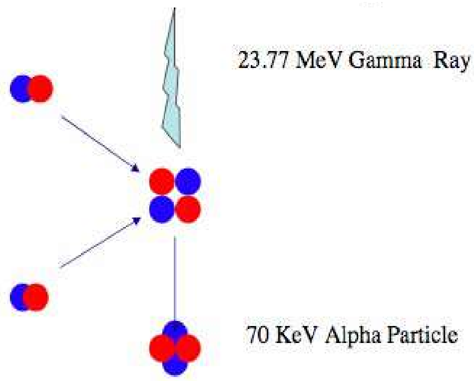

FIGURE 2. Schematic Diagram of $d+d \rightarrow {}^4He+\gamma$; the common assumption, that the reaction occurs infrequently because the energy release is too large and involves a static "Coulomb Barrier," is wrong. The relevant dynamical interaction potential V *does not involve the strong force*. V is proportional to $J(r,t) \bullet A(r,t)$ ($J(r,t)$=current at location r and time t; $A(r,t)$="vector potential," which creates and/or destroys photons), has both a time- and spatial- dependence everywhere, not just in the neighborhood of the reaction. This reaction is rare because far from the reaction, proton (red sphere) neutron (blue sphere) pairs are prepared with vanishing, total spin, and with relative, orbital angular momentum $l=2\hbar$. The reaction, which occurs through a quadrupolar transition, has a dynamical range that is considerably longer than the conventional strong force dynamical range, associated with $d+d \rightarrow {}^3He+n$ and $d+d \rightarrow {}^3H+p$.

Roles of Approximate Symmetry and Finite Size in Resonant EMI in $d+d\rightarrow{}^4He+23.8$ MeV in PdD

A detailed description of resonant EMI is provided elsewhere[1]. This paper also summarizes how resonant EMI effects can be used to relate conventional energy band theory, as it applies to infinitely repeating, periodic lattices, to situations in which the lattices possess finite extent. An important point is that although it is impossible to precisely determine the boundary of an approximately ordered region of a solid, because the ground state and lowest lying excited states are required to have minimal overlap with processes that couple to the outside world through the exchange of energy and/or momentum, it is possible to identify important forms of approximate translational symmetry (associated with rigid displacements of approximately ordered regions), involving a form of Galilean invariance, that can be used to characterize and identify the lowest energy excitations. In the limit in which these excitations involve no net flux of particles and momentum, forms of “resonant” coupling can take place, in which, in the interior of the periodic regions, rigid forms of oscillatory motion (referred to as “Bloch Oscillations”) are allowed to take place, in which the separations between particles do not change. When these oscillations occur, the center-of-mass (CM) momentum of large numbers of d’s (which effectively can occupy a single state, through the formation of a Bose Einstein Condensate) can increase, and coupling (through the time evolution between states involving different CM momenta) can take place that can result in large changes in the relative momentum between d’s, over short length scales, when externally applied, static, electric fields are applied.

Through these resonant EMI’s, effectively, a finite region of a solid, that is approximately periodically ordered, can appear to behave like one of any number of “moving targets,” in sufficiently small crystals, that can absorb changes in momentum, rigidly, through many possible processes (referred to as “virtual processes”) that are entirely elastic and conserve momentum, non-locally, but provide a way, for momentum to be transferred instantly to the CM of a system or a portion of a system, involving many, charged particles. This can explain how the momentum (and energy) from a potential reaction (involving many different states) can couple to the environment that is profoundly different from a situation involving two isolated d’s colliding at a point. Ideas associated with resonant EMI can be used to explain the underlying dynamics. In particular, an analogy exists between a situation involving triggering effects associated with resonant EMI’s, resulting from finite size effects, in possible LENR, involving $d+d\rightarrow{}^4He$+energy, with an alternative situation, involving the acceleration effects associated with gravity, in a different (known) system (not related to LENR).

These kinds of processes, in principle, provide a way for many particles to transfer momentum coherently to many different, indistinguishable locations where particles can be present, instantly, through virtual processes that allow for the possibility that changes in momentum between two, indistinguishable particles can become large, without either particle acquiring large momentum or velocity. With increasing time, larger and larger changes in momentum over shorter and shorter length scales are allowed to take place, through these ("Bloch") oscillations. Provided collisions, between particles, occur sufficiently slowly, these forms of resonant EMI can induce nuclear dimension overlap and interaction, in which the dominant, dynamical portion of the interaction potential involves QED, not the strong force. Here, in particular, the initial and final states are eigenstates of a static, as opposed to dynamic, strong force potential, in a manner that is similar to the way that the initial and final states in an atom, prior to an electromagnetically induced transition, are defined to be eigenstates of a time-independent (electrostatic) potential.

The analogy that exists between the kind of situation involving triggering effects associated with resonant EMI's, resulting from finite size effects, in possible LENR, involving $d+d \rightarrow {}^4He$+energy, with identifying the acceleration effects associated with gravity, is related to the underlying dynamics. In both situations, it is possible for a periodic "lattice" (or a portion of it) to accelerate rigidly. In the alternative system, involving gravity, the "lattice" (which is referred to as an optical lattice) is created artificially, by introducing an interaction between finely tuned counter-propagating laser beams, and an Atomic Bose Einstein Condensate (ABEC). In particular, an ABEC is formed, using characteristic (nearly resonant) excitations of an alkali vapor, through non-linear optics and applied, external magnetic fields (using a magneto-optical trap—or MOT), through a process that is referred to as Laser Cooling. After the ABEC is formed, the initial fields are turned off, and counter-propagating laser beams are turned on, at a frequency (or frequencies) that is (are) finely tuned, relative to each other. When this (these) frequency (frequencies) is (are) far from the resonant frequency that is used to form the ABEC, the counter-propagating laser beams are used to form standing waves that interact with the ABEC, effectively, in an elastic fashion. Because the associated ABEC laser beam scattering (which occurs through the A.C. Stark effect) involves a periodic electromagnetic field, effectively, the atoms in the ABEC interact with a periodic potential (referred to as an optical potential), and provided the ABEC remains confined, within the region that has approximate periodic symmetry, the atoms in the ABEC can behave cooperatively in a way that is similar to how deuterons can behave, when they are in a common (Bose Einstein Condensate) ion band state, and they interact with a periodic potential.

In the situation involving an ABEC, it is possible to control the velocity of the (optical) lattice precisely and, effectively, to make it accelerate, relative to the atoms in the ABEC, by externally increasing or decreasing the frequency of one of the laser beams, in a manner that varies linearly with time. The associated "chirp" procedure can be used to induce an acceleration that closely mimics the acceleration that is induced in the center-of-mass motion of the ABEC, as a result of gravity, provided the lattice is sufficiently small, and the external fields induce an acceleration that is sufficiently close to the gravitational acceleration. Because it is never possible to determine if the "lattice" (in these kinds of situations) is either in motion or at rest, a potentially huge time-dependent degeneracy is present (associated with alternative configurations in which the lattice "moves" with slightly different velocities), that can result in implicit forms of coupling, through "virtual" transitions, that are required to take place in the limit in which particle-particle collisions (resulting from interaction at the boundaries of the lattice) are allowed to take place.

A feed-back (servo-) mechanism, involving altering the chirp frequency, in response to changes in the occupation of atoms within the ABEC, can be constructed that, in principle, can force the gravitational and lattice acceleration to approach each other. This can be accomplished by altering the chirp frequency in response to changes in the intensity of absorption and/or fluorescence images of the atoms, that are formed by turning off the counter-propagating lasers and simultaneously tuning one of the lasers to a nearly-resonant frequency.

In the LENR situation, the boundaries "of the lattice" occur in regions where charge, locally, need not be conserved, which not only includes regions immediately at the boundaries of the lattice (near surfaces and interfaces, where periodic order disappears), but it also includes regions where deuterons potentially can have overlap at nuclear-size length-scale. When changes in momentum in these (nuclear) regions become appreciable over a sufficiently small length-scale, nuclear reactions can occur, in which the momentum of the reaction is transferred rigidly to all of the d's that potentially can interact, and (in sufficiently small crystals) the helium-4 product is released at the boundaries of the lattice. In this situation, as opposed to "chirping" a laser, to cause the "lattice" to accelerate, provided the "lattice" is sufficiently small and/or an applied electric field is sufficiently weak, the analogous configuration, associated with confining the atoms in the ABEC within the optical lattice, occurs at the point of perfect stoichiometry: x=1 in PdD_x. The associated limit, in nano-scale crystals, in which the lattice accelerates, can occur when an external, static, electric field $\vec{E}$, that is sufficiently weak, is applied.

When this occurs, resonant forms of interaction can take place when the change in momentum Δp of the CM of any collection of indistinguishable, charged particles equals the product of a reciprocal lattice vector, G_n, with $\hbar$ (i.e., when $\Delta p = \hbar G_n$). When this occurs, momentum can be transferred coherently (and rigidly) to the center of mass of the lattice. This resonant condition was postulated by Bloch to take place at each time t_n defined when the condition,

$$q\vec{E}t_n = \hbar\vec{G}_n, \tag{1}$$

is satisfied. Here, q is the total charge, associated with particles that are involved with the resonant condition, and the associated form of resonance (as identified above) is referred to as a Bloch Oscillation.

When the limit x=1 in PdD_x occurs (associated in the gravity situation with the limit in which no atoms leave the lattice), the most coherent form of interaction (which I have referred to Zener/Ionic breakdown in PdD[7,8]) can take place. This corresponds, effectively, to a situation in which the d's do not occupy ion band states (and can be viewed as being in an insulating state) but are constrained to acquire larger and larger momentum ($\hbar\vec{G}_n$), until the momentum reaches the critical value that is necessary to create the d+d→^{4}He reaction. In the semi-classical limit, the reaction will then take place provided the total energy E, defined by the integral of the power (expressed using the dot product of the force $\vec{F}$ of each "particle"— charged or neutral, and located inside or outside the lattice and/or the solid — with its possible velocity v), over time, equals 23.8 MeV. Here, when the applied electric field $\vec{E}$ is constant and uniform, within the lattice, each value of the wave-vector, for each electron and ion band state, evolves from its initial value, k_o, through the associated change in the zero of momentum[2], defined by $\vec{k}(t) = k_o + q\vec{E}t$.

Then, inside the lattice, the possible electron and ion band (excited) state transitions associated with the resonant effect can be constructed using the representation of the power (defined by the product of the charge of the particles in the band $q(\vec{k}(t))$, with the dot product, $\frac{\partial\varepsilon(\vec{k}(t))}{\hbar\partial\vec{k}(t)} \bullet \vec{E}$, between the group velocity $\frac{\partial\varepsilon(\vec{k}(t))}{\hbar\partial\vec{k}(t)}$ and the applied field, $\vec{E}$). In general, additional contributions to the power occur through forces and changes in the velocity of particles outside the lattice and/or the solid. In situations associated with gas-loading, a number of the more important, additional contributions can be constructed, using the applied pressure and density. Details about the associated construction are developed elsewhere[9]. Previously, I showed for the model to be self-consistent, the requirements that collisions be stifled, which require that when all d's occupy a common band, the group speed be sufficiently small and that the d's remain in an insulating state, lead to the result that the crystal be sufficiently large but not too large. Optimal crystals, in the context of this model, have characteristic dimensions of ~ 60 nm[7,8].

The possibility that overlap can take place at nuclear scale size is associated with the potential for momentum to change abruptly, over sufficiently short length scales. When this occurs, the conventional tunneling picture completely breaks down, and overlap becomes possible because the variance in momentum can become appreciable, through processes that are not forbidden by the uncertainty relationship. These forms of potential overlap become more likely with increasing time because as time increases, larger and larger changes in momentum can result from the associated forms of resonant coupling, through the oscillations of the charged particles within this approximately periodic region. A new result, in this context, involves the idea of modeling the underlying dynamics in smaller, nano-scale structures, in which these idealized compounds are allowed to form through resonant EMI, transiently, for finite periods of time, in which small variations δ, in loading $x=1\pm|\delta|$ are allowed to take place through EMI coupling that results from the possibility that d's and electrons associated with the variations in x involve the occupation of energy band states.

Provided $|\delta|$ is sufficiently small, this occurs in situations when $x = 1-|\delta|$, effectively, from ion band states that have "negative" ionic charge (and each of the associated states can be viewed as forming a "hole," in the ion energy band, similar to the positively charged "electron hole" states that can be created by doping a semi-conductor), and when $x = 1+|\delta|$, the situation can be viewed as involving the occupation of conventional (positively) charged, deuteron, ion band states. In an analogy with the situation associated with electron-hole pairs and electron-hole annihilation in semi-conductors, we can infer that in suitably small crystals, slight variations in loading, potentially triggered by external fields, in principle, can induce coherent fluctuations, involving delayed forms of excitation and the emission of light. The associated forms of coupling, potentially, can be generalized and be applied in other systems, including some of the kinds of situations encountered in some of the glow discharge work. These results, as well as other results, presented elsewhere[1], which suggest that the orientation of externally applied fields, potentially, can be important for triggering high energy particles in situations involving the SPAWAR protocol[10], suggest that it could be useful to conduct a series of experiments, involving a detailed investigation of the potential role of field orientation and variation, in possible forms of electromagnetic radiation emission and the creation of high energy particles.

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