

Erratum

## Errata and Comments on a Recent Set of Papers in *Journal of Condensed Matter in Nuclear Science*

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### Abstract

Recently we published a series of papers that focused on coherent energy exchange in the context of the lossy spin–boson model in this journal. Minor errors have been identified, and we provide corrections here. In addition, we give additional discussion of some of the issues.

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*Keywords:* Excess heat, Fleischmann–Pons effect, Spin–boson model

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### 1. Introduction

Over the years we have been developing the lossy spin–boson model as part of a proposed explanation for coherent energy exchange for the excess heat effect in the Fleischmann–Pons experiment. We recently documented some of our work on the model in a series of papers that appeared recently in this journal. After the papers were published, we noticed some errors while using them in the course of our research efforts. We found enough errors in both the text and in the equations that it seemed useful to go through them systematically and develop an errata.

However, in working with the papers we noticed an additional issue as well. In some cases results are given that probably should have been discussed further, and there are subtleties which are probably worth additional comment. In what follows, we list the errors we have found, and provide some additional thoughts on a paper by paper basis.

### 2. Energy Exchange in the Lossy Spin–Boson Model

In [1] there is a discussion on page 59, in which degenerate states are discussed. As published, the text explains (paragraph 1): “States that are resonant (such as  $\Phi_1$  and  $\Phi_{12}$ ) are assumed to be stable against zero-energy decay

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process.” The word “resonant” here should probably have been instead “degenerate”.

### 2.1. Loss model

The loss model discussed in the main text of the paper [1], and derived in Appendix A, probably deserves further discussion. Perhaps the biggest issue is that the approach will be most useful in the case where the decay process is one-directional, so that we do not need source terms in the sector Hamiltonian. Within this restriction, pretty much any loss process can be modeled using the infinite-order Brillouin–Wigner formalism.

Oscillator loss mechanisms near  $\omega_0$  do not work this way if  $k_B T$  is on the order of  $\hbar\omega_0$  or larger. In this case, it would still be possible to develop a model based on the formalism described, as long as it were augmented to include source terms for the coupling from the different sectors. The coupling between the different sectors in such a problem would greatly increase the amount of work needed to develop solutions, since one would need to develop solutions for the different sectors self-consistently.

As a result, we have recently been coming around to a point of view in which loss generally impacts the coherent energy exchange rate in the multiphoton regime of the spin–boson model, for the reasons described in the paper. It is not the case that we require some very restricted loss model or process to see the effect; instead, it is likely that the loss mechanisms associated with a physical system may be good enough in principle to do the job qualitatively, as long as the associated decay rates are sufficiently fast.

## 3. Dynamics in the Case of Coupled Degenerate States

In models based on operators that form a finite closed Lie group, Ehrenfest’s theorem will lead to a finite set of evolution equations that involve expectation values of those operators. This occurs for linear and quadratic position and momentum operators in the simple harmonic oscillator model. Although we have presented two-coupled evolution equations for the model under discussion describing coupling between neighboring degenerate states [2], the associated operators do not form a closed Lie group. We stop with the evolution equation of Eq. (17) on p. 76, since this is sometimes done in potential well problems in order to make a connection between the quantum version of the problem and the classical version of the problem. In the classical limit of the problem we can determine the force if we know the position (whereas in the associated quantum problem we only have an estimate of the expectation value of the force given the expectation value of the position).

## 4. Second-order Formulation and Scaling in the Lossy Spin–Boson Model

In the lossless version of the spin–boson problem, coherent energy exchange in the multiphoton regime only occurs when the coupling is moderately strong. Such coupling causes the levels of the two-level system to shift substantially. As a result, the resonance condition for coherent energy exchange would include this shift. We would denote this in the case of a three-quantum exchange as

$$\Delta E(g) = 3\hbar\omega_0, \quad (1)$$

where  $\Delta E(g)$  means the shifted transition energy, and where  $g$  is the dimensionless coupling constant, which in the lossless spin–boson model is

$$g = \frac{V\sqrt{n}}{\Delta E} \quad (\text{lossless problem}) \quad (2)$$

In the lossy spin–boson problem, we would also expect a shift to occur. As a result, the resonance condition should be written so as to include the shift. Equation (7) of [?] could reasonably be revised so as to take this into account:

$$\Delta E = 3\hbar\omega_0 \quad \rightarrow \quad \Delta E(g) = 3\hbar\omega_0,$$

where the relevant dimensionless coupling coefficient for the lossy spin–boson model is

$$g = \frac{V\sqrt{n}}{\Delta E} \sqrt{S^2 - m^2} \quad (\text{lossy problem}). \quad (3)$$

#### 4.1. Difference between lossy and lossless spin–boson models

However, there is an important difference between the two models that is worth some discussion. In the lossless spin–boson model, the individual two-level systems are very nearly independent (and especially so in the large  $n$  limit), and the dimensionless coupling constant can be interpreted as the ratio of an (adiabatic) interaction matrix element to the transition energy. What this means is that the interaction for each two-level system has to be very strong in order for the coupling to be strong. The large level shifts that occur in the lossless model are on the order of the transition energy for  $g$  near unity. This is reflected in the associated experiments where a great deal of effort is put in to find transitions with small energy differences and large dipole moments.

In the lossy spin–boson model, the dimensionless coupling constant must be large for substantial coherent energy exchange to occur when many quanta are exchanged. But in this case, the associated phonon exchange matrix elements are individually very small, and a large dimensionless coupling constant occurs only because of the presence of the Dicke factor  $\sqrt{S^2 - m^2}$  in the definition of  $g$ . This is not just a matter of different definitions, in the numerical calculations we find that the lossless model respects the smaller  $g$  definition, and the lossy model respects the larger  $g$  definition. The presence of loss results in cooperation between the two-level systems that is not present in the lossless version of the model.

#### 4.2. Level shifts in the lossy model

As a result, the level shifts that are included when we write  $\Delta E(g)$  for the lossy problem are very small, especially when  $|m| \ll S$ . The transition energy in the local approximation can be estimated from

$$\Delta E(g) \approx \Delta E + \Sigma \left( \frac{V\sqrt{n}}{\Delta E} \sqrt{S^2 - (m + 1/2)^2} \right) - \Sigma \left( \frac{V\sqrt{n}}{\Delta E} \sqrt{S^2 - (m - 1/2)^2} \right). \quad (4)$$

In the strong coupling limit

$$\Sigma(g) \rightarrow -4g \quad (5)$$

so that

$$\Delta E(g) \approx \Delta E + 4(V\sqrt{n}) \frac{m}{\sqrt{S^2 - m^2}}. \quad (6)$$

Away from the boundaries at  $\pm S$ , the shift in the transition energy is small.

We have recently analyzed the coupling for an E1 transition between the ground state and first excited state of  $^{181}\text{Tm}$ , with the result that the zero-phonon exchange matrix element is expected to be on the order of  $10^{-7}$  eV, and the single phonon exchange matrix element ( $V\sqrt{n}$ ) is near  $10^{-9}$  eV. These are very much less than the associated transition energy (6.24 keV). As a result the shifts expected for the lossy spin–boson model for  $|m| \ll S$  in Eq. (??) are quite small.

#### 4.3. Level shift near $m = -S$

Near the boundary at  $m = -S$ , the dimensionless coupling coefficient  $g$  becomes smaller since  $\sqrt{S^2 - m^2}$  approaches zero. In this case, we require an expression for the self-energy in the weak coupling approximation

$$\Sigma(g) \rightarrow -2g^2 \Delta E \quad (7)$$

We can use this to estimate

$$\Delta E(g) \approx \Delta E + 4 \frac{(V\sqrt{n})^2}{\Delta E} m \quad (8)$$

The transition between the two self-energy expressions occurs near  $g = 1$ , so the maximum shift has a magnitude on the order of  $2\sqrt{2}|V|\sqrt{n}\sqrt{S}$ , which may be significant.

### 5. Local Approximation for the Lossy Spin–boson Model

On p. 103 (paragraph 3) of [?] one finds written in connection with the two-laser experiment: “The excess power in these experiments is seen in many cases to persist when the lasers are turned off.” Unstated (but it should have been stated) is that this is in contrast to the single laser experiments, where the excess power turns off when the laser turns off.

A more significant error appears on p. 107 in Eq. (21), where the existing incorrect equation should be fixed to read

$$\Psi = \sum_m \sum_n d_m v_{n+m\Delta n} |S, m\rangle |n\rangle$$

The  $|n\rangle$  term here appears as  $|n + m\Delta n\rangle$  in [?]. As we shall see, this problem occurred more than once in the papers.

Equation (35) needs to be fixed as well; it should read

$$\frac{E(0) - E(\phi)}{E(0) - E(\pi)} \rightarrow \frac{1 - \cos \phi}{2}.$$

### 6. Coherent Energy Exchange in the Strong Coupling Limit of the Lossy Spin-Boson Model

On p. 120, we find in Eq. (18) the notation  $E(g)$ , which seems odd since previously the energy eigenvalue has been considered a function of  $\phi$ . In the local approximation, the energy eigenvalue is a function of  $\phi$  and also  $g$ , so that we might have used a notation  $E(\phi, g)$  throughout the papers. However, our focus was on the determination of the indirect coupling matrix element, so that the  $\phi$ -dependence was more important to us. So, in Eq. (18), we are interested in the dependence of the eigenvalue on the coupling strength  $g$ , where the spread of energies with different  $\phi$  is too small to be seen in a plot of the energy eigenvalues as a function of  $g$ .

We read on page 121 in Section 4 of [?]: “From the results of the previous section, we see that the solutions do not change suddenly between different values of  $n$ , which suggests that we might be able to develop a continuum model.” Sadly, the previous section discussed something else. The results which this refers to appear later on, and can be seen in Figs. 3 and 4.

On p. 129 Eq. (47) reads

$$v(z) = \text{Ai} \left[ \left( \frac{\Delta n^2}{2g} \right)^{1/3} (z - z_0) \right].$$

Now, as defined  $z$  only ranges between 0 and 1, so this solution should be assumed approximately good only in this range.

On p. 129, Eq. (51) is missing an  $a_m$ ; it should be corrected to

$$\begin{aligned} \epsilon_0 \langle u_n | u_n \rangle a_m &= \langle u_n | \frac{n}{\Delta n} | u_n \rangle a_m - g \langle u_n | u_{n+1} \rangle a_{m+1} - g \langle u_n | u_{n-1} \rangle a_{m+1} \\ &\quad - g \langle u_n | u_{n+1} \rangle a_{m-1} - g \langle u_n | u_{n-1} \rangle a_{m-1}. \end{aligned}$$

In this equation, we should interpret the notation  $\langle u_n | u_n \rangle$  and  $\langle u_n | u_{n\pm 1} \rangle$  as

$$\langle u_n | u_n \rangle = \sum_n u_n^2, \quad \langle u_n | u_{n\pm 1} \rangle = \sum_n u_n u_{n\pm 1}, \quad (9)$$

where the summation includes the  $n$  values within one pulse over a range of  $\Delta n$ .

On p. 130, Eq. (53) is

$$\left\langle \frac{n}{\Delta n} \right\rangle = m + \delta n \left( \frac{g}{\Delta n^2} \right).$$

This should be interpreted as  $m$  plus the function  $\delta n$ , which is a function of the parameter  $g/\Delta n^2$ . The problem is that the same notation could indicate the some parameter  $\delta n$  should be multiplied by  $(g/\Delta n^2)$ , which was not intended. The existing text does not clarify this.

There is an unfortunate prefactor error in Eqs. (80) and (81) that badly needs to be fixed. Equation (80) should read

$$\Gamma_0 = \frac{1}{S} \left| \frac{dm}{dt} \right|_{\max} = \frac{8}{S} \left( \frac{\Delta E}{\hbar} \right) \left( \frac{g_{\max}}{\Delta n^2} \right) \Phi \left( \frac{g_{\max}}{\Delta n^2} \right) = 8\Omega_0 \Phi \left( \frac{g_{\max}}{\Delta n^2} \right)$$

and Eq. (81) should read

$$\Gamma_0 = 8 \frac{1}{(\Delta n)^2} \frac{V\sqrt{n}}{\hbar} \Phi \left( \frac{g_{\max}}{(\Delta n)^2} \right).$$

## 7. Generalization of the Lossy Spin-Boson Model to Donor and Receiver Systems

On p. 141 (paragraph 4) of [?], there are some minor typos. If we translate the resulting garbled text into English, we would read: “Unfortunately, in the experiments that have been done so far, we generally lack the experimental clarity that would result in unambiguous choices. Consequently, there is no agreement within the community of scientists working on the problem as to what states should be focused on, and at this point some discussion of the problem is worth while.”

On p. 146, Eq. (15) has an error and should be corrected to read

$$\Psi = \sum_{m_1} \sum_{m_2} \sum_n d_{m_1, m_2} u_{n+m_1 \Delta n_1 + m_2 \Delta n_2} |S_1, m_1\rangle |S_2, m_2\rangle |n\rangle.$$

The  $|n\rangle$  appeared instead as  $|n + m_1 \Delta n_1 + m_2 \Delta n_2\rangle$  in the published paper. A similar error shows up later on p. 148 in Eq. (29), which should read

$$\Psi = \sum_{m_1} \sum_{m_2} \sum_n d_{m_1}(t) e^{im_2 \phi_2} u_{n+m_1 \Delta n_1 + m_2 \Delta n_2} |S_1, m_1\rangle |S_2, m_2\rangle |n\rangle.$$

Once again, the oscillator state  $|n\rangle$  appeared incorrectly as  $|n + m_1 \Delta n_1 + m_2 \Delta n_2\rangle$ .

A minor error appears in Equation (30), which should read as

$$i\hbar \frac{d}{dt} d_{m_1}(t) e^{im_2 \phi_2} u_{n+m_1 \Delta n_1 + m_2 \Delta n_2} =$$

$$\begin{aligned}
& \left[ \Delta E_1 m_1 + \Delta E_2 m_2 + n \hbar \omega_0 - i \frac{\hbar}{2} \hat{\Gamma}(E) \right] d_{m_1}(t) e^{i m_2 \phi_2} u_{n+m_1 \Delta n_1 + m_2 \Delta n_2} \\
& + g_1 e^{-G} \Delta E_1 \left[ d_{m_1+1}(t) e^{i m_2 \phi_2} (u_{n+1+(m_1+1) \Delta n_1 + m_2 \Delta n_2} + u_{n-1+(m_1+1) \Delta n_1 + m_2 \Delta n_2}) \right. \\
& \quad \left. + d_{m_1-1}(t) e^{i m_2 \phi_2} (u_{n+1+(m_1-1) \Delta n_1 + m_2 \Delta n_2} + u_{n-1+(m_1-1) \Delta n_1 + m_2 \Delta n_2}) \right] \\
& + g_2 \Delta E_2 \left[ d_{m_1}(t) e^{i(m_2+1) \phi_2} (u_{n+1+m_1 \Delta n_1 + (m_2+1) \Delta n_2} + u_{n-1+m_1 \Delta n_1 + (m_2+1) \Delta n_2}) \right. \\
& \quad \left. + d_{m_1}(t) e^{i(m_2-1) \phi_2} (u_{n+1+m_1 \Delta n_1 + (m_2-1) \Delta n_2} + u_{n-1+m_1 \Delta n_1 + (m_2-1) \Delta n_2}) \right].
\end{aligned}$$

This error is that  $e^{i m_2 \phi_2}$  in the second line was instead  $e^{i m_2}$ .

### 7.1. Limit of slow receiver coherent energy exchange

In Section 5, we obtain results for the donor dynamics in the case that the receiver is strongly coupled to the oscillator. However, if we consider the donor dynamics under conditions where coherent energy exchange between the receiver and the oscillator is very slow (conditions under which the model would be expected to break down in some way), the overlap matrix elements may still be near unity for  $\Delta n_1$  values near  $\Delta n_2$ ,  $2\Delta n_2$ ,  $3\Delta n_2$ , and so forth (as shown in Fig. 2 of [?]). In this case, Eq. (34) seems to predict that donor transitions still occur under conditions where we would not expect them to. This issue seems worthy of further discussion.

After some consideration, it is possible to conclude that the origin of this effect is in the use of periodic solutions of the form

$$\Psi = \sum_{m_1} \sum_{m_2} \sum_n e^{i(m_1 \phi_1 + m_2 \phi_2)} u_{n+m_1 \Delta n_1 + m_2 \Delta n_2} |S_1, m_1\rangle |S_2, m_2\rangle |n\rangle.$$

Peaks in the overlap matrix element arise because the solution contains basis states of the form

$$\cdots, |S_1, m_1\rangle |S_2, m_2 - 1\rangle |n + \Delta n_2\rangle, |S_1, m_1\rangle |S_2, m_2\rangle |n\rangle, |S_1, m_1\rangle |S_2, m_2 + 1\rangle |n - \Delta n_2\rangle \cdots$$

Now, if coherent energy exchange occurs between the receiver and the oscillator at a rate faster than the relevant dephasing rate, then one would expect these states to be present and contribute to produce peaks. On the other hand, if this coherent energy exchange is very slow, then we would expect dephasing to dominate, and there would be no coupling between these distant nearly degenerate states. In this slow energy exchange limit, we would not expect a significant superposition of states to develop. In this case, a formulation in terms of periodic states is probably not appropriate, and the overlap matrix element associated with localized basis states would not show peaks in the overlap matrix element.

To include this effect, we require the development of a more sophisticated version of the model that includes dephasing effects when the coherent energy exchange is slow.

## 7.2. Lack of receiver transitions described by two-level systems

In the Introduction, we discussed briefly our efforts to find transitions that correspond to two-level models relevant to the receiver, with the conclusion that there were no transitions which could couple strongly to the lattice and also have a long lifetime. Strictly speaking, the analysis that led to this conclusion focussed on transitions in the different Pd, Pt, and Li isotopes since these are present near the cathode surface.

Subsequent work has identified an E1 transition in  $^{181}\text{Ta}$  at 6.24 keV which should be considered as a possible receiver for excess heat production in tantalum deuteride (or for the HD/ $^3\text{He}$  donor in tantalum hydride with some deuteration). In this case, the two-level lossy spin–boson model described in [?] could be relevant.

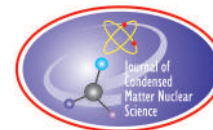
## 8. Discussion

There are many issues, discussions, and equations in these papers [1–6], so perhaps it should be expected that some of the equations might end up with errors, and also that some clarification might be needed. Although some of the errors that we found in the equations are unfortunate, in general they are either minor or annoying; fortunately, none of them as yet have resulted in a more significant problem with the basic theory under discussion.

In subsequent work we have found that if the strongly coupled two-level system is very lossy, then it does not get excited, yet still can act to produce a spread in the overlap matrix element corresponding to the lowest order peak in Fig. 2 of Ref. [6]. In this case there is no subdivision effect since there would be no real excitation of the receiver. The strongest such transitions appear to be due to nuclear configuration mixing under conditions where the oscillator is sufficiently strong to exchange phonons in association with the mass shift of the excited configurations. In this case, modeling the receiver using oscillator creation and annihilation operators is an approximation to what should be Duschinsky (phonon mode rearrangement) operators. In this case, when the oscillator is highly excited and the receiver is strongly coupled (with phonon exchange), donor transitions can occur if the spread of the equivalent lowest peak of the above-mentioned Fig. 2 is sufficiently broad.

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Letter to the Editor

## More Evidence of Microscopic Ball Lightning (Plasmoids) in CF Devices

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### Abstract

The traces and marks of micrometer-sized plasmoids have been found in many transmutation and cold fusion experiments. This author has counted about 12 groups that have published photographs that show such microscopic markings on their electrodes, experimental apparatus, X-ray films, or particle track-detecting nuclear emulsions. Twenty years ago, this author proposed a theory that these objects will be commonly produced in these kinds of devices. A survey article of such markings and traces exhibited in various experiments from the year 2000 to 2007 was published in this journal in 2009. In it, the author compared the markings to those previously detected by T. Matsumoto and K. Shoulders. In this letter, markings and features that were published more recently by Mosier-Boss et al. and Adamenko et al. are described. The author believes that this kind of highly anomalous microscopic plasmoid is similar to macroscopic natural ball lightning and so calls these objects "microscopic ball lightning." The author proposes that more focus on investigating these objects will greatly enhance the researchers' understanding of the processes involved in atomic transmutations.

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**Keywords:** Cold fusion, Microscopic ball lightning, Plasmoids, Traces, Tracks, Transmutation

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I thought Issue No. 4 for 2011 was good. There was a paper by the Mosier-Boss [1] showing structures and craters. I would like to comment about them. I think the concept of plasmoids is vitally important for CF researchers to understand since these are produced in CF devices and are a part of the energy output and effects. As I wrote in articles almost 20 years ago, since plasmoids produced in various devices behave like ball lightning, the natural phenomena and the experimentally produced phenomena are identifiable. Even if micro-meter sized ball lightning-type objects are not produced in a particular device or experiment, understanding the concept helps people to understand atomic effects when atoms transform to a ball lightning state. Here is an update about plasmoid effects in CF devices since my article was published in this journal in 2009 [2]; and to show evidence of the relationship of transmutation and plasmoids, K. Shoulder's evidence from the 1990s is described.

In the past issues of *Infinite Energy* starting from the earliest issues in 1997, there are articles I have written about plasmoid theory, ball lightning in CF-LENR devices, ball lightning and tornadoes. My most recent articles on this

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subject were published in *Infinite Energy* (Issue 83) and in the *Journal of Condensed Matter Nuclear Physics* in 2009 [2]. These two latest articles explain the BL markings and previously unknown phenomena such as post-experiment filament growth and plasmoid activity found by the several groups in the decade of the 2000s.

Now about 11 different groups have reported finding similar-looking unusual craters and markings that I believe are similar to those shown more than 14 years ago by Matsumoto and Ken Shoulders. The most recent new reports that I am aware of are those of Adamenko et al. who describe a “Lochak Monopole” hypothesis to explain the markings and those of the SPAWAR group and Mosier-Boss. Since I wrote the 2009 article in 2008, both Adamenko and Mosier-Boss have published microscopic pictures of their apparatus that show pits or craters. For example, Fig. 5b in the paper by Mosier-Boss et al. [1] shows a crater that could be due to the impact or the emergence of a ball lightning-type object. Compare it to the pit markings pictured in my 2009 article [2].

The pit in Figs. 4c and d of Adamenko’s article [3] is about  $1.6 \mu\text{m}$  wide, and its “sloshing” around it (as Ken Shoulders calls it) is probably due to the boring of a ball lightning object since a typical BL track leads to it. These kinds of “tire-track” traces (as several groups of Russian researchers termed them) also appeared in the experiments of Savvatimova and Urutskoev. The lip of material around the side of the half moon-shaped hole looks much like the lips of materials sloshed around the pits and tunnels photographed by Ken Shoulders. For example, similar sloshings are seen around the pits in Figs. 4–7, 9, 13, and 19 of Shoulder’s 1999 article titled “Charged Clusters in Action.[4]” His article is about the effects of EV (plasmoid) impact. Can it be simple coincidence that the pits are similarly shaped and of similar sizes? Or do the similarities imply that micro-BL is the cause of the markings in both Shoulders’ experiments and Adamenko’s experiments? In my article [2], I tried to explain that a spiral motion of BL objects may be the cause for several kinds of the tire-track markings of the researchers. Shoulders later wrote the same thing in an article.

Early evidence of the link between ball lightning and transmutation is in Shoulder’s 1999 article [4]. For the pit in Fig. 19 that was described above, Shoulders did an elemental analysis, and his results are shown in Fig. 20. That is clear evidence of elemental change at the point of the pit.

Recently, super-fast video cameras are revealing the pervasiveness of the ball lightning phenomena in nature. Ken Shoulders sent me links to recent videos of lightning bolts that were made by Tom Warner. By using a new kind of super-fast video camera, people can see that balls of light lead many of the lightning bolts before the bolts become visible. People can see the lightning bolts with their eyes. What they can not see are the big ball lightning moving around that lead the bolts and the bolts lighting up behind them. These bright leading objects are caught on the videos. The big balls of light that lead the lightnings are fast-moving macroscopic natural ball lightnings.

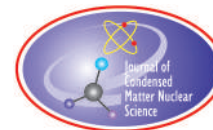
I would like to encourage researchers to study ball lightning and plasmoids. Plasmoid research goes back to W. Bostick, and the phenomena was pursued by Ken Shoulders. Winston Bostick called these objects that make these kinds of markings “plasmoids” decades ago. This information is important for researchers because a microscopic electrical object that most researchers do not know about plays a large part in transmutation and CF reactions. The more of them, the more energetic and transmutation effects according to reports by Matsumoto, Shoulders, and Savvatimova. Do people understand the connection to ball lightning? Natural ball lightnings are a kind of a general class of material objects I call “plasmoids”.

*PS*

I would also like to point out that there was a typographical error in the abstract of my 2009 article in the journal. Instead of “angstroms”, the unit of measurement should be micrometers. I think that there are micro-BL that are angstroms wide. However, I think the unusual microscopic pits and traces in their pictures are due to BL-type phenomena that are about 0.1–400 micrometers wide. I am sorry there was a typographical error. Maybe software put in the symbol automatically.

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Review Article

# Biological Transmutations: Historical Perspective

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## Abstract

In this review paper, it is shown that in biological systems, chemical elements can be transmuted into other elements. These facts have been established since the early 19th century, but they have been ignored by established science ever since. The purpose of this work is to show how during the past two centuries, a number of experimentalists have questioned the mass conservation law established by Antoine Lavoisier [1] for chemical reactions. They have proved experimentally in plants, bacteria and other living organisms, some elements are transmuted into other elements.

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*Keywords:* Biological transmutations, Cold fusion, History, LENR

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## 1. Introduction

The discovery of Cold Fusion in 1989 by Stan Pons and Martin Fleischmann [2] has triggered new attention in the field of biological transmutations. Even though experiments have shown that transmutations of elements occur in living cells, this field has been totally ignored by the scientific community. The situation is not different now, but recently new experiments, in particular, by Vysotskii and Kornilova [3] have brought new results using modern analytical techniques.

It is interesting to recall the situation of chemistry before Lavoisier, which was the time of alchemy, when the modern scientific method had not yet been developed. Also the nature of the elements had not been clearly identified.

Most of the works come directly from Herzelee's experiments. They triggered the experiments made by Baranger, Kervran, Goldfein, Holleman and then Vysotskii. Many experimental results described in this paper are not of a good quality because they have been performed in the 19th century or in the early 20th century, and the full data are not easily available. Some are coming from a secondary source, and therefore are less reliable. However, if we consider the totality of these data, including the most modern ones, there is compelling evidence that biological transmutations are a real scientific fact.

Very few theoreticians have tried to understand the possible mechanisms involved in these kinds of reactions, and it is more likely to take a long time before a reliable theory can be developed. One of the reasons is the lack of useful data where all elements before and after are well known to the scientists.

In this review, I also recall some of the works that I have performed myself [4] with germinating seeds and bacteria.

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## 2. Before Lavoisier

### 2.1. Jan Baptist von Helmont (1579–1644)

The work by von Helmont [5] in the 17th century is probably the first experiment that tried to study the workings of plants. He wanted to prove that the alchemical theory of the four elements was incorrect. He grew a willow tree in a clay vessel with 90 kg of dried soil. He covered the vessel with an iron cover having small holes. In his report, he explained that he did not take into account either falling leaves or dust. For 5 years, he watered the plant with filtered rainwater or if necessary with distilled water. He observed that the tree had gained 76 kg, whereas after drying the soil had only lost 57 g. He concluded: “Water alone had, therefore, been sufficient to produce 76 kg of wood, bark and roots”. Von Helmont proved that the elements of water and earth were not elementary, since water had changed into wood, bark and roots. This experiment proved that the elements of water could change into elements of soil.

## 3. Antoine Lavoisier (1743–1794)

In 1789, the famous French scientist Antoine Lavoisier [1] performed very accurate experiments showing conservation of mass during chemical reactions. He wrote:

*“ We can state as an indisputable axiom that under all conditions, artificial or natural, nothing is created; an equal quantity of matter exists before and after the experiment and nothing occurs outside the changes and modifications in the combinations of the elements ”.*

Unfortunately, for him and science, he was beheaded because of his function as “fermier général”, i.e. an unpopular tax collector of the old regime. It is also interesting to note his inventions of an accurate ice calorimeter to measure the heat of respiration of a guinea pig, proving that breathing is actually a combustion process.

Landolt [6] has confirmed the mass conservation during chemical reactions with better accuracy in 1908 with an accuracy of one part in  $10^6$ , and later in 1913 by Manly [7] with one part in  $10^8$ .

## 4. During the 19th Century

### 4.1. Johann Christian Carl Schrader (1762–1826)

From 1795 to 1797, the Berlin Academy of Science announced a competition with the following aim:

*“ Of which types of the earthly materials, which are encountered by means of chemical analysis, of native grain species? Do they either come into the grains as they are found or come into being by means of the life force and brought into growth by the workings of the plant? ”*

In 1799, the German scientist Schrader [8] won the competition for his experiments on the formation of minerals in grains. He used the seeds of wheat, barley and rye, amongst others, to germinate in an artificial medium of flowers of sulphur (amorphous sulfur in fine powder) (that was shown to be completely ash free) and watered with distilled water. The dust contamination was prevented during the experiments. From the analyses of the developed seedlings, he compared with the seeds which are planted, he concluded that the mineral matter had indeed been created.

#### 4.2. Henri Braconnot (1780–1855)

In 1807, the highly reputable French scientist Henri Braconnot [9] reproduced Schrader's experiments. He allowed plants from seed to grow on different artificial media (flowers of sulphur, red lead oxide, granulated lead, pure river sand and even an organic product; decomposed wood that was extracted using hot water). He concluded that considerable formation of the mineral components, especially potassium in experiments with mustard seed and radish, had taken place.

#### 4.3. Louis Nicolas Vauquelin (1763–1814)

In 1799, the French chemist Louis Vauquelin [10] became intrigued by the quantity of lime which hens excrete every day. He isolated a hen and feed it a pound of oats, which were analyzed for lime (CaO). Vauquelin analyzed the eggs and faeces and found that five times more calcium was excreted than was consumed. He observed, not only the increase of calcium but also a subsequent decrease of silicon. He is certainly the first scientist to have demonstrated the biological transmutation of silicon into calcium.

In his conclusion he remarked that a loss of only 1.274 g of silica cannot account for an increase of 14.118 g of limestone. He concluded that lime had been formed, but could not figure out how it happened. Further more, he encouraged other scientists to replicate his experiment.

#### 4.4. Albrecht Thaer (1752–1828)

In the 18th century organic reactions are attributed to a "life force". Thaer [11] showed that under some circumstances, calcium transforms into silicon. According to him, silicon could come from potassium. Under certain circumstances calcium in the plant became changed into silicon, whilst this substance may itself be formed from potassium

#### 4.5. William Prout (1785–1850)

In 1822, the English physiologist, Prout [12] studied chicken eggs in incubation. He found that hatched chicks had more lime (calcium) in their bodies than originally present in the egg, and it was not contributed from the shell.

#### 4.6. Wilhelm Augustus Lampadius (1772–1842)

In 1832, Lampadius [13] thought that plants themselves create silicon in plants.

#### 4.7. Vogel

In 1844, a German researcher named Vogel planted watercress seeds (*Lepidum sativum*) in a bell jar in crushed glass in a controlled air environment. They were fed nothing but distilled water, yet when grown they contained more sulphur than had been in the seeds originally. J.J. Berzelius reported the experiment in his book [14]. Vogel's answer was that sulphur was not a simple element or that sulphur was introduced from sources unknown.

#### 4.8. Choubard

In 1831, Choubard [15] germinated watercress seeds in clean glass vessels and showed that the sprouts contained minerals, which did not previously exist in the seeds.

#### 4.9. John Bennet Lawes (1814–1900) and Joseph Henry Gilbert (1817–1901)

In 1856–1873, two British researchers, Lawes and Gilbert observed an inexplicable variation in the amount of magnesium in the ashes of plants. They could “extract” more elements from the soil than the soil actually contained in the first place, in particular the formation of magnesium in grass.

#### 4.10. Albrecht Von Herzelee(1821–?)

In 1876 Herzelee [16], a German pharmacist published a series of books in which he showed research proving that plants continuously create material elements. From 1875 to 1883, in Berlin, he conducted 500 analyses with different types of seeds. He worked with: clover, crimson, vetch, rapeseed, barley, watercress, bean, white beans, kidney beans, turnips, rye, peas lupine, coltsfoot and angelica. A typical experiment showed the variation of calcium, potassium and phosphorus in *Vicia sativa* during germination with or without addition of mineral salts in distilled water. Also he showed that the addition of various calcium salts to the medium increased the formation of potassium. The addition of  $K_2CO_3$ , increased the formation of calcium.

He concluded that “Plants are capable of affecting the transmutation of elements”. His publications outraged so much the scientific community of the time that they were removed from libraries. His writings were lost for more than 50 years until about ca.1930 when a collection was found by accident in Berlin by Dr. Hauschka, who subsequently published Von Herzelee’s findings (the philosopher W.H. Preuss had dedicated an article to him; Preuss defended the idea that inorganic nature was a product of the organic; Herzelee was in agreement, apparently inspired by Goethe).

### 5. During the 20th Century

#### 5.1. Freudler

Freudler was a Professor at the famous French University, La Sorbonne. In 1928, he published a book based on his 10 years of research on the production of iodine by algae. He noticed a connection between tin and granite in which the algae produced and iodine in the plants.

#### 5.2. Earle Augustus Spessard

In 1940, Spessard [17] performed an experiment in which an organic process was studied in a hermetically sealed container. The bottles were weighed after some years. At the end, living protozoa were still seen through the glass walls. Presumably plant assimilation and animal respiration followed each other more or less in balance. There was a weight *increase* of a few tenths of a milligram (with a balance accuracy of 0.02 mg). Sources of errors, so far as they were known, were carefully eliminated. The predicted continuation of this work did not appear. The increase in weight that was found was far too big to be considered as a “materialization” of the received light rays.

#### 5.3. Rudolph Steiner (1861–1925)

Rudolph Steiner [18] in 1924 gave a series of lectures giving indications for the development of a new approach to agriculture that later became known as biodynamics. In the 5th series of his lectures, he referred to composting, he stated “even according to the purely external standards of analytical chemistry, this ought to betray the fact that there is a kinship between the way in which oxygen and nitrogen are connected in the air and that in which lime and hydrogen are connected in organic processes. Under the influence of hydrogen, lime and potash are constantly being changed into nitrogenous matter, and finally into actual nitrogen. And the nitrogen, which has come into being in this way, has a

tremendous value for plant growth. Silicic acid, as we know, contains silicon and this in turn undergoes transmutation in the living organism. It is changed into a substance which is of exceptional importance but which is not reckoned by present-day science to be among the elements.”

#### 5.4. Henri Spindler

In 1946–1947, the French Scientist and Director of the Laboratoire Maritime de Dinard, Spindler [19] discovered Herzelee’s work on the decrease of phosphorus and increase of calcium. In 1959, he measured an increase of iodine by 30% in algae, *Laminaria flexicaulis* and 80–100% in *Laminaria sacharina*.

#### 5.5. Rudolf Hauschka (1891–1969)

An Austrian chemist, Hauschka [20] during the years 1934–1940, in sealed glass containers, weighed cress seeds, and found an increase in weight of 0.54% during the full moon, and a decrease of 0.58% during the new moon. He published several books in which he re-evaluated Herzelee’s work, which he included as appendix in his books, *Substanzlehre* (though it has not been included in the English translation, *The Nature of Substances*).

#### 5.6. Perrault

French scientist Perrault [21], from the Paris University, found that the hormone aldosterone provoked a transmutation of Na to K, which could be fatal to a patient.

#### 5.7. Julien

Julien [22] was a French Scientist, from the Besançon University. In 1959, he proved that if tench are put in water containing 14% NaCl, their production of KCl increased by 36% within 4 h.

#### 5.8. George Oshawa (1893–1966)

Oshawa [23] was a Japanese scientist, and an inventor of macrobiotics. He collaborated with Louis Kervran. His opinion was that transmutation occurs during mastication.

#### 5.9. Pierre Baranger (1900–1970)

Pierre Baranger was a French Scientist, a professor of organic chemistry at the famous Ecole Polytechnique, and head of the Laboratory of Chemical Biology. He became intrigued with Herzelee’s experiments, but he thought that the number of trials had been too limited and the precautions against error were insufficient. Baranger decided to repeat the experiments with all possible precautions and a very large number of cases, which would allow a statistical study. His research project from 1950 to 1970 involved thousands of analyses. Baranger verified the content of phosphorus, potassium, calcium and iron of vetch seeds before and after germination in twice-distilled water to which pure calcium chloride was not added. Hundreds of samples of 7–10 g each were selected, weighed to 1/100th milligram, and graded, then germinated in a controlled environment.

Baranger found an increase of 4.2% in calcium, and 8.3% of iron, and subsequently a decrease in phosphorus of 1.9%, and of potassium of 1.1%. Interestingly, an addition of  $\text{MnCl}_2$  increases the amount of iron produced.

None of the specialists who examined Baranger’s work were able to find any experimental errors. Baranger concluded:

*“These results, obtained by taking all possible precautions, confirm the general conclusions proposed by Von Herzele and lead one to think that under certain conditions the plants are capable of forming elements, which did not exist before in the external environment”.*

In May 1959, he submitted an article for publication in the French Academy of Sciences, but was not accepted. Later in 1972, his family tried another submission without success. He had difficulties in publishing his findings, and died without being able to do so. Later, in 1977, his family asked Jean Marie Gatheron, a close friend of Baranger to publish Baranger’s work [24]. In 1976, his family submitted the final report of Baranger to the Academic Commission of the French Academy of Agriculture. It was decided that the work would be presented to the full assembly in a secret meeting. The proposal of publication in a public meeting was rejected without any reason.

Baranger failed to provide relevant theory to explain his findings.

#### 5.10. Leendert Willem Jacob Holleman (1906–1994)

From 1975 to 1989 Holleman [25], a Deutch scientist, performed experiments with alga *Chlorella*. He observed a decrease, then subsequent increase, of potassium. However, in spite of several attempts, he could not reproduce his own first positive experiments.

#### 5.11. Correntin Louis Kervran (1901–1983)

Kervran is certainly the most well-known scientist having worked in the field of biological transmutations. He had a broad knowledge of plants, geology and nuclear science. His findings have been published in French in ten books [26], some of them have been translated into English [27]. He was also nominated for the Nobel Prize.

##### *Observations*

From 1935 Kervran [28] collected facts and performed experiments, which showed that transmutations of chemical elements do indeed occur in living organisms. It started when he investigated fatal accidents from carbon monoxide poisoning when none was detectable in the air. Next he analysed why Sahara oilfield workers excreted a daily average of 320 mg more calcium than they ingested without decalcification occurring.

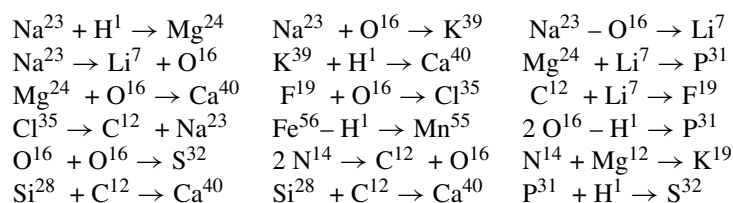
Kervran pointed out that the ground in Brittany contained no calcium; however, every day a hen would lay a perfectly normal egg, with a perfectly normal shell containing calcium. The hens eagerly pecked mica from the soil, and mica contains potassium. It appears that the hens may transmute some of the potassium into calcium.

##### *Experiments with seeds*

From 1960 to 1980, Kervran reported the astounding results of his research showing that living plants were able to accomplish limited transmutation of elements. Then Kervran was the Conferences Director of the University of Paris, and his first paper was published in *La Revue Générale Des Sciences*, July 1960.

Kervran found that in nuclide-biological reactions, oxygen is always in the form of O, never O<sub>2</sub>; reactions with nitrogen occur only with N<sub>2</sub>, insofar as is known. The following reactions have been proposed:





In 1980, Kevran [29] performed an experiment with oat seeds analysed using mass spectroscopy. They looked at phosphorus and calcium variations. They observed the following:

	Phosphorus (mg)	Calcium (mg)
Seeds	485	76
Plants	310	115.5
Difference (mg)	-175	+39.5

It is clear that the calcium increased with germination, whereas phosphorus decreased. There are certainly other elements that played a role, but they were not analysed in this experiment.

#### *The French Society of Agriculture*

In 1971, the laboratory of the French Society of Agriculture sprouted rye seeds under controlled conditions.

	Seeds	Sprouts	Difference (mg)	Difference (%)
Mg (mg)	13.34	3.20	-10.14	-335%
K (mg)	7.36	16.67	+9.31	+133%

These results are in good agreement with Kervran's previous findings.

Kervran was very active in promoting his work through books, conferences and mass medias. However, the Academy of Agriculture strongly opposed his efforts. In October 7, 1970, Stéphane Henin on one side and Léon Guéguen and Allez on the other side sent reports to the Academy by criticizing Kervran's results [30].

#### 5.12. J.E. Zündel

Zündel [31] was a Swiss scientist, head of a paper company, and a chemical engineer at the Polytechnic School of Zurich (ETH Zurich) in Switzerland. Following Kervran's observations from 1970, he studied germinating seeds and observed a 54–616% increase of calcium. In another experiment, he grew 150 oats seeds (fläminkrone) in a controlled environment for 6 weeks. 1243 sprouts were analysed using atomic absorption spectroscopy for the presence of magnesium and calcium. The potassium decreased by 0.033%, the calcium increased by 0.032%, and magnesium decreased by 0.007%. The variation of magnesium was not significant, but the decrease in potassium balanced the increase of calcium. In 1972 with oat seeds, he observed an increase of calcium of 118%, a decrease of magnesium of 23%, and potassium 29%.

In 1971, he gave a lecture at the French Academy of Agriculture (Bull No. 4, 1972). In his lecture, he announced the following variations between seeds and sprouts:

	SiO <sub>2</sub>	Ca	Mg	K
Seeds	111 mg	28 mg	27 mg	108 mg
Sprouts	123 mg	116 mg	27 mg	70 mg
	+10%	+314%	0%	–35%

In spite of the excellent quality of his works, the audience criticized him, including S. Henin, the head of the Department of Agronomy.

Later in 1979, Zündel, using a mass spectrometer at the the Microanalysis Laboratory of the French National Scientific Research Center, and neutron activation analysis at the Swiss Institute for Nuclear Research in Villigen (Aargau), confirmed the increase of calcium by 61%. There was also an increase of 29% in phosphorus and 36% in sulphur) [32].

However, the French Atomic Energy Commission has analysed Zündel's experiments in 1975 by neutron activation analysis of oat seeds. They found no change in calcium, sodium and manganese, but only a small decrease of potassium, also no isotopic variation in Ca<sup>48</sup> and K<sup>41</sup>.

### 5.13. Hisatoki Komaki

Following Kervran's work in 1970–1980, Komaki [33] from the Biological and Agricultural Research Institute studied the development of bacteria, mould and yeast. Among those: *Aspergillus niger*, *Penicillium chrysogenum*, *Rhizopus nigricans*, *Mucor rouxii*, *Saccharomyces cerevisiae*, *Torulopsis utilis*, *Saccharomyces ellipsoideus* and *Hansenula anomala*. Komaki reported that eight strains of microorganisms grown in potassium deficient culture media increased the total of potassium by transmutation of calcium to potassium. He also showed that phosphorus can be formed by the fusion of nitrogen and oxygen:  $N + O \rightarrow P$ . He even marketed a brewer's yeast product that, when applied to composts, increases their potassium content.

## 6. Present Times

### 6.1. Panos T. Pappas

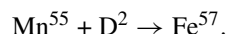
In 1998, Pappas [34] published an article suggesting that biological transmutation occurs as a form of cold fusion in the cellular membrane sodium–potassium pump. According to Pappas, the ions are not pumped back and forth through the membrane, but instead transmute back and forth between Na and K.

### 6.2. Jean-Paul Biberian

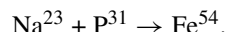
Experiments were performed with seeds: wheat and oats as well as bacteria: Marine bacteria (Marinobacter sp strain CAB) and Lactobacillus [4]. In most of the experiments, variations in the concentration of minerals have been observed. In particular, it is interesting to note that when the seeds grew, heavy metals decrease in large amounts. Even though these results are only preliminary, they confirm the observations made by others, in particular Kervran.

### 6.3. Vladimir Vysotskii

Vysotskii is a scientist from Ukraine. He started working on biological transmutations in the 1990s. He is well known for using modern analytical techniques. In particular, he used Mossbauer spectroscopy, very sensitive to  $\text{Fe}^{57}$ , to measure its production. In natural iron,  $\text{Fe}^{57}$  represents only 2.2% of the total. The main isotope of iron is  $\text{Fe}^{56}$ , which represents 91.7%. Measuring  $\text{Fe}^{57}$  is also very easy by mass spectroscopy, since there is no possible interference with another element. The proposed transmutation is

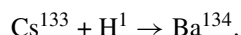


The experiments conducted by Vysotskii and Kornilova [3] were performed with bacteria capable of developing in heavy water. They chose *Bacillus subtilis*, *Escherichia coli* and *Deinococcus radiodurans*, as well as a yeast culture *Saccharomyces cerevisiae*. When manganese was introduced with  $\text{MnSO}_4$ , a clear spectrum was measured, indicating that manganese had been transmuted into iron. The authors analysed the material by time-of-flight mass spectroscopy showing that the mass 57 peak was as large as that of mass 56. This is another confirmation of the production of  $\text{Fe}^{57}$ . Vysotskii and Kornilova have also analysed another reaction

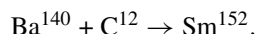


In natural iron,  $\text{Fe}^{54}$  represents only 5.8%. The bacteria developed in a medium without iron, and after development they measured  $\text{Fe}^{54}$  as large as  $\text{Fe}^{56}$ .

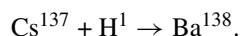
In similar experiments they observed the following reaction



In experiments destined to reducing radioactivity, they conducted experiments with synthetic microbiological cultures, which were up to 20 times more effective than the standard microbiological cultures. It was shown that  $\text{Ba}^{140}$ , which is radioactive with a half-life of 12 days, transforms into  $\text{Sm}^{152}$ , which is stable with the possible following reaction:



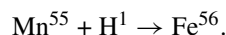
Interestingly,  $\text{Cs}^{137}$ , which is radioactive with a half-lifetime of 30 years, transmutes into  $\text{Ba}^{138}$ , which has a much shorter lifetime of 310 days.



This work is certainly the best proof of biological transmutations.

### 6.4. Edwin Engel, Rudolf Gruber

In 2006, Engel and Gruber [35] from Germany wished to confirm Kervran and Baranger's works. They showed that during germination, manganese transmutes into iron. They used mung beans sprouted in  $\text{MnCl}_2$ . They showed an increase of iron. They assumed the following reaction



## 7. Negative Experiments

Even though many positive experiments have been performed by indicating the reality of the phenomenon of biological transmutations, several experiments contradict these findings.

#### 7.1. Nicolas Théodore de Saussure (1767–1845)

In 1804, de Saussure published his work: “Recherches chimiques sur la végétation”, Nyon, Paris (Chemical Researches on Végétation). As a follower of Lavoisier, Saussure stood strongly with the standpoint of the conservation of matter and referred all transmutations and creation to the realm of fables. He puts special emphasis on the necessity of this field to be absolutely certain, with experiments, that the so-called created matter was not already present in the environment. So he demonstrated, for example, that the presence of silicates in plants, which were attributed to the life-force by Lampadius, was in reality determined by the amount of silicon present in the soil.

#### 7.2. Jean-Louis Lassaigne (1800–1859)

Lassaigne initially worked in the laboratory of Louis-Nicolas Vauquelin. He was a professeur at Ecole Vétérinaire d’Alfort. His works were published in 1821 with the germination of grains supported the findings of de Saussure. His later works on the development of chicks contradicted the results of Vauquelin.

#### 7.3. P.E. Jablonski

In 1836, Jablonski found no increase in the amount of ashes in the plants above the one in the seed. Therefore, criticizing Schrader and Braconnot.

#### 7.4. Arend Joachim Friedrich Wiegmann (1770–1853) and A.L. Polstorff

Wiegmann and Polstorff made the following experiment: They followed the techniques of their predecessors, but with a soil that consisted of the most inert material known to them at that time. They let 28 seeds of garden cress (*Lepidium sativum*) germinate in distilled water in a platinum crucible that was filled with fine platinum wires. The crucible was placed under a glass bell jar through which circulated a mixture of 1% carbon dioxide. The seeds germinated and grew into small plants until, after 26 days, they began to die. After drying the crucible and its contents, ashing and weighing obtained 0.0025 g of ash. The weight of the ash obtained from 28 seeds was likewise 0.0025 g. Therefore, there was neither weight change nor new elements formed. However, this conclusion does not contradict previous experiments, since only the weights were compared. No attempt was made to check for the transmutation of one element into another.

#### 7.5. M. Emile Rinck

In 1947, Rinck checked Hauschka’s work and found only 0.02% weight change.

#### 7.6. Léon Guéguin

In 1970, Guéguin from the INRA (The French Institut of Agronomical Research) has shown that there was no transmutation in Kervran’s type experiments.

#### 7.7. D.B. Long

Long was a British scientist, from the Michaelis Nutricional Research laboratory, Harpenden, UK. In 1971, he published a report [36] indicating that he did not observe differences in K, Mg, Ca, Mn, Fe, Zn and Cu when looking at rye and oat seeds germinated. The table shown below shows his experimental results.

Elements	Seeds		Plants		Change (%)
	Average value	Standard deviation	Average value	Standard deviation	
Potassium (mg)	1.582	0.009	1.506	0.016	−4.8
Magnesium (mg)	1.270	0.006	1.273	0.006	+0.2
Calcium ( $\mu\text{g}$ )	2.122	0.016	2.157	0.019	+1.6
Manganese ( $\mu\text{g}$ )	28.8	0.1	24.9	0.2	−13.5
Iron ( $\mu\text{g}$ )	49.7	0.2	48.6	0.5	−2.2
Zinc ( $\mu\text{g}$ )	20.9	0.2	21.7	0.05	+3.8
Copper ( $\mu\text{g}$ )	6.22	0.2	6.57	0.1	+5.6

#### 7.8. L. Soubiès and R. Gadet

Following Baranger's work, and his attempts to get his findings accepted by the scientific community, Soubiès and Gadet performed similar experiments with the Baranger's protocol and a more rigorous one. They presented their results in 1972 in the bulletin of the French Chamber of Agriculture. They demonstrated that using their better protocol no transmutation is detected, whereas with the original one there is less sodium produced. They proposed that the anomalies were due to diffusion of minerals from the glass used in the experiments.

#### 7.9. Horber

In 1976, Horber, a Swiss scientist from Zurich, looked at calcium variations by neutron activation analysis. He found a 2% variation, but with a precision of  $\pm 5\%$ .

#### 7.10. J.A. Jungerman and Murphy

In February 1977, Professor Jungerman and Murphy from the University of California, Davis reported the results of an experiment: the growth of oat seeds under carefully controlled conditions. Analysis was made by atomic absorption and X-ray fluorescence for Ca and K. They found no evidence of transmutation.

#### 7.11. Carolyn E. Damon

In 1978, Damon from the U.S. Customs Technical Service Division conducted tests for biological transmutation with *Aspergillus terreus* and *Rhizopus nigricans*, he obtained negative results.

#### 7.12. Bernd Franke

In 1978, Franke defended his thesis for States Exam at the Botanical Institute of the University of Heidelberg in Germany, the title of which was: "Critical examination of tests on the transformation of biological elements". He analysed calcium, magnesium and potassium during the growth of oats seeds (*Avena sativa*) and yeast (*Sacharomycus cervisiae*). He did not find any significant changes in the composition of the seeds and yeast during their analyses.

#### 7.13. Enrico Di Vito, Carla Candian, Luigi Garlaschelli and Antonio Triassi

In 2002, these scientists from Italy failed to replicate Kervran's work. They looked at the growth of oat seeds (cultivar *Nave*). They analysed their products using ICP emission, but found no variation in Ca, Mg and K in sprouting oat seeds.

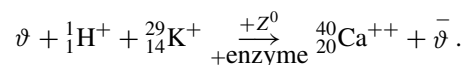
## 8. Theory

### 8.1. Kervran

Kervran thought that the nuclear reactions that occur in biology were connected to the structure of the nucleus. He developed a unique model of the nucleus with a design that explains the potential transmutations.

### 8.2. Costa de Beauregard(1911–2007)

Costa de Beauregard [37] was the Research Director at the Centre National de la Recherche Scientifique, Paris, and Professor of Theoretical Physics at the Institut de Physique Théorique Henri Poincaré. He studied Kervran's works in 1962 and began to correspond and met with him. He suggested that such transmutations neither take place through strong interactions nor through electromagnetic forces, but through the weak interaction. This takes place through the neutral current of the intermediate vector boson, the so-called  $Z^0$ , particle. Kervran's reaction for a biological transmutation from potassium to calcium in germinating oats is thus explained as being initiated by neutrino capture (from cosmic rays) and the weak interaction follows mediated by the  $Z$ , neutral current.



In 2006, I called Costa de Beauregard at his home in Paris, and asked him if he continued his research. He replied that he did not.

### 8.3. Goldfein

In 1978, an officially funded effort from the U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia positively confirmed that mechanisms for elemental transmutations could occur in biological systems. The work was performed under the direction of Emil J. York, Chief of the Material Technology Laboratory. Solomon Goldfein was the principal investigator for the effort. Robert C. McMillan, Chief of the Radiation Research Group of the laboratory, provided guidance on matters of physics and nuclear physics. The abstract of the final report [38] reads as follows:

“The purpose of the study was to determine whether recent disclosures of elemental transmutations occurring in biological entities have revealed new possible sources of energy. The works of Kervran, Komaki and others were surveyed, and it was concluded that, granted the existence of such transmutations (Na to Mg, K to Ca and Mn to Fe), a net surplus of energy was also produced. The proposed mechanism was described in which Mg adenosine triphosphate, located in the mitochondrion of the cell, played a double role as an energy producer. In addition to the widely accepted biochemical role of Mg-ATP in which it produces energy as it disintegrates part by part, Mg-ATP can also be considered to be a cyclotron on a molecular scale. The Mg-ATP when placed in layers one atop the other has all the attributes of a cyclotron in accordance with the requirements set forth by E.O. Lawrence, inventor of the cyclotron.” “It was concluded that elemental transmutations were indeed occurring in life organisms [sic] and were probably accompanied by a net energy gain.”

Goldfein postulated a conformational structure of a stack of Mg-ATP molecules forming a helical chain. The Mg-ATP chelate produces oscillating electrical currents, which act as a micromini-cyclotron that accelerates hydrogen ions to relativistic speeds with sufficient potential to transmute an element to the next higher number. It was concluded that the elemental transmutations occurring in living organisms are accompanied by losses in mass representing conversion to thermal energy and that such energy probably is a net gain when compared to the amount required to effect the transmutation.

#### 8.4. Conclusion

Lavoisier has established a mass conservation law which is valid in chemistry. Now we know that it is not true when nuclear reactions are involved. The review of more than two centuries of research demonstrates that this is not true in biology. It appears that all living organisms can under some circumstances produce nuclear reactions. However, there is an important need of finding an adequate theory to explain these results. It is highly probable that such a theory should also be capable of explaining Cold Fusion, or more generally, nuclear reactions in condensed matter. Another point is the irreproducibility of some experiments. Probably, in order to produce significant transmutation of an element, it is necessary that another element be missing. It seems that nature has a tendency to find ways to transmute an element into another to provide the necessary ingredients for the healthy growth of the four kingdoms of bacteria, fungi, plants and animals, including human beings.

Historically, the sequence of discoveries in biological transmutation is the following: Vauquelin was the initiator in 1799. Later Herzelee in 1876–1883 did a lot of research, but his work was removed. Later Hauschka rediscovered Von Herzelee's work. Baranger and Kervran discovered this work. As a consequence of their contribution to the field Zündel continued the work as well as Goldfein. Finally Vysotskii knowing the work of Kervran brought an important contribution.

This review shows that biological transmutations deserve a lot of attention from the scientific community. The consequences of this are important for science, medicine, agriculture and diet. The cost of research in this field is so low compare with other fields that it is unacceptable not to do it.

Studies of the process called cold fusion or Low Energy Nuclear Reactions (LENR) over the past 22 years show that nuclear reactions of various kinds can be initiated in inorganic solid materials under conditions similar to those present during the claimed biological transmutations. These reactions all have the basic characteristic of producing energy as would be required of a spontaneous reaction. In contrast, many of the proposed nuclear reactions in biological systems cannot result in energy production because mass is not lost in the process. Instead, the mass gain would require the concentration of significant energy from the environment. This violates the basic laws of thermodynamics and makes the suggested reactions impossible. In addition, the elements involved in the proposed nuclear reaction must have a way to find each other in the same biological structure and experience a reduction in their Coulomb barrier before interaction can occur. These several limitations severely limit possible explanations. However, these limitations do not make the nuclear reactions impossible, just more of a challenge to explain. The basic question to be answered is do such reactions actually occur in Nature? The evidence strongly indicates that some of the observed reactions actually occur, requiring an explanation to be found.

#### Acknowledgements

I wish to thank various people who have helped me in the realization of the biological transmutation experiments: The Holleman Stichting, David Cuthbertson, Valérie Michotey, Jean-Jacques Allegraud and Pascal Gos.

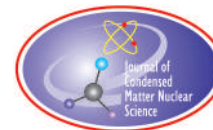
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Research Article

# Evidence Concerning the Mechanism of the Nuclear Reaction between Deuterium and Tritium

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## Abstract

Both hydrogen and deuterium in their electrolysis on palladium gave linear Tafel lines but each had a kink in it at about 0.35 V overpotential ( $\eta$ ). At this value damage begins to be seen in the SEM photographs of the interior of the electrodes. Tritium formation became detectable at an overpotential ( $\eta$ ) of about 0.4 V. The reaction occurs in two consecutive steps: the first is a Volmer–Tafel reaction which occurs when the overpotential is less than 0.3 V. But as the measured coverage  $\theta_D$  approaches unity, the deuterons begin to discharge onto the adsorbed deuterium (Heyrovsky mechanism). The second (consecutive) step leads to the tritium formation via a neutron transfer from the electrode to the Pd–D bond which at this stage (near to full occupancy by D) is relatively weak. The ready availability of neutrons in the surface region of the metal catalyst is rationalized in terms of the high electron concentration associated with the surface and the presence of D arriving from  $D_2O$  in the solution:  $e^- + D^+ = 2 \text{ neutrons} + \text{a neutrino}$ . The model is applied to two anomalies which have troubled this reaction. One is irreproducibility and also the long time (100 h or more) before any *nuclear* activity is seen.

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*Keywords:* Deuterium, Mechanism, Neutron, Nuclear, Tritium

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## 1. Introduction

This paper contains interpretive material of results in a paper published in 2000; the special nature of which was that it correlated the reaction deuterium to tritium with changes inside the electrode [1]. The experimental paper showed that a breakup of the internal structure of the palladium correlates with the beginning of nuclear activity.

The present paper begins with a brief summary of new facts recorded in the previous publication and then the mechanism is discussed in some detail. Thereafter, the model, which has been suggested, is applied to two outstanding anomalies of the tritium formation reaction, irreproducibility and the long latency period for tritium formation to begin on wire electrodes.

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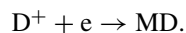
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## 2. Summary of Facts Previously Established

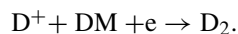
- (1) In respect to the two Tafel lines for the hydrogen and deuterium evolution, each showed [1] a marked change in slope at about 0.35 V ( $\eta$ ) for the deuterium line. The lower slope of  $d\eta/d \log i$  was 0.15 whilst the higher slope 0.22.
- (2) An examination of the pictures of damage taken at various overpotentials, time and temperature shows that the damage starts at  $\eta = 0.35$  V for the room temperature measurements. The damage grows as the overpotential is increased. The information is available [1] up to 0.8 V ( $\eta$ ).
- (3) Nuclear phenomena are observed when the “loading factor” is high.<sup>a</sup> But the loading factor depends directly upon the surface concentration of the deuterium. In starting in an experiment up to, typically, 15–20 h, the transport of deuterium through the electrode is happening and building up the “loading.” The beginning of the damage is observed at about 0.35 V and the nuclear phenomena just afterwards (0.4 V) suggests damage precedes the onset of the second stage: the actual production of tritium.
- (4) An infrared spectrometer was equipped with Fourier transform mathematics and was used to indicate the presence or absence of adsorbed deuterium (or hydrogen) on the electrode surface [2]. The width of the spectroscopic peak for Pd–D spectra measures the occupancy with adsorbed hydrogen and its isotope. Here again, a break occurs at about 0.3 V ( $\eta$ ). Above 0.4 V, little increase in the breadth of the spectroscopic peak occurs. Thus, the overpotential region of 0.3–0.4 is that at which the electrode coverage approaches unity. Thus, this potential region includes the internal loading coming up to, that which corresponds to  $\theta \rightarrow$  unity, the beginning of damage, and slightly below the detectable production of tritium.<sup>b</sup>
- (5) At higher  $\theta$ s, there is no longer a smooth increase of permeation rate with time. The permeation decreases in a jagged fashion. Thus, damage evidently has begun and some of the deuterium which would have reached the other side of the membrane has been trapped in the damaged electrode material [1].
- (6) The stoichiometric number ( $\nu$ ) came out to be 1.11 at constant overpotential for conditions in overpotential greater than 0.4 V [3].

## 3. Mechanism of Tritium Formation

The parameters observed for the deuterium evolution reaction, in the lower Tafel line, were consistent with a rate determining deuterium transfer to an adsorbed site on the metal surface where the resulting MD could be observed spectroscopically:



Thus, for an  $\eta$  less than 0.35 V, the deuterium discharges with a Volmer–Tafel mechanism [5]. Above the  $\eta$  of 0.35 V, the surface is approaching complete occupancy with adsorbed deuterium. The course of the reaction now changes and the facts are consistent with a Heyrovsky desorption mechanism [4]:

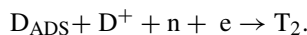


<sup>a</sup>It is important to determine the Tafel lines after the reaction has settled down. The delay before nuclear activity is observed (radioactivity of tritium!) was variable and could be as little as 10 h at low electrolysis current density (overpotential less than 0.3) then the second Tafel line began after a delay of as much as 50–100 h and the electrolysis continued with the higher slope and the production of tritium. The fact that one had to wait for the nuclear phenomenon to switch on is the direct cause of why so many experienced workers rejected the phenomenon in the years 1989–1991. Many switched on their apparatus and waited for some unusual phenomenon to happen. They saw no tritium so they switched off and concluded the phenomenon did not exist.

<sup>b</sup>The early runs in this work were analyzed for tritium in the nuclear engineering department at Texas A&M, but later runs were recorded within our group by an apparatus specifically designed to detect and measure tritium.

The SEM pictures published in the foregoing paper [1] show that the internal damage starts about  $\eta = 0.35$  V [5]. Then with a higher surface occupancy with D, the deuterons in the double layer find the probability of discharge onto the adsorbed deuterium preferred. The stoichiometric number of 1.1 favors the Heyrovsky mechanism for the higher Tafel slope (for which theoretically the stoichiometric number should be 1.0).<sup>c</sup>

The tritium formation occurs in two steps. The first is the deuterium discharge; firstly onto the palladium surface (Volmer) and then, with a change of slope, onto the adsorbed deuterium (Heyrovsky) with the direct evolution of D<sub>2</sub>. In the second step, now with a high coverage of the metal with D, there are conditions suitable for a neutron transfer (high coverage corresponds to weak M–D bonding). The overall reaction becomes:



Here the n represents a neutron and T is for tritium. The neutron (see below) is suggested as joining the Pd–D bond when it is weak.

#### 4. Neutrons: their Origin

Takahashi [7] hypothesized that there are free neutrons available inside the metal and they take part in the reaction stated. Fisher [8] supported this hypothesis suggesting that the neutrons inside metals exist in clumps. He obtained support from Oriani [9] who came into the picture because he had observed CO<sub>2</sub> with properties which seemed too heavy for a normal CO<sub>2</sub> molecule. This made him suggest that Fisher's clumps were in fact CO<sub>2</sub> carrying neutrons. Widom and Larsen [13] used neutrons in a number of their explanations of transmutation reactions.

Storms [10] hesitates in accepting neutrons as available for an electrochemical reaction. He points out that this would imply Pd<sup>111</sup> which is a  $\beta$  and a  $\gamma$  emitter, and such emissions have not yet been reported. This tritium is in fact deuterium to which a neutron has been added. So we have, finally, to have neutrons for the reaction to occur. However, tritium formation reaction is the most common reaction until the present examined up to around 100 individual papers of with Storms quotes 50 (the BARC team is responsible for many further replications).

We are dealing in a model, which sees the electrical double layer formed between the surface and the first layer of ions in solution as a main factor. Electric fields within this double layer region may reach as high as 10<sup>7</sup> V/cm. Calculations [11] show the field distorts molecules, which come into its region. Reactivity in general has to be reconsidered in regions with such a high field strength. Adsorbed D comes from the solution, which contains the deuterium and gets adsorbed in the surface later undergoing electron transfer.

A suggestion made in a recent contribution by Widom and Larsen [14] is that neutrons are supplied at the surface by the reaction:



There is no supply of neutrons inside the electrode. They form on the surface. This formation in the strong electric field is part of the potential dependent of the rate of reaction.

The model is consistent with the dependence of the rate of these nuclear reactions upon potential. The D concentration on the surface is potential dependent and depends on the double layer field, as mentioned.

#### 5. Latency Period in Commencement of Nuclear Activity

The tritium formation reaction is anomalously characterized by a delay in a start up of the appearance of the radioactive material. The delay is between 10 and 100 h for most papers, although occasionally a longer time is needed. Some

<sup>c</sup>The stoichiometric number is 2 for the Volmer–Tafel mechanism (lower slope) [5].

workers have found that the need to wait for such a time is too much and have given up after a few hours. However, they would be disappointed in most of the “tries” for the deuterium to tritium reaction, which seldom switches on under 10 h of low current density and therefore low overpotential.

The above mechanism will lead to tritium formation only in the presence of weak Pd–D bonds associated with a high  $\theta$ . The time that is necessary for  $\theta$  to increase and therefore the strength of the Pd–D bond to decrease, will new tritium form? The breakdown of the internal palladium which has been evidenced by the electron microscope photographs in reference [1] increases the number of possibilities for internal surfaces, which gradually increase  $\theta$ s for provide slowly more sites, which produce the tritium. The solution will leak inside the electrode as and make active therefore the new sites, which are being formed by the breakdown.

This D–Pd bond on the surface of palladium electrode would add to the time needed for the appropriate condition for the neutron – Pd–D reaction to occur ( $D + \text{neutron} = \text{tritium}$ ).

Our model sees the critical tritium formation step as that which a neutron formed on the surface as explained above “breaking into” the weakened Pd–D bond. Information becomes easier; activation energy becomes lower and its rate faster. The tritium formation stops and gets a lower activation energy and hence faster rate.

## 6. Irreproducibility

Experience suggests that there are no electrodes, which are simple failures. All electrodes produce tritium but all need different amounts of waiting time, which may be too much for some experimentalists. These are the ones, which the latter may call “failures.” Investigators who have experience of this reaction also suggest that there are no failures for investigators who wait.

One factor bearing on the variability of the waiting time may lie in the origin of the palladium samples. In the first two years of work on the tritium work reaction with wires of 1–2 mm, the *origin* of the palladium was varied. It was seldom that one run used palladium from the same manufacturer. One of the principal factors of a metal in the manufacturing phase is the mode of crystallization from the liquid and how much time is given for annealing. Few manufacturers anneal at all (i.e. cool on a known scientifically established schedule). This is a factor, which would give rise to different properties and feedback on the strength of the D–Pd bonds.

It is also noteworthy to record here that just before the heat starts evolving (i.e. the tritium forming), there is a period of cooling at constant current density that lasts for a short time such as 10 min, but nevertheless, the endothermic reaction implied involves a change of internal structure of palladium and is significant in any considerations of the extent of latency.

## 7. Dendrites Falling off

The author has experience with dendrite formation and its behavior [6]. Some of the break-off is visible. The presence of the dendrites is accelerative because of the high fields at the dendrite tips leading to a higher rate of D aggregation on the surface. When these high electric field points are removed, the reaction slows. If the removal were complete, one would see about a 10–100 times reduction in the reaction for the same applied potential. An observer would likely conclude the reaction has stopped functioning; whereas, it has just been reduced a considerable amount. <sup>d</sup>

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<sup>d</sup>As to the presence of copper and whether it is critical, we detected that after the electrode of special longevity had a copper impurity in the solution, we added copper in another solution but could find no further effect.

## 8. Water in D<sub>2</sub>O?

In 1992 in collaboration with Nigel Pakham, experiments were carried out on water absorption from the atmosphere, which contains up to 15% water vapor. D<sub>2</sub>O in an open beaker was put on the bench for up to two weeks and analyzed for water at regular intervals. It was found to continue to absorb water until 26% of the D<sub>2</sub>O was diluted H<sub>2</sub>O. Little variation in rate of the reaction was observed before 15% water.

## 9. Comparison with Non-electrochemical Performance of Similar Cold Fusion Reactions

Many reactions may be carried out electrochemically or chemically over the whole field of chemistry. However, all interfaces bare electric charges so that if in an attempt to carry out the reaction without electronic control, one has to take into account that charges are still there although undetermined.

The virtue of the electrochemical case is that the use of a potentiostat, allows one to control the potential and thus the concentration of electrons at the interface. The rate of the reaction is therefore under control and this provides a warning for those who carry out nuclear reactions in the cold but do not know what the potential is, other investigators may try the same reaction but under different circumstances also without control and these two reactions will not be comparable as far as their rate is concerned. It is only possible to compare a reaction with another investigator if the rate of overpotential is known. It is noteworthy that about 2 to 1 from ICCF 16 papers chose the electrochemical method of carrying out the reaction.

The excess surface charge is positive or negative. There is a potential of zero charge but that is difficult to maintain without electronic control.<sup>e</sup>

## Acknowledgements

I acknowledge helpful discussion with Ed Storms and with Nigel Packham who was the first to find tritium, and also with Ramesh Kainthla who was a senior post doc working for me but who proved his experience in research particularly in the early years by helping me with the supervision of the large number of coworkers who were in the group studying tritium formation.

## Appendix

Tritium is created from deuterium under electrochemical conditions for the most part and with more than 100 papers in support. Writing it as  $d + n \rightarrow t$ , has to take into account the bonding d–pd and the t–pd. Although we have no means of determining their bond strengths these bonds at the moment (separation factors), it is clear that the t to Pd should be stronger than the d–Pd. Although neutrons would have some small exchange force in respect to palladium, it would be too little to concern us. So I think the overall reaction would be somewhat  $\Delta G^0$  negative taken in the usual way of the right–left.

As the reaction fundamentally depends on neutrons, it is necessary to explain their existence and this has been done by Widom and Larsen [14]. According to them, the d in the presence of an electron rich surface will give two neutrons. This is easy to understand.

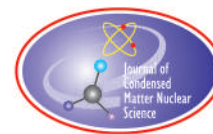
On the other hand, a more complex series of reactions might be necessary and these would be:  $d + d + e + n \rightarrow t + 2n$

The main point of the paper is the switch on of the nuclear reaction when damage shows up inside the structure.

<sup>e</sup>A number of laws had been set up long ago for electrochemical reactions. One knows, for example, that a Tafel slope (the gradient of the overpotential-log current density relationship) has a certain mechanistic meaning.

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Research Article

## Priority in Nuclear Reactions in the Cold

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### Abstract

Fleischman, Pons and Hawkins [1] have been thought to have published the first invitro (but unknown) nuclear reaction in the cold in March 23, 1989. Bockris and Mallove [2] published in 1999 a survey of earlier nuclear reactions in the cold (later condensed matter nuclear reactions). Included in their list was a publication by two Italian engineers Speri and Zorzi [3] which came out in 1989. Drawn by this latter fact, in 2011, I investigated further the Speri and Zorzi paper which Mallove and I had mentioned with only a publication date. I found the paper in an obscure medium and discovered upon being able to read it that Speri and Zorzi had been awarded an Italian patent in 1978. The patent was awarded for the discovery of the fusion of hydrogen isotopes to form helium. The original work was carried out in 1974.

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*Keywords:* Feischmann, Nuclear reactions, Priority, Speri and Zorzi

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### 1. Background

The experiments of Rutherford led to the concept held by all physicists: nuclei were extremely difficult to break, needing bombardment by neutrons and temperature in the region of 900°C.

In view of doubts raised about Feischmann et al., we converted deuterium to tritium. I decided to attempt a reaction, where the products would be there only if a nuclear reaction had taken place.

Starting the day after the Feischmann and Pons announcement, we found tritium by August of the same year.

When, eventually, I found the Speri and Zorzi *paper*, it revealed a change in the important position of priority as to nuclear reactions “in the cold”. The Italian workers had taken hydrocarbon mixtures and sparked them off to explosion, measuring the heat evolved in that action.

Speri and Zorzi found that they were measuring more heat than the classical rules would allow and it was then that they made their fundamental suggestion eleven years in advance of Fleischmann and Pons that they were seeing the effect of a nuclear parallel reaction (1978).

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**Table 1.** Priority in (INVITRO) Nuclear Reactions in the Cold

Authors	Claim	Confirmation	Comments
Speri and Zorzi, 1978 [3,4].	Shows evidence that sparking mixtures of hydrocarbons produces He <sup>4</sup> . Suggests: D + D → He <sup>4</sup> , 1974.	Patent 1978 [4].	Publication 1989 [3].
Fleischman and Pons, 1989 [1].	Electrolysis of LiOD/D <sub>2</sub> O gave excess heat: Suggests an unknown nuclear reaction, March 23, 1989.	Melvin Miles claimed co-production of He <sup>4</sup> through D + D → He <sup>4</sup> at Como, 1991. (Objections: Glass transparent to air He) [6].	Bockris and Chien [7] using mass spectroscopy at Rockwell International to investigate helium inside palladium (found helium 1992).
Bockris and Packham, 1989 [5].	Found tritium after long pre-electrolysis, August 1989.	Bhabha Atomic (India). Eleven teams attempting tritium . Nine successful, 1989.	E. Storms and C.Talcott-Storms at Los Alamos published tritium study in 1991 [8].

## 2. The Speri and Zorzi Work

Speri and Zorzi were persuaded (cf., Professor Pappas from the University of Athens) to reveal the work that they had done in 1974 in a patent in 1978 [4].

The hydrocarbon mixture and finer details of this work are to be found in the patent itself, but the important thing is that they found a significant excess of heat over that which would be calculable by means of classical considerations and made the historical suggestion that what was happening was the reaction of deuterium atoms together to form helium.

Although it is reasonable to speculate that Speri and Zorzi were eager to keep “quiet” about their suggestion, they did take out a patent of the Italian office and received finally in 1978 an Italian patent, the number of which is 1024274 (1978).

It is possible to suggest that Speri and Zorzi did not publish their paper shortly after they had obtained a patent, and indeed published in a report of a conference devoted to the origin of mathematics and physics – about as obscure a source as one could get – and avoided thus the repudiation at the suggestion that a nuclear reaction could occur in the temperature of a chemical gas reaction.

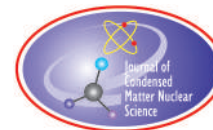
## Acknowledgement

I thank my office staff here in Florida for excellence in being able to find the obscure Speri and Zorzi paper in a report on the study of the origin of ideas in mathematics and physics.

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Research Article

# Including Nuclear Degrees of Freedom in a Lattice Hamiltonian

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## Abstract

Motivated by many observations of anomalies in condensed matter systems, we consider a new fundamental Hamiltonian in which condensed matter and nuclear systems are described initially on the same footing. Since it may be possible that the lattice will respond to the mass change associated with an excited nuclear state, we adopt a relativistic description throughout based on a many-particle Dirac formalism. This approach has not been used in the past, perhaps due to the difficulty in separating the center of mass and relative degrees of freedom of the nuclear system, or perhaps due to an absence of applications for such a model. In response to some recent ideas about how to think about the center of mass and relative separation, we obtained from the Dirac model a new fundamental Hamiltonian in which the lattice couples to different states within the composite nuclei within the lattice. In this description the different nuclear states have different mass energies and kinetic energies, as we had expected. In addition there appear new terms which provide for nuclear excitation as a result of coupling to the composite momentum. This new effect comes about because of changes in the composite nuclear state as a result of the dynamical Lorentz boost in the lattice.

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*Keywords:* Condensed matter nuclear science, Fleischmann–Pons effect, Fundamental Hamiltonian, Lattice–nuclear coupling, Relativistic effects, Spin-boson model

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## 1. Introduction

From a condensed matter viewpoint, a solid is made of nuclei and electrons, where the nuclei can for the most part be treated as point particles [1]. In cases where a more sophisticated description is needed, the basic description is augmented with nuclear spin, magnetic moments, and electric quadrupole moments [2]. Essentially the only place that excited states show up is in Mössbauer studies where they are required in order to describe the absorption or emission of a gamma [3]. The picture that results is both wonderfully simple and very rich; simple, in that the Born-Oppenheimer separation allows us to reduce the problem to electronic bands and phonon modes; and rich, as the models that result describe a wide range of basic, subtle, and occasionally unexpected physical phenomena. This basic approach to

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condensed matter physics has been sufficiently successful over the years that it would require some rather dramatic new experimental result before we might be motivated to revise it in any significant way.

In recent years there have been claims of experimental results which at a fundamental level seem not to be consistent with this basic viewpoint of condensed matter physics. In the Fleischmann–Pons excess heat effect [4,5], a great deal of energy is generated which is thought to have a nuclear origin (since there are no commensurate chemical byproducts, and since  $^4\text{He}$  is observed as a possible product in amounts proportional to the energy produced [6–8]), without commensurate energetic nuclear products [9]. In these experiments it almost seems as if the solid is taking up an MeV quantum; if so, then this constitutes an effect which seems very hard to understand within our current condensed matter framework. Given that such an effect seems impossible to contemplate within modern condensed matter physics (and also within modern nuclear physics), a natural reaction has been to go with the existing picture (supported by a very large body of experimental results and a consistent and mature theory), and to reject the Fleischmann–Pons experiment as simply being in error [10].

During the past two decades and more this de facto solution has been adopted generally, and it has worked surprisingly well. Science has advanced substantially; there are now even more experimental and theoretical results which support the modern condensed matter viewpoint; and those who pursue anomalies such as the Fleischmann–Pons experiment are isolated from science and ignored [11].

Meanwhile, another experimental result has been put forth which challenges our modern view of condensed matter physics. Karabut has studied a variety of anomalies in high-current density glow discharge experiments, and in the course of the work noticed that collimated X-ray emission occurred in powerful bursts normal to metal coin-shaped samples that served as cathodes [12–15]. Although anomalous emission effects are seen when the discharge is on, the powerful bursts of collimated X-rays are observed on the order of a millisecond after the discharge is turned off. A current spike occurs when the discharge is shut off, which we might imagine causes vibrations in the sample. It seems as if the vibrational energy is being communicated somehow to produce in-phase electronic or nuclear excitation at X-ray energies, which then produces collimated X-ray emission through a phased array emission effect. We note that a related effect involving the collimated emission of gamma-rays in beamlets was reported earlier by Gozzi [16]. Needless to say, such an effect has no place in modern condensed matter physics.

In experiments performed by the Piantelli group, hydrogen is absorbed in nickel samples at elevated temperature, resulting in a thermal effect (consistent with energy generation) [17,18], low-level nuclear effects (gamma and neutron emission [19,20]), and the appearance of new elements [21]. This latter effect (appearance of new elements) in these experiments is not a low-level effect. Once again, such effects are not predicted in modern condensed matter physics.

These experimental results, and many others, have motivated us to explore new models that might be relevant. A major issue that we have been interested in is the possibility of coherent energy exchange between quantum systems with mismatched characteristic energies, which we considered to be the biggest theoretical problem associated with the anomalies. Coherent energy exchange between mismatched quantum systems occurs in high harmonic generation [22], so we know that it is possible in principle. However, there seems to be no analog to Corkum's mechanism [23,24] present in the condensed matter system. A lesser version of the effect is known within the multiphoton regime of the spin-boson model, which is used to model basic linear interactions of two-level systems with an oscillator [25–27]. We found that if the two-level system is augmented with loss, the coherent energy exchange rate is increased dramatically. This is due to the fact that destructive interference limits the rate at which coherent energy exchange occurs in the spin-boson model, so augmenting the model with a mechanism that removes this destructive interference would be expected to improve coherent energy exchange rates [28–31].

Coherent energy exchange in these models works best when the coupling between the two-level transition (representing electronic and nuclear transitions) and oscillator (representing a vibrational mode) is strong. We studied a further generalization of the lossy spin-boson model in which two transitions are coupled to an oscillator, where one is strongly coupled and one is weakly coupled [32]. We found that the strongly coupled system could assist coherent

energy exchange for the weakly coupled system. The model that resulted appeared to us to be very closely related to excess heat production in the Fleischmann–Pons experiment, assuming that the mechanism involved  $D_2/{}^4\text{He}$  transitions that were weakly coupled to a phonon mode (weakly coupled due to the Coulomb repulsion between the deuterons), and that a strongly coupled transition were also present. The big problem in this kind of model ends up being the identification of the strongly coupled transition. Finding an appropriate strongly coupled transition with sufficiently strong coupling to do the job seems problematic within the approach [33].

After analyzing many candidate transitions, we came to the conclusion that there were no physical transitions which could serve as the strongly coupled two-level transition within the model. We were optimistic in our writing about the possibility that systems described by three-level systems (or  $N$ -level systems) would be able to do the job. After putting in a great deal of work on analyzing the strongly coupled three-level system, it seemed once again that the coupling was simply not strong enough to make a connection with experiment. This conclusion was supported by spectral data from Karabut [34], which seemed to be qualitatively consistent with the approach and models, but which would require much stronger coupling to explain.

All of this has led us to the conclusion that we are going to need a new kind of model in order to account for the experimental results. To obtain coupling sufficiently strong to be consistent with the Karabut experiment, we require very strong interactions that are on the general order of what would occur in a nuclear configuration mixing calculation. Yet there is no reason to expect that nuclear configuration interactions can couple to a phonon mode. In our earlier efforts to describe such an effect, we concluded that the internal nuclear degrees of freedom associated with configuration mixing separated cleanly from the vibrational degrees of freedom. For many years there has seemed to be no viable solution within the general approach, which has been very discouraging.

The intuitive picture that has emerged over the past few years of thinking about the problem is that the different excited states of the nucleus have different masses, and under appropriate conditions it may be possible for the nucleus to notice the mass differences of the different configurations. This could provide the physical basis for phonon exchange in association with configuration mixing. To describe such an effect, we need to develop a description of the associated coupling, which seems not to be available in the literature. One approach is to begin with a relativistic model for the nucleons, and then reduce it in some way to obtain a low momentum approximation in which the associated mass effects are retained.

The issues under discussion fit within the generic heading of relativistic quantum mechanics, which before 1950 would likely have implied the two-body Dirac equation as a starting place. However, the need for a manifestly covariant relativistic quantum theory more generally led to the development of modern quantum field theory, which could in principle be used for problems of interest to us. Field theory is much more complicated than relativistic quantum mechanics, so we would prefer a simpler model derived from relativistic quantum mechanics if possible. In this day and age, there are many relativistic quantum models that have been derived from field theory (such as the Bethe–Salpeter equation, as well as others [35]).

The separation of relative and center of mass degrees of freedom that is possible in the nonrelativistic problem does not extend to the relativistic problem, which complicates things. In a recent manuscript [36] we obtained a result with the two-body Dirac model that seemed to suggest it was possible to arrange for a separation of the relative and center of mass contributions to the energy in a simple way. We originally made use of this approach in the this paper to obtain an approximate model for the center of mass and relative dynamics discussed in this paper. However, in responding to the reviewers' comments on the paper, it became clear that there were weaknesses in the approach outline, and our interpretation of the results have changed. We were able to revise this paper in the galley proof stage in order to take into account the improved point of view. The model that results (which is essentially the same in both cases) can then be used directly to develop a new Hamiltonian for nuclei in a lattice that includes the coupling consistent with a many-particle Dirac formulation.

Interestingly, the model that results seems to include a relativistic effect which provides a direct coupling between

the lattice motion and excitations in the nucleus. The resulting model appears to be much more closely connected with our earlier models than we had expected, which provides the motivation to explore the model further in the future.

## 2. Center of Mass and Relative Contributions to the Energy

We begin with a description of the free nucleus in terms of Dirac particles within the context of a many-particle Dirac Hamiltonian

$$\hat{H} = \sum_j \alpha_j \cdot c \hat{\mathbf{p}}_j + \beta_j M_j c^2 + \sum_{j < k} V_{jk}(\mathbf{r}_k - \mathbf{r}_j). \quad (1)$$

Protons and neutrons are composite particles with internal quark structure, and one might criticize the use of a Dirac point-particle description for composites in this case; however, for our purposes it seems the simplest place to start. The Dirac  $\alpha$  and  $\beta$  matrices are

$$\alpha_j = \begin{pmatrix} 0 & \sigma_j \\ \sigma_j & 0 \end{pmatrix}_j, \quad \beta = \begin{pmatrix} I & 0 \\ 0 & -I \end{pmatrix}_j. \quad (2)$$

The interaction between two nucleons appears here as  $V_{jk}(\mathbf{r}_k - \mathbf{r}_j)$ ; we assume that this includes strong force and electromagnetic interactions. We assume the  $\Phi$  is an exact solution to the time-independent equation

$$E\Phi = \left[ \sum_j \alpha_j \cdot c \hat{\mathbf{p}}_j + \beta_j M_j c^2 + \sum_{j < k} V_{jk}(\mathbf{r}_k - \mathbf{r}_j) \right] \Phi. \quad (3)$$

### 2.1. Center of mass and relative coordinates

The classical center of mass coordinate satisfy

$$M\mathbf{R} = \sum_j m_j \mathbf{r}_j \quad (4)$$

with

$$M = \sum_j m_j. \quad (5)$$

The relative position coordinates are

$$\xi_j = \mathbf{r}_j - \mathbf{R}. \quad (6)$$

The total classical momentum is

$$\mathbf{P} = \sum_j \mathbf{p}_j \quad (7)$$

and the relative momenta are

$$\boldsymbol{\pi}_j = \mathbf{p}_j - \frac{m_j}{M} \mathbf{P}. \quad (8)$$

One of the relative position operators is redundant, since the sum of all relative position operators is zero; similarly one of the relative momentum operators is redundant.

## 2.2. Mass parameter

The eigenvalue can be expressed in terms of relative and center of mass matrix elements according to

$$E = \left\langle \Phi \left| \left( \sum_j \frac{m_j}{M} \boldsymbol{\alpha}_j \right) \cdot c \hat{\mathbf{P}} \right| \Phi \right\rangle + \left\langle \Phi \left| \sum_j \boldsymbol{\alpha}_j \cdot c \hat{\boldsymbol{\pi}}_j + \sum_j \beta_j m_j c^2 + \sum_{j < k} V_{jk} (\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) \right| \Phi \right\rangle, \quad (9)$$

where  $\Phi$  is an exact solution to the eigenvalue equation (Eq. (3)). We add and subtract mass terms to obtain

$$E = \left\langle \Phi \left| \left( \sum_j \frac{m_j}{M} \boldsymbol{\alpha}_j \right) \cdot c \hat{\mathbf{P}} + \left( \sum_j \frac{m_j}{M} \beta_j \right) M^* c^2 \right| \Phi \right\rangle + \left\langle \Phi \left| \sum_j \boldsymbol{\alpha}_j \cdot c \hat{\boldsymbol{\pi}}_j + \sum_j \beta_j m_j c^2 + \sum_{j < k} V_{jk} (\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) - \left( \sum_j \frac{m_j}{M} \beta_j \right) M^* c^2 \right| \Phi \right\rangle. \quad (10)$$

If we define the mass parameter  $M^*$  according to

$$M^* c^2 = \frac{\left\langle \Phi \left| \sum_j \boldsymbol{\alpha}_j \cdot c \hat{\boldsymbol{\pi}}_j + \sum_j \beta_j m_j c^2 + \sum_{j < k} V_{jk} (\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) \right| \Phi \right\rangle}{\left\langle \Phi \left| \sum_j \frac{m_j}{M} \beta_j \right| \Phi \right\rangle}, \quad (11)$$

then the associated matrix element for the modified relative contribution vanishes. The idea here is that the contribution of the relative problem now appears in the mass parameter associated with the center of mass contribution to the eigenvalue.

### 2.3. Eigenvalue relation for a single configuration

With this definition of the mass parameter the eigenvalue simplifies to

$$E = \left\langle \Phi \left| \left( \sum_j \frac{m_j}{M} \alpha_j \right) \cdot c \hat{\mathbf{P}} + \left( \sum_j \frac{m_j}{M} \beta_j \right) M^* c^2 \right| \Phi \right\rangle. \quad (12)$$

We can rotate to obtain

$$E = \left\langle \Phi' \left| \sum_j \frac{m_j}{M} \beta_j \right| \Phi' \right\rangle \sqrt{(M^* c^2)^2 + c^2 |\mathbf{P}|^2}, \quad (13)$$

where we used

$$\Phi' \sim e^{i\mathbf{P}\cdot\mathbf{R}/\hbar}. \quad (14)$$

These are the basic results that we reported in [36]. However, our interpretation now is different. The mass parameter  $M^*$  can allow us to connect the center of mass problem for the interacting Dirac particles with the center of mass problem of a set of equivalent non-interacting Dirac particles that have a different rest mass.

### 2.4. Composite masses

In general the mass parameter  $M^*$  for the composite will in general depend on  $\mathbf{P}$  since the Dirac Hamiltonian is in general not covariant (it has not yet been shown that  $M^*$  should be invariant for a covariant model, but we think it likely). Also, in a covariant model we would expect the energy-momentum relation to be

$$E = \sqrt{(M_0 c^2)^2 + c^2 |\mathbf{P}|^2} \quad (15)$$

where  $M_0$  is the composite rest mass. In light of this, we could correct the non-covariant Dirac model by requiring

$$\left\langle \Phi' \left| \sum_j \frac{m_j}{M} \beta_j \right| \Phi' \right\rangle \sqrt{(M^* c^2)^2 + c^2 |\mathbf{P}|^2} \rightarrow \sqrt{(M_0 c^2)^2 + c^2 |\mathbf{P}|^2} \quad (16)$$

In this case, we can recover the nonrelativistic limit

$$E \rightarrow M_0 c^2 + \frac{|\mathbf{P}|^2}{2M_0} + \dots \quad (17)$$

## 3. Finite Basis State Model

We would like to expand our description to include a finite set of states, and in the process we would like a formulation in which the state mass impacts the kinematics. We begin by assuming a finite basis state model of the form

$$\Psi = \sum_j c_j \Phi_j. \quad (18)$$



We make use of the variational method to obtain the matrix equation

$$E\mathbf{c} = \mathbf{H} \cdot \mathbf{c}, \quad (19)$$

where the matrix  $\mathbf{H}$  has individual matrix elements given by

$$H_{kl} = \langle \Phi_k | \hat{H} | \Phi_l \rangle. \quad (20)$$

The vector  $\mathbf{c}$  made up of the different expansion coefficients is

$$\mathbf{c} = \begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \end{pmatrix}. \quad (21)$$

This coefficient vector  $\mathbf{c}$  should not be confused with the speed of light  $c$ .

### 3.1. Diagonal matrix elements and mass parameters

To arrange for dynamics with the mass parameter matched to the state, we focus first on the diagonal matrix elements and write

$$H_{kk} = \langle \Phi_k | \hat{H}_{\mathbf{R}} | \Phi_k \rangle + \langle \Phi_k | \hat{H}_{\mathbf{r}} | \Phi_k \rangle, \quad (22)$$

where the center of mass and relative parts are

$$\langle \Phi_k | \hat{H}_{\mathbf{R}} | \Phi_k \rangle = \left\langle \Phi_k \left| \left( \sum_j \frac{m_j}{M} \boldsymbol{\alpha}_j \right) \cdot c \hat{\mathbf{P}} + \left( \sum_j \frac{m_j}{M} \beta_j \right) M_k^* c^2 \right| \Phi_k \right\rangle, \quad (23)$$

$$\langle \Phi_k | \hat{H}_{\mathbf{r}} | \Phi_k \rangle = \left\langle \Phi_k \left| \sum_j \boldsymbol{\alpha}_j \cdot c \hat{\boldsymbol{\pi}}_j + \sum_j \beta_j m_j c^2 + \sum_{j < k} V_{jk} (\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) - \left( \sum_j \frac{m_j}{M} \beta_j \right) M_k^* c^2 \right| \Phi_k \right\rangle. \quad (24)$$

If we require the relative contribution to vanish (as discussed above), then the state-dependent mass parameter  $M_k^*$  is consistent with

$$M_k^* c^2 = \frac{\left\langle \Phi_k \left| \sum_j \boldsymbol{\alpha}_j \cdot c \hat{\boldsymbol{\pi}}_j + \sum_j \beta_j m_j c^2 + \sum_{j < k} V_{jk} (\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) \right| \Phi_k \right\rangle}{\left\langle \Phi_k \left| \sum_j \frac{m_j}{M} \beta_j \right| \Phi_k \right\rangle}. \quad (25)$$

### 3.2. Off-diagonal matrix elements

The off-diagonal matrix elements may be written as

$$H_{kl} = \left\langle \Phi_k \left| \sum_j \frac{m_j}{M} \alpha_j \cdot c \hat{\mathbf{P}} \right| \Phi_l \right\rangle + \left\langle \Phi_k \left| \sum_j \alpha_j \cdot c \hat{\boldsymbol{\pi}}_j + \sum_j \beta_j m_j c^2 + \sum_{j < k} V_{jk} (\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) \right| \Phi_l \right\rangle, \quad (26)$$

where the first term is associated with the center of mass, and the second term is associated with the relative problem.

### 3.3. Finite basis eigenvalue relations

The finite basis eigenvalue relations for a composite in free space can be written in the form

$$Ec_k = \left[ \left\langle \Phi'_k \left| \sum_j \frac{m_j}{M} \beta_j \right| \Phi'_k \right\rangle \sqrt{(M_k^* c^2)^2 + c^2 |\mathbf{P}|^2} \right] c_k + \sum_{l \neq k} H_{kl} c_l. \quad (27)$$

It will be convenient to write the off-diagonal matrix element in this case as

$$H_{kl} = \bar{\boldsymbol{\alpha}}_{kl} \cdot (c \mathbf{P}) + V_{kl}, \quad (28)$$

where  $V_{kl}$  is the coupling matrix element from the relative part of the problem

$$V_{kl} = \left\langle \Phi_k \left| \sum_j \alpha_j \cdot c \hat{\boldsymbol{\pi}}_j + \sum_j \beta_j m_j c^2 + \sum_{j < k} V_{jk} (\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) \right| \Phi_l \right\rangle \quad (29)$$

and where the vectors  $\bar{\boldsymbol{\alpha}}_{kl}$  are defined by

$$\bar{\boldsymbol{\alpha}}_{kl} = \left\langle \Phi_k \left| \sum_j \frac{m_j}{M} \alpha_j \right| \Phi_l \right\rangle. \quad (30)$$

We consider in the Appendix the nonrelativistic reduction of a representative  $\bar{\boldsymbol{\alpha}}_{kl} \cdot c \hat{\mathbf{P}}$  matrix element.

### 3.4. Rest frame eigenvalue equations

The eigenvalue equations above are unfamiliar and moderately complicated. It is useful to consider them in the rest frame; in this case, we obtain

$$Ec_k = \left[ \left\langle \Phi_k \left| \sum_j \frac{m_j}{M} \beta_j \right| \Phi_k \right\rangle M_k^* c^2 \right] c_k + \sum_{l \neq k} V_{kl} c_l. \quad (31)$$

For such a finite basis state model we would expect the basis state masses to appear; consequently we may write

$$M_k c^2 = \left\langle \Phi_k \left| \sum_j \frac{m_j}{M} \beta_j \right| \Phi_k \right\rangle M_k^* c^2. \quad (32)$$

This allows us to write

$$E \begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \end{pmatrix} = \begin{pmatrix} M_1 c^2 & V_{12} & V_{13} & \cdots \\ V_{21} & M_2 c^2 & V_{23} & \cdots \\ V_{31} & V_{32} & M_3 c^2 & \cdots \\ \vdots & \vdots & \vdots & \vdots \end{pmatrix} \cdot \begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \end{pmatrix}. \quad (33)$$

It will be convenient to think of this as the basic unperturbed problem

$$E \mathbf{c} = \mathbf{H}_0 \cdot \mathbf{c}. \quad (34)$$

### 3.5. Low-momentum eigenvalue relations

We can expand the square root terms to lowest order to obtain an eigenvalue equation relevant to the low-momentum case; we write

$$E c_k = \left[ M_k c^2 + \frac{|\mathbf{P}|^2}{2M_k} + \cdots \right] c_k + \sum_{l \neq k} \left[ \bar{\alpha}_{kl} \cdot (c \mathbf{P}) + V_{kl} \right] c_l, \quad (35)$$

where we have approximated the Dirac model as covariant in the estimates of the diagonal matrix elements. In matrix notation, this might be written as

$$E \mathbf{c} = \left[ \mathbf{M} c^2 + \mathbf{M}^{-1} \frac{|\mathbf{P}|^2}{2} + \mathbf{a} \cdot (c \mathbf{P}) \right] \cdot \mathbf{c}, \quad (36)$$

where

$$\mathbf{M} = \begin{pmatrix} M_1 & 0 & 0 & \cdots \\ 0 & M_2 & 0 & \cdots \\ 0 & 0 & M_3 & \cdots \\ \vdots & \vdots & \vdots & \vdots \end{pmatrix} \quad (37)$$

and where

$$\mathbf{a} = \begin{pmatrix} 0 & \bar{\alpha}_{12} & \bar{\alpha}_{13} & \cdots \\ \bar{\alpha}_{21} & 0 & \bar{\alpha}_{23} & \cdots \\ \bar{\alpha}_{31} & \bar{\alpha}_{32} & 0 & \cdots \\ \vdots & \vdots & \vdots & \vdots \end{pmatrix}. \quad (38)$$

#### 4. A Hamiltonian for Nuclei in a Lattice

There has been discussion over the years as to develop a suitable formalism that would be capable of systematically addressing the anomalies of interest in condensed matter nuclear science. It was proposed in [37] that one begin with a fundamental Hamiltonian based on nucleons and electrons, and then reduce the model for applications by first building up nuclei from nucleons, then solving for electronic degrees of freedom in a Born–Oppenheimer picture, and finally focusing on the vibrational problem. We imagine a similar approach here, only instead of starting with a nonrelativistic fundamental Hamiltonian we use a relativistic one.

The separation of center of mass and relative degrees of freedom is straightforward in the nonrelativistic version of the problem, which is why we focused on it in [37]. But we see in the discussion above that it is possible to separate the center of mass and relative Hamiltonians for a many-particle Dirac model, even in the context of a finite basis approximation. This separation allows us to extend the earlier program systematically to a relativistic formulation (including now a new relativistic coupling between the nuclear motion and internal nuclear degrees of freedom) based on an underlying many-particle Dirac model.

##### 4.1. Hamiltonian for electrons and nucleons

We begin with a formal model based on many-particle Dirac Hamiltonians for the electrons and nucleons

$$\begin{aligned} \hat{H} = & \left[ \sum_j \boldsymbol{\alpha}_j \cdot c \hat{\mathbf{p}}_j + \beta_j M_j c^2 + \sum_{j < k} V_{jk}^{nn}(\mathbf{r}_k - \mathbf{r}_j) \right]_{\text{nucleons}} \\ & + \left[ \sum_j \boldsymbol{\alpha}_j \cdot c \hat{\mathbf{p}}_j + \beta_j m_e c^2 + \sum_{j < k} V_{jk}^{ee}(\mathbf{r}_k - \mathbf{r}_j) \right]_{\text{electrons}} + \sum_{j,k} V_{jk}^{en}(\mathbf{r}_k - \mathbf{r}_j). \end{aligned} \quad (39)$$

In the first term in brackets we find a relativistic nucleon Hamiltonian including mass, velocity, and potential terms (including strong force interactions as well as electromagnetic interactions). Nuclear models of this kind can be found in the literature [38,39]. In the second term in brackets we find a relativistic electron Hamiltonian also including mass, velocity and potential terms (in this case electromagnetic interactions). Electronic models of this kind provide the foundation for relativistic electron band calculations; one can find a discussion of this model in [40]. Although there is no reason to believe that a relativistic description for the electrons is required for the problems of interest, somehow it seems appropriate to maintain the same level of description in the fundamental Hamiltonian. Finally, the last term includes electron-nucleon potential terms, which are electromagnetic here. A further augmentation of the model to include weak interaction physics is possible, but we will not pursue it here.

##### 4.2. Reduction of the nucleon Hamiltonian

The developments presented in the previous sections allow for a systematic reduction for the nucleon Hamiltonian in the form

$$\begin{aligned} & \left[ \sum_j \boldsymbol{\alpha}_j \cdot c \hat{\mathbf{p}}_j + \beta_j M_j c^2 + \sum_{j < k} V_{jk}^{nn}(\mathbf{r}_k - \mathbf{r}_j) \right]_{\text{nucleons}} \\ & \rightarrow \sum_l \left[ \mathbf{M} c^2 + \frac{|\hat{\mathbf{P}}|^2}{2\mathbf{M}} + \mathbf{a} \cdot (c \hat{\mathbf{P}}) \right]_l, \end{aligned} \quad (40)$$

where the sum over nucleons is now replaced with a sum over nuclei, and where the different matrices associated with the nuclear finite basis expansion are selected to be appropriate for the nucleus indexed by  $l$ .

The excited state energies in the rest frame appear as the eigenvalues of the mass term  $\mathbf{M}c^2$ . The lowest-order contribution to the kinetic energy of the nucleus as a composite Dirac particle is included in  $|\hat{\mathbf{P}}|^2/2\mathbf{M}$ , which allows for the energy of a basis state to impact the kinetic energy appropriately. Finally, there is a new term  $\mathbf{a} \cdot (c\hat{\mathbf{P}})$  that describes a relativistic effect in which the nucleus center of mass momentum (which will subsequently be part of the lattice vibrations) is coupled to transitions between the different basis states. The summation over  $l$  here indicates a sum over the different nuclei in the lattice, so that there will be separate mass matrices and lattice coupling terms for each nuclei. The condensed matter Hamiltonian that results is

$$\hat{H} = \left[ \sum_l \left[ \mathbf{M}c^2 + \frac{|\hat{\mathbf{P}}|^2}{2\mathbf{M}} + \mathbf{a} \cdot (c\hat{\mathbf{P}}) \right] \right]_{\text{nuclei}} + \left[ \sum_j \alpha_j \cdot c\hat{\mathbf{p}}_j + \beta_j m_e c^2 + \sum_{j<k} V_{jk}^{ee}(\mathbf{r}_k - \mathbf{r}_j) \right]_{\text{electrons}} + \sum_{j,k} V_{jk}^{en}(\mathbf{r}_k - \mathbf{r}_j). \quad (41)$$

This represents a generalization of the conventional starting place for condensed matter physics calculations.

#### 4.3. Born–Oppenheimer approximation

With nucleons replaced by nuclei, the resulting model is very similar to the standard condensed matter model, and we can similarly make use of the Born–Oppenheimer approximation to obtain a potential model for the nuclei

$$\hat{H} = \sum_l \left[ \mathbf{M}c^2 + \frac{|\hat{\mathbf{P}}|^2}{2\mathbf{M}} + \mathbf{a} \cdot (c\hat{\mathbf{P}}) \right] + \sum_{j<k} V_{jk}^{NN}(\mathbf{R}_k - \mathbf{R}_j). \quad (42)$$

This Hamiltonian is made up of individual mass, kinetic energy, and lattice coupling terms for each nucleus individually, and augmented now with effective potential interactions (electromagnetic plus electronic) between the nuclei. This model provides a generalization of the usual lattice Hamiltonian to include nuclear mass effects and lattice coupling with the nuclei.

#### 4.4. Reduction to a standard lattice Hamiltonian

In the event that the effects associated with nuclear excitation are weak, then the new terms in the model can be dispensed with; if we we assume

$$\mathbf{a}_l \rightarrow 0, \quad (43)$$

then we recover a model that is essentially the standard condensed matter lattice Hamiltonian:

$$\hat{H} = \sum_l \left[ \mathbf{M}c^2 + \frac{|\hat{\mathbf{P}}|^2}{2\mathbf{M}} \right] + \sum_{j<k} V_{jk}^{NN}(\mathbf{R}_k - \mathbf{R}_j). \quad (44)$$

In this approximation there is no direct coupling between the nuclear excited states and lattice vibrations. If the nuclei are in ground states, we could replace the mass matrices by the mass eigenvalues, which completes the reduction:

$$\hat{H} = \sum_l \left[ Mc^2 + \frac{|\hat{\mathbf{P}}|^2}{2M} \right]_l + \sum_{j < k} V_{jk}^{NN}(\mathbf{R}_k - \mathbf{R}_j). \quad (45)$$

## 5. Discussion and Conclusions

This study was motivated by our interest in deriving a lattice Hamiltonian from a relativistic starting Hamiltonian in which we could study the effect of the different configuration masses on the lattice dynamics, with the goal of developing a systematic description of the anomalies associated with condensed matter nuclear science. The derivation of such a Hamiltonian from the many-particle Dirac model in particular is in general problematic due to difficulties in the separation of relative and center of mass degrees of freedom for the relativistic problem. We recently obtained a weaker result that seemed to suggest a systematic way of separating center of mass and relative contributions to the energy, which prompted us to use it to isolate nuclear center of mass and nuclear terms in a lattice Hamiltonian. We obtained terms for the mass energy and kinetic energy that had been expected. In addition we obtained an additional coupling term due to the  $\boldsymbol{\alpha} \cdot c\mathbf{P}$  terms in the Dirac model; this we had not anticipated. The presence of this new term is not an artifact of our derivation, as we found subsequently that it can also be obtained in a straightforward manner using perturbation theory.

The origin of this effect is that the nuclear states of the composite nucleus transform under a boost in the many-particle Dirac model, which implies a mixing with other states. In the case of constant  $\mathbf{P}$  the eigenvalue problem is seeking to create a version of the boosted wavefunction out of the rest frame states. However, with the composite momentum is dynamical (as occurs in a lattice), the model tries to develop boosted wavefunctions for a composite momentum that keeps changing magnitude and direction, which requires in this picture a dynamical admixture of different rest frame states.

In the end, we obtain a Hamiltonian that describes lattice dynamics and nuclear excitation that is derived consistently from an underlying relativistic Hamiltonian (the many-particle Dirac model). This model appears to be very closely related to models for two-level systems coupled to an oscillator that we have investigated over the years [28–31] in connection with the excess heat effect in the Fleischmann–Pons experiment.

## Appendix A. Nonrelativistic Limit for the Transition Operator

Transitions in this model are described by the off-diagonal matrix element

$$\bar{\boldsymbol{\alpha}}_{fi} \cdot c\hat{\mathbf{P}} = \left\langle \Phi_f \left| \sum_j \frac{m_j}{M} \boldsymbol{\alpha}_j \cdot c\hat{\mathbf{P}} \right| \Phi_i \right\rangle. \quad (A.1)$$

We are interested in developing a nonrelativistic approximation for this operator which may be useful for understanding the coupling.

### Appendix A.1. Expansion of the wavefunction

We assume that the solution to the relative problem can be expanded in the form

$$\Phi = \Phi_{++++} + \Phi_{-+++} + \Phi_{+--+} + \Phi_{++--} + \cdots, \quad (A.2)$$

where the first term involves large component channels for all nucleons, where the second involves a small component channel for the first particle, and so forth.

### Appendix A.2. Channel equations

For the first term, the relative eigenvalue problem in the rest frame results in

$$\begin{aligned} \left[ E - Mc^2 - \sum_{j < k} V_{jk}(\xi_k - \xi_j) \right] \Phi_{++++} &= \sigma_1 \cdot (c\hat{\pi}_1) \Phi_{-+++} + \sigma_2 \cdot (c\hat{\pi}_2) \Phi_{+--+} \\ &+ \sigma_3 \cdot (c\hat{\pi}_3) \Phi_{++--} + \dots \end{aligned} \quad (\text{A.3})$$

For the second term we have

$$\begin{aligned} \left[ E - Mc^2 + 2m_1c^2 - \sum_{j < k} V_{jk}(\xi_k - \xi_j) \right] \Phi_{-+++} &= \sigma_1 \cdot (c\hat{\pi}_1) \Phi_{++++} + \sigma_2 \cdot (c\hat{\pi}_2) \Phi_{-+--} \\ &+ \sigma_3 \cdot (c\hat{\pi}_3) \Phi_{-+-+} + \dots \end{aligned} \quad (\text{A.4})$$

from which we approximate the channel wavefunction as

$$\Phi_{-+++} = \left[ E - Mc^2 + 2m_1c^2 - \sum_{j < k} V_{jk}(\xi_k - \xi_j) \right]^{-1} (\sigma_1 \cdot c\hat{\pi}_1) \Phi_{++++} \quad (\text{A.5})$$

### Appendix A.3. Approximate transition matrix element

To proceed we expand the transition matrix element in terms of the different pieces

$$\begin{aligned} \left\langle \Phi_f \left| \sum_j \frac{m_j}{M} \alpha_j \cdot c\hat{\mathbf{P}} \right| \Phi_i \right\rangle &= \frac{m_1}{M} \left[ \left\langle \Phi_f(+ + + \dots) \left| (\sigma_1 \cdot c\hat{\mathbf{P}}) \right| \Phi_i(- + + \dots) \right\rangle \right. \\ &\left. + \left\langle \Phi_f(- + + \dots) \left| (\sigma_1 \cdot c\hat{\mathbf{P}}) \right| \Phi_i(+ + + \dots) \right\rangle \right] + \dots \end{aligned} \quad (\text{A.6})$$

We expect the large component to dominate, so we keep terms with a single small component and approximate according to

$$\begin{aligned} \left\langle \Phi_f \left| \sum_j \frac{m_j}{M} \alpha_j \cdot c\hat{\mathbf{P}} \right| \Phi_i \right\rangle &= \\ \frac{m_1}{M} \left[ \left\langle \Phi_f(+ + + \dots) \left| (\sigma_1 \cdot c\hat{\mathbf{P}}) \left[ E - Mc^2 + 2m_1c^2 - \sum_{j < k} V_{jk}(\xi_k - \xi_j) \right]^{-1} (\sigma_1 \cdot c\hat{\pi}_1) \right| \Phi_i(+ + + \dots) \right\rangle \right. \\ &\left. + \left\langle \Phi_f(+ + + \dots) \left| (\sigma_1 \cdot c\hat{\pi}_1) \left[ E - Mc^2 + 2m_1c^2 - \sum_{j < k} V_{jk}(\xi_k - \xi_j) \right]^{-1} (\sigma_1 \cdot c\hat{\mathbf{P}}) \right| \Phi_i(+ + + \dots) \right\rangle \right] \\ &+ \dots \end{aligned} \quad (\text{A.7})$$

## Appendix A.4. Taylor series expansion

A Taylor series expansion yields

$$\begin{aligned}
 & \left[ E - Mc^2 + 2m_1c^2 - \sum_{j < k} V_{jk}(\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) \right]^{-1} \\
 &= \frac{1}{2m_1c^2} \left[ 1 + \frac{E - Mc^2}{2m_1c^2} - \frac{1}{2m_1c^2} \sum_{j < k} V_{jk}(\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) \right]^{-1} \\
 &= \frac{1}{2m_1c^2} \left[ 1 - \frac{E - Mc^2}{2m_1c^2} + \frac{1}{2m_1c^2} \sum_{j < k} V_{jk}(\boldsymbol{\xi}_k - \boldsymbol{\xi}_j) + \dots \right]
 \end{aligned} \tag{A.8}$$

## Appendix A.5. Leading-order contribution

To evaluate the leading-order term in the expansion of the transition matrix element, we require the identity

$$(\mathbf{a} \cdot \boldsymbol{\sigma})(\mathbf{b} \cdot \boldsymbol{\sigma}) = \mathbf{a} \cdot \mathbf{b} + i\boldsymbol{\sigma} \cdot \mathbf{a} \times \mathbf{b}. \tag{A.9}$$

This allows us to write

$$\begin{aligned}
 (\boldsymbol{\sigma} \cdot c\hat{\mathbf{P}})(\boldsymbol{\sigma} \cdot c\hat{\boldsymbol{\pi}}) + (\boldsymbol{\sigma} \cdot c\hat{\boldsymbol{\pi}})(\boldsymbol{\sigma} \cdot c\hat{\mathbf{P}}) &= 2c^2\hat{\boldsymbol{\pi}} \cdot \hat{\mathbf{P}} + i\boldsymbol{\sigma} \cdot (\hat{\mathbf{P}} \times \hat{\boldsymbol{\pi}} + \hat{\boldsymbol{\pi}} \times \hat{\mathbf{P}}) \\
 &= 2c^2\hat{\boldsymbol{\pi}} \cdot \hat{\mathbf{P}}.
 \end{aligned} \tag{A.10}$$

Consequently, the leading-order term vanishes

$$\begin{aligned}
 & \sum_j \frac{m_j}{M} \left[ \left\langle \Phi_f(+++\dots) \left| (\boldsymbol{\sigma}_j \cdot c\hat{\mathbf{P}}) \frac{1}{2m_jc^2} (\boldsymbol{\sigma}_j \cdot c\hat{\boldsymbol{\pi}}_j) \right| \Phi_i(+++\dots) \right\rangle \right. \\
 & \quad \left. + \left\langle \Phi_f(+++\dots) \left| (\boldsymbol{\sigma}_j \cdot c\hat{\boldsymbol{\pi}}_j) \frac{1}{2m_jc^2} (\boldsymbol{\sigma}_j \cdot c\hat{\mathbf{P}}) \right| \Phi_i(+++\dots) \right\rangle \right] \\
 &= \frac{1}{M} \left[ \left\langle \Phi_f(+++\dots) \left| \hat{\mathbf{P}} \cdot \sum_j \hat{\boldsymbol{\pi}}_j \right| \Phi_i(+++\dots) \right\rangle \right],
 \end{aligned} \tag{A.11}$$

, since

$$\sum_j \boldsymbol{\pi}_j = \sum_j \mathbf{p}_j - \frac{m_j}{M} \mathbf{P} = 0. \tag{A.12}$$



### Appendix A.6. First next-order term

There are two next-order terms; the first of these is

$$\begin{aligned} & \sum_j 2 \frac{m_j}{M} \left\langle \Phi_f(+ + + \dots) \left| (\sigma_j \cdot c\hat{\mathbf{P}}) \frac{E - Mc^2}{(2m_j c^2)^2} (\sigma_j \cdot c\hat{\boldsymbol{\pi}}_j) \right| \Phi_i(+ + + \dots) \right\rangle \\ &= \frac{(E - Mc^2)}{2Mc^2} \left\langle \Phi_f(+ + + \dots) \left| \sum_j \frac{\hat{\boldsymbol{\pi}}_j \cdot \hat{\mathbf{P}}}{m_j} \right| \Phi_i(+ + + \dots) \right\rangle. \end{aligned} \quad (\text{A.13})$$

Note that this term contains the sum  $\sum_j \frac{\hat{\boldsymbol{\pi}}_j}{m_j}$  which we may rewrite as

$$\sum_j \frac{\hat{\boldsymbol{\pi}}_j}{m_j} = \sum_j \hat{\boldsymbol{\pi}}_j \left( \frac{1}{m_j} - \frac{1}{m_{av}} \right), \quad (\text{A.14})$$

since  $\sum_j \hat{\boldsymbol{\pi}}_j = 0$ , where  $m_{av}$  might be an appropriate average of the different masses. Since the proton mass is 938.27 MeV/c<sup>2</sup> and the neutron mass is 939.56 MeV/c<sup>2</sup>, the individual nucleon masses are little different from the average nucleon mass. Consequently, we expect this term to be small.

### Appendix A.7. Second next-order term

The other next-order term is

$$\begin{aligned} & \sum_j \frac{m_j}{M} \left[ \left\langle \Phi_f(+ + + \dots) \left| (\sigma_j \cdot c\hat{\mathbf{P}}) \left[ \frac{1}{(2m_j c^2)^2} \sum_{k < l} V_{kl}(\boldsymbol{\xi}_l - \boldsymbol{\xi}_k) \right] (\sigma_j \cdot c\hat{\boldsymbol{\pi}}_j) \right| \Phi_i(+ + + \dots) \right\rangle \right. \\ & \quad \left. + \left\langle \Phi_f(+ + + \dots) \left| (\sigma_j \cdot c\hat{\boldsymbol{\pi}}_j) \left[ \frac{1}{(2m_j c^2)^2} \sum_{k < l} V_{kl}(\boldsymbol{\xi}_l - \boldsymbol{\xi}_k) \right] (\sigma_j \cdot c\hat{\mathbf{P}}) \right| \Phi_i(+ + + \dots) \right\rangle \right] \\ &= \frac{1}{2Mc^2} \left[ \left\langle \Phi_f(+ + + \dots) \left| \sum_j (\sigma_j \cdot c\hat{\mathbf{P}}) \left[ \frac{1}{2m_j c^2} \sum_{k < l} V_{kl}(\boldsymbol{\xi}_l - \boldsymbol{\xi}_k) \right] (\sigma_j \cdot c\hat{\boldsymbol{\pi}}_j) \right| \Phi_i(+ + + \dots) \right\rangle \right. \\ & \quad \left. + \left\langle \Phi_f(+ + + \dots) \left| \sum_j (\sigma_j \cdot c\hat{\boldsymbol{\pi}}_j) \left[ \frac{1}{2m_j c^2} \sum_{k < l} V_{kl}(\boldsymbol{\xi}_l - \boldsymbol{\xi}_k) \right] (\sigma_j \cdot c\hat{\mathbf{P}}) \right| \Phi_i(+ + + \dots) \right\rangle \right]. \end{aligned} \quad (\text{A.15})$$

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