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Research Article

Electron Quasi-particle Catalysis of Nuclear Reactions

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Abstract

Our model applies solid state, nuclear, and quantum mechanics principles to the molecular chemistry process. We show how most of our predicted transmutation products are consistent with experimental data from a wide variety of LENR experiments, and how they can be triggered. Chemical physics recently discovered a new type of chemical reaction that concentrated most of the energy of reactants into electrons that were originally trapped between reactants. The reaction leaves the reaction product molecule relatively cool. Considering the rules of solid state physics, we apply the pattern of these chemical reactions to nuclear reactions, referred to as "Lattice Enabled Nuclear Reactions" (LENR, also called "Low Energy Nuclear Reactions"). The predicted nuclear energy release also concentrates the energy in electrons, energized inside the nuclear product. The nuclear products are predicted to be "cold", implying non-radioactive, ground state. In some cases the excitation energy of the compound nucleus is sufficient to fracture it into more isotopes that were not originally present. The total attraction energy (coulomb plus nuclear) can overcome the quantum kinetic energy repulsion of the squeezed electron quasi-particles (Heisenberg Uncertainty Principle) when the effective electron mass exceeds a threshold value. Our model is consistent with cold nuclear fusion reactions catalyzed by muons in isotopes of hydrogen (Alvarez, UC Berkeley, 1956). We identify mechanisms to create transient, sufficiently elevated effective mass electron quasi-particles. According to our model some of these reactions should produce highly energetic neutral helium or helium-3, but they are difficult to measure. Our model predicts no "cold fusion" of deuterium plus deuterium into helium, even though it predicts copious, energetic helium emission. We will describe the model principles and compare its predictions with data from various reactions. Our model also predicts that certain LENR reactions should transmute radioactive fission products into normal elements, neutralizing the radioactivity. Other possible applications include process heat, hydrogen production, direct generation of electricity, and space propulsion.
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Keywords: Electron catalysis, Electron scattering, Kinetic energy of confinement, Transmutation, Vibrationally promoted electron emission

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1. Chemical Physics Basis

Our reaction model is based on chemical physics research performed at University California –Berkeley and Santa Barbara. The energy of a fuel (f) and a reactant (R) binding together by molecular attraction is transferred directly to an electron (e^-) trapped between them (Fig. 1).

The reaction partitions the RF binding energy into electron kinetic energy, internal vibration of the Rf molecule (if any remains), and a small recoil energy of the molecule. This "Vibrationally Promoted Electron Emission" is a direct conversion of binding energy to electron kinetic energy [1,2].

Figure 2 shows only the binding energy, not the coulomb attraction energy. At the moment of ejection, the electron is born with both reactant binding and electron coulomb bonding energy. The electron expends the coulomb bonding energy while escaping the coulomb potential, and it carries away the reactant binding energy, minus the small product molecule recoil (and internal vibration energy, if any remains). Appendix A discusses the chemical physics reactions.

The electron satisfies the Heisenberg Uncertainty Principle (HUP) as it is confined in the potential well of width σ_x between the reactants R and f. Its repulsive momentum (also called "kinetic energy of confinement") counteracts the attractive potentials of molecular binding and coulomb attraction (discussed below). When the attractive potential is insufficient to overcome momentum repulsion, there is no transition, and a vibrationally excited molecule decays in familiar ways, such as by thermalizing with its environment or by vibrational de-excitation radiation.

When applying the model to the *nuclear* reactants, such as hydrogen and nickel, the coulomb attraction is insufficient to bring the reactants close enough for the nuclear potential to act, and the transition is forbidden. However, we will show that the momentum repulsion can be reduced if the effective electron quasi-particle mass can be temporarily increased. Then, when the reduced momentum repulsion is barely exceeded by the attractive potentials, R and f bind, and the excitation energy of the compound nucleus de-excites. The resultant nucleus would be in the ground state (or have a very long half-life).

After discussing the system Hamiltonian and kinetic energy of confinement we will derive the effective mass threshold for the electron quasi-particle to trigger catalysis. Then we will discuss how to transiently elevate some of the electron quasi-particle masses.

2. Hamiltonian and Quantum Kinetic Energy

When an electron is confined to a small volume, its momentum increases in accordance with the Heisenberg uncertainty principle, creating a back-pressure against the confining walls. This momentum repulsion is also called "kinetic energy of confinement (KEC)."

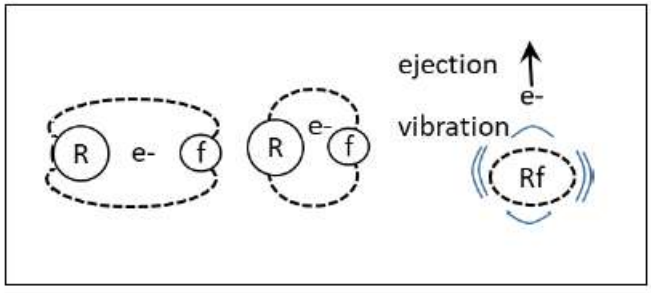

Figure 1. Molecular binding of f and R ejects an electron, leaving the Rf molecule in a low vibrational state.

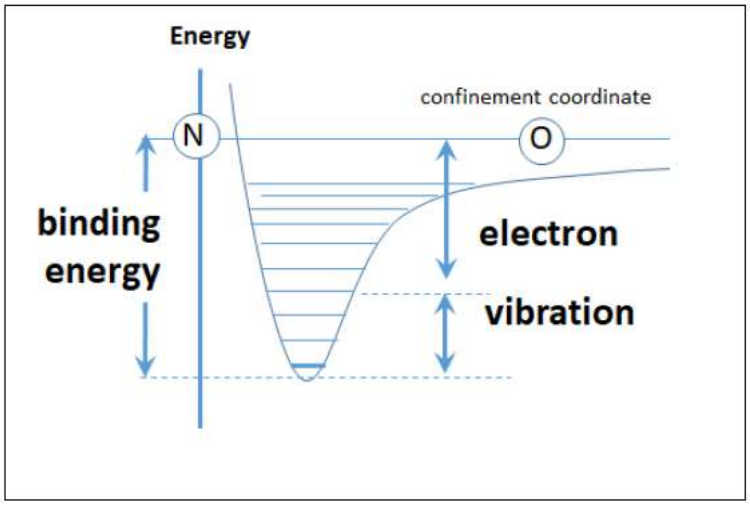

Figure 2. Potential energy of nitrogen and oxygen molecular system vs. "confinement coordinate" (representing molecular separation distance).

The one-dimensional Hamiltonian may be written

$$H = T_{\rm i} + T_{\rm e} + V_{\rm nuc} + V_{\rm e}, \tag{1}$$

where $V_{\rm e}$ is the three-body Coulomb potential, $V_{\rm nuc}$ an independent nuclear binding energy, $T_{\rm i}$ the kinetic energy of the ions, and $T_{\rm e}$ is the kinetic energy of the electron. $T_{\rm e}$ becomes very high when the electron is squeezed between narrow boundaries. $V_{\rm e}$ is relatively weak ($\sim$ eV) with a chemical range of order 100 pm. The nuclear binding potential $V_{\rm nuc}$ is relatively strong (MeV), with a very short range (several fm). The ion chemical turning points occur where the attractive term $V_{\rm e} + V_{\rm nuc}$ is balanced by the repulsive momentum from kinetic energy of confinement, bringing $T_{\rm i} = 0$. A nuclear reaction is possible only if the attractive potential energy is greater than the repulsive KEC:

$$|V_{\rm e} + V_{\rm nuc}| > T_{\rm e} \qquad \text{at } \; x = x_{\rm n}, \tag{2}$$

where $x_{\rm n}$ is the nuclear force radius.

We can estimate the kinetic energy of the electron from the Robertson–Schrödinger relation (modern form of HUP), which relates electron quasi-particle momentum p to its spatial confinement dimension. The confinement dimension σ_x is approximately the ion separation distance x:

$$\sigma_x^2 \sigma_{\rm p}^2 = (\hbar/2)^2 K(n), \tag{3}$$

where the variances are

$$\sigma_x^2 = \langle x^2 \rangle - \langle x \rangle^2, \qquad \sigma_{\rm p}^2 = \langle p^2 \rangle - \langle p \rangle^2$$

,

and $\hbar$ is the reduced Planck constant. And for ground states K (ground state) ~ 1, for a quantum harmonic oscillator stationary state $K(n) = (2n+1)^2,\ \ n = 0, 1, \ldots$; for a Gaussian initial condition or for a coherent state $K = 1$; for a particle in a box $K(n) = (n^2\pi^2/3 - 2),\ \ n = 1, 2, \ldots$

We assume a Born–Oppenheimer approximation where the electron motion accommodates fast compared to ion motions. This implies an oscillatory motion with $\langle p \rangle = 0$, and $\sigma_{\rm p}^2 = \langle p^2 \rangle$. The expected value of the electron KEC is therefore

$$\langle T_{\rm e} \rangle = \langle p^2/2m \rangle = \hbar^2 K(n)/8m\sigma_x^2. \tag{4}$$

If m is heavier, then repulsive $\langle T_{\rm e} \rangle$ is reduced, and the ion turning point occurs at a smaller value of x. Combining Eq. (4) with Eqs. (1) and (2), and solving for the threshold electron quasi-particle mass $m_{\rm th}$, we find

$$m_{\rm th} = \hbar K(n)/8\sigma_x^2 |V_{\rm e} + V_{\rm nuc}| \qquad \text{at } \ x = x_{\rm n}. \tag{5}$$

A trapped electron needs to acquire $m_{\rm th}$ in the chemical molecule formed by (f e^- R) or by (p muon d). We ask: "What is the probability density of the chemical electron quasi-particle at a dimension just inside the nuclear force region?" This is the procedure used in K-capture physics, where the normal electron has a density inside a normal nucleus. When energy can be lowered by a proton in the nucleus absorbing the electron to form a neutron, a new nucleus appears, and neutrinos are emitted. The absorbed electron is a K shell electron.

In our LENR case we use the same procedure as for K-capture analysis, but the fractional electron penetration is from the chemical molecule instead of from a K shell electron. The tri-body Ve term is analyzed elsewhere. [3].

When an electron's mass $m < m_{\rm th}$, its probability density in the nuclear region is only imaginary and no reaction is possible. When $m > m_{\rm th}$ a finite real component of the probability density is possible by tunneling. We estimate the tunneling probability for several example LENR cases. When we plot the total energy as a function of confinement parameter for different values of effective mass we can visualize how $m > m_{\rm th}$ can trigger a reaction (Fig. 3).

When the effective mass exceeds the threshold (bottom curve Fig. 3) the relative position of the ground state of the nuclear system lowers to below the zero of energy and matches the energy level of the chemical state. Figure 4 shows the resonant electron tunneling can then occur to the nuclear force region between reactants. Upon tunneling, the reactants transfer their kinetic energy to the electron when they collide with the electron. The electron scatters, leaving the reactants together with only the energy of the ground state. This means the reactants bind in the ground state and the energy is transferred to the electron. The electron catalyzed the nuclear reaction.

Note that the electron need not be confined at nuclear dimension. The total energy allows the electron to appear as if it collided with a moving wall that gave it the entire binding and bonding energy, the nuclear plus coulomb potential energy in the region of the nucleus. The result is a prompt transition to a bound nucleus in the ground state and an unbound electron. (The model is discussed further in Appendix B.)

We will discuss how to achieve $m_{\rm th}$, calculate it for many reactions, and compare the model predictions with experimental data.

3. Increase of Electron Quasi-particle Mass

Instead of solving the Bloch equations for an electron quasi-particle in a crystallite, and then computing an effective mass, we use the quasi-particle shortcut: use solid state effective mass. The effective mass of a ballistic electron quasi-particle in a periodic crystal conductor is proportional to the inverse of curvature of its Band Structure diagram. The effective mass of an electron quasi-particle is

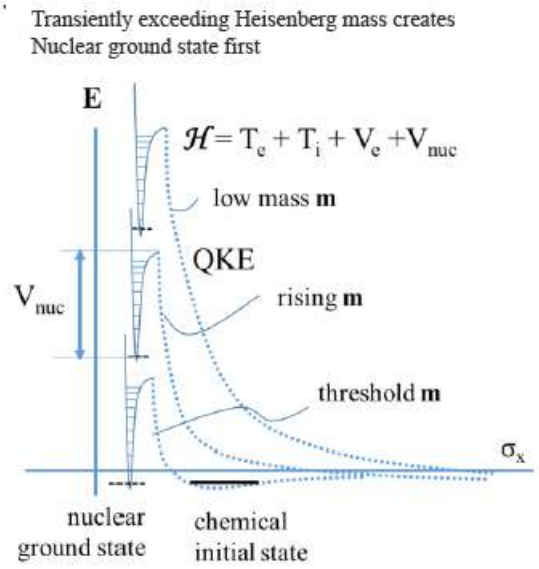

Figure 3. Total energy vs. confinement parameter for three different quasi-particle masses.

$$m = \hbar^2/(\partial^2 E/\partial k^2) = \hbar/\text{curvature}, \tag{6}$$

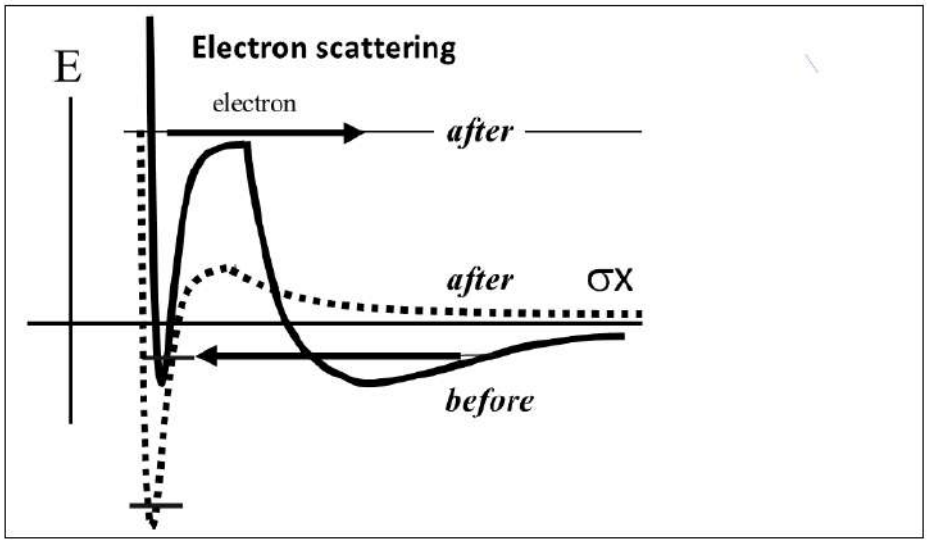

Figure 4. Potential energy transfer from binding and bonding potentials to electron quantum kinetic energy is stimulated the instant an electron tunnels to nuclear region.

where $\hbar$ is the reduced Planck constant [4].

The quasi-particle can only have energy and crystal momentum values on the diagram. Electrons can be placed in the region of an inflection point by simultaneous injection of particular values of crystal momentum (phonons) and electron energy into a crystallite region. One of many ways to inject a spread of crystal momentum values and energy values into a crystal's band structure is adsorbing or desorbing a nucleus, which may produce a spectrum of energies and momenta in the crystal, Fig. 5.

More inflection points are created in a crystal with facets. Therefore, crystals in the process of disintegrating or integrating create a splatter of inflection point targets. This means adsorbing or desorbing nuclei and disintegrating and integrating crystallites may place some fraction of the electrons sufficiently near an inflection point to usefully raise their effective masses, Fig. 6.

When we increase the effective mass, we also increase the apparent density of electrons in the chemical region.

4. Example Reactions

Whenever we see the same potential energy schematic or diagram, we suspect the solutions are similar. We notice that the proton–muon–deuteron picture is like that of the chemical research (Fig. 7). The negative muon brings p and d close enough to create the transition state where the nuclear force can bind them. The muon has a mass well above the threshold. It should immediately eject the muon, which is a transient heavy electron. The muon would carry away the binding energy leaving the merged product (pd), which is helium-3. This was observed [5–9].

Table 1 lists some other reactions of interest. Some nuclear reactions have the same f e R pattern, but with several fuel ions and electrons, such as

$$4f4e^{-}R \rightarrow [4fR] + \text{energy}$$

.

If electron quasi-particles could acquire sufficient mass, then most LENR transmutations could be understood.

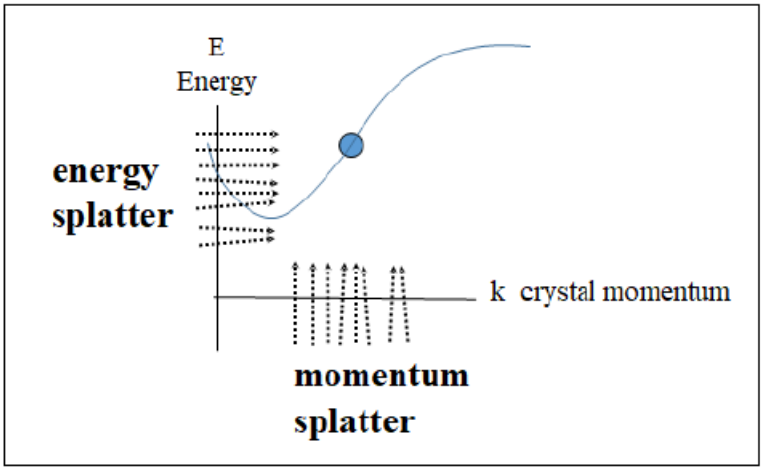

Figure 5. Splatter of energy and momentum can place some electrons near the inflection point.

Table 1. Selected chemical and nuclear tri-body reactions.

f	e^-	R	$\longrightarrow$	fR
H	e^-	Metal	$\longrightarrow$	HM
OH	e^-	Ag	$\longrightarrow$	OH-Ag
N	e^-	O	$\longrightarrow$	NO
O	e^-	CO	$\longrightarrow$	CO_2
p	μ^-	d	$\longrightarrow$	^{3}He
p	e^-	^{62}Ni	$\longrightarrow$	^{63}Cu
2p	$2e^-$	^{62}Ni	$\longrightarrow$	^{64}Zn
d	e^-	^{105}Pd	$\longrightarrow$	^{107}Ag
4d	$4e^-$	^{133}Cs	$\longrightarrow$	^{141}Pr

A revealing example uses only protons with a lattice reactant to produce helium and isotopes. The example suggests the process is not a fusion of protons or deuterons together, but instead a binding of protons or deuterons with a lattice reactant. For example, the model predicts that two protons will bind with ^{62}Ni or ^{64}Ni to generate Fe, Cu, Zn, and Co. Reference [8] quantified the relative amounts of the isotopes to the original Ni. Brillouin Energy (2015) reported the observation of helium. The 2H + ^{64}Ni + 2 heavy electrons with effective mass $\sim$ 35 electron rest masses would create excited state Zn with 13 MeV within the ^{64}Zn product nucleus and decay by one of several branches. Helium with 11.8 MeV and ^{62}Ni can be ejected, or two helium sharing 4.8 MeV and ^{58}Fe can be ejected. Other branches may emit Cu, Cr, Ti, and C and have been variously reported. Similarly, 2H + ^{62}Ni can produce ^{60}Ni + helium or ^{56}Fe + 2 He.

Helium production from proton–metal reactions as predicted by our 1D model appears to confirm the process is not fusion, cold or hot. It is instead a form of nuclear vibrationally promoted electron emission with the energy re-used inside the reacting nucleus.

During electrolysis of H and D with Pd Alexandrov observed both ^{4}He and ^{3}He [9]. This is consistent with our prediction of a catalytic reaction where H and D merge with Pd to make an intermediate Cd compound nucleus and containing two electrons with about 20 MeV total. This energy is enough that it could fracture the Cd into stable parts: Pd and ^{3}He. Effective mass threshold for H–D–Pd reactions is of order 12 – 14. In this reaction palladium is a

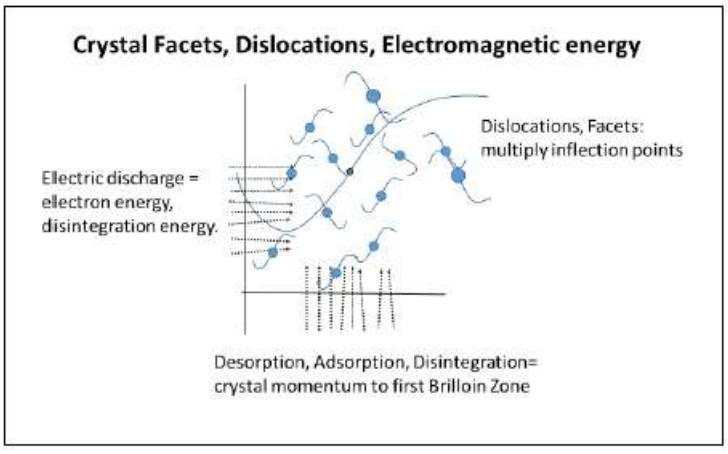

Figure 6. Multiple crystal facets introduce more and different band curves, with new inflection points.

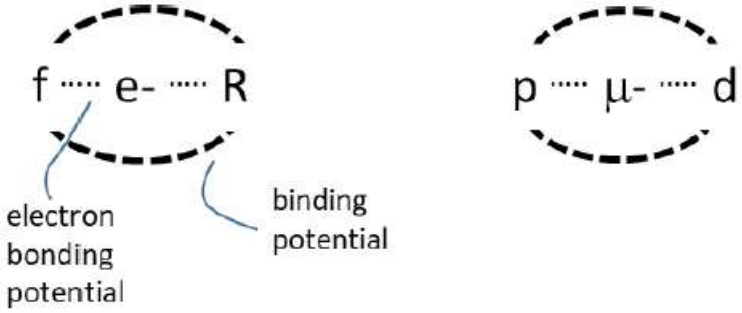

Figure 7. The molecular chemistry model and the muon catalysis model.

catalyst that is regenerated. The mixture also produced the expected $\mathrm{D} + \mathrm{D} + 2\mathrm{e}^- + \mathrm{Pd} \rightarrow (\mathrm{Cd}^* + 2\mathrm{e}^-) \rightarrow \mathrm{Pd} + {}^4\mathrm{He}$. Effective mass threshold for deuteron–Pd reactions are of order 10–13. Another example is $\mathrm{H} + \mathrm{H} + 2\mathrm{e}^- + {}^{104}\mathrm{Pd} \rightarrow (\mathrm{Cd}^* + 2\mathrm{e}^-) \rightarrow {}^{102}\mathrm{Pd} + {}^4\mathrm{He}$. Effective mass threshold for proton–Pd reactions are of order 22–29. Here, the Pd is a reactant and a different Pd isotope product.

5. Rules for Producing LENR in Crystallites

Rule 1: *The Mass–energy difference* between reactants and product must be exothermic. (The mass of the starting reactants must be greater than the mass of the products.)
Rule 2: *Inject a splatter of crystal momentum and energy* to raise the electron quasi-particle mass m above the threshold mass m_{th}. Expect either energetic electron emission or heat resulting from their thermalization.
Rule 3: *Ignore the normal electrons*, including the core electrons, around nuclei. Muon–nucleus particle physics observed that the heavy electrons may approximately ignore the normal and low mass electrons.
Rule 4: *Highest atomic number attracts heavy electrons* Muon–nucleus particle physics definitively observed that heavy electrons are strongly attracted to the nuclei with the highest number of protons. The isotopes with the highest proton number should either react with the heavy electrons or thermalize them without reaction.
Rule 5: *Evaluate possible emissions using "excitation energy"* that is available in the compound nucleus. The binding energy is transferred to multi-MeV electron quasi-particles inside the nucleus. Stable subunits of the nucleus, such as alpha particles, can be emitted if the excitation energy is above the alpha binding energy.
Rule 6: *Consider electron capture* of the injected heavy electrons when electrons have > 0.8 MeV. Expect this energy to escape the "excess heat" measurements, because the lowest mass absorbs the highest energy, neutrinos are almost zero mass and they rarely interact, so that neutrino emission is nearly undetectable.

We have considered many different LENR reactions, including:

- When deuterium (D) was reacted by electrolysis with natural palladium-105 (^{105}Pd), silver-107 (^{107}Ag) appeared [10].
- When cesium, barium, strontium, calcium and tungsten (Cs, Sr, Ba, Ca, and W) were separately reacted with deuterium using deuterium adsorption and desorption, the isotope products looked like nuclei with 2, 4 or 6 more deuterons had been added (^{141}Pr, ^{96}Mo, Sm, Ti, Os, and Pt) [11–13].
- Praseodymium (^{141}Pr) appeared, as if cesium (^{133}Cs) merged with four deuterium [12]. Iron (^{56}Fe) appeared as if calcium (^{44}Ca) absorbed six deuterium to make iron (^{56}Fe), with intermediates titanium (^{44}Ti) and

chrome (^{52}Cr) [12].
- When a titanium fuse was exploded in light water, Ni, Zn, Cu, and Fe appeared [14].
- In electrolysis of a mixture of heavy and light water, both ^{3}He and ^{4}He were observed [9,15].
- When dislocations, crystallite boundaries and imperfections were included, LENR reactions increased [16].
- When rubidium salt was included in a light water electrolysis, radioactive emissions consistent with the three-day half life of ^{87}Y were observed [17].
- When $LiAlH_4$ was included in a nickel reaction, all the nickel isotopes reacted with lithium and hydrogen fuels in combination, resulting in the expected Fe, Cu, Co and other isotopes. The Al also reacted with Li and H, generating Cl and Si. [8,18–20].

Our model predictions are consistent with the transmutation data from each of these experiments.

Two types of alpha emitting reactions should occur with about 1/10 of the isotopes in the periodic table. The hydrogen reaction is ^{A}X + 2H $\rightarrow^{A-2}$X $+^{4}$He. The deuterium reaction is ^{A}X $+2n$*D $\rightarrow^{A}$X $+n$*^{4}He, where n is an integer. These reactions can be almost invisible.

Many of the emitted alpha particles (He^{++}) may pick up electrons from the surrounding dense cloud of electrons (both heavy and light) and emerge as energetic ($\sim$10 MeV) neutral atoms. These energetic neutral atoms' (ENA) ranges should be much longer than the range of charged alpha particles, making them difficult to measure.

A few radioactive isotopes should be produced, even though the theory predicts that most the products are "born in the ground state." The hydrogen-nickel reactions (2H + Ni $\rightarrow$ isotopes + energy) seem to react with all the Ni isotopes. Some of the intermediate nickel isotope products should be "stable" on nanosecond time scales, but could be beta emitting and electron capture isotopes. Such products look like a "ground state" because of their stability (seconds to mega years) on the time scale of nuclear reactions (10^{-20} s).

These intermediates should be beta emitters or electron capture isotopes. One would not see the K-alpha radiation of the usual K-capture process because the externally supplied electron is already inside the nucleus and does not come from the K shell. One would not see much beta emission because electrons have such a short range in real materials. Many ejected electrons are thermalized in the electron cloud around the emitting nucleus during tens of fs, resulting in heat. However, Karabut and Saavatimova have reported isotopic evidence of the radioactive beta and electron capture isotopes in conducting targets of proton glow discharges with energies under about 3 keV [21–25]. Lipoglavsek apparently observed evidence for the expected 5.3 MeV electron from proton–electron–deuteron transmutations [26–28].

A third branch might explain a small fraction of observed isotopes: the production of neutrons from energetic electrons inside the nucleus colliding with protons, which would be a weak interaction inside the nucleus.

6. Reaction Branches

Three branches have been identified:

(1) transmutations to other stable isotopes emitting electron quasi-particles as energy,
(2) prompt fracturing to another branch, emitting energetic stable products (such as He), possibly charge neutral,
(3) prompt electron capture to stable products emitting neutrino energy.

7. Conclusions

Our tri-body catalysis model assumes that a particular crystal momentum and electron energy addition can transiently elevate some electron *quasi-particle masses* in a crystalline lattice containing reactants. The size of chemical entities is inversely proportional to the quasi-particle mass. When the effective mass exceeds a threshold value m_{th}, the size

of chemistry shrinks and the chemical separation distance can become small enough that electron tunneling into the region of the forces binding the reactants can apparently catalyze reactions.

The recently discovered *chemical physics* of Vibrationally Promoted Electron Emission (VPEE) reported by LaRue [1] provides the physics for a model to use nuclear binding potentials in place of chemical potentials to bind reactants together. Instead of chemical reactant binding, nuclear reactant bindings (transmutations) can be stimulated when the shrinking of chemical size exceeds a threshold. VPEE with elevated effective mass quasi-particles provide a model to characterize and predict the rates and products of hydrogen/reactant interactions in the solid state.

Alvarez [5] provided the first example of nuclear reactions stimulated by a shrinking of the size of chemical entities when he used a *mu meson* as the bonding electron in a hydrogen–heavy electron–reactant molecule. The result was similar to its chemical counterpart. A new nucleus can be formed from its reactants and nuclear binding energy is delivered to electrons inside the region of nuclear forces. The electron quasi-particles may eject and thermalize to heat within the lifetime of a ballistic electron in the lattice, with the transmuted product remaining in its ground state. Or the electron may deliver the energy to the product itself, causing partitioning and ejection of stable subnuclei, also transmutation products.

Reactions of *protons* binding with *nickel* isotopes should result in a form of fission of the zinc product into helium and transmutation nuclei. The helium and the isotopes have been observed. No deuterons need be involved, and no fusion, hot or cold, need be invoked.

Solid state *methods* to transiently *elevate* the electron effective mass are identified. In each case of a claimed transmutation stimulated by chemical means, one or more of the identified methods to transiently elevate electron quasi-particle mass appear to be activated.

Helium-3 and Helium-4 productions were predicted for mixed light and heavy hydrogen *electrolysis* with *palladium*. The intermediate product was a cadmium, energized with $\sim$20 MeV electrons inside the nuclear force region. The final products include the original palladium and helium-3 from H + D + Pd and helium-4 from D + D + Pd reactions, which Alexandrov reported.

When *multiple pairs* of deuterium were reacted with various isotopes including Cs, Sr, Ba, Ca, and W, the observed ground state isotope products looked like nuclei with 2, 4 or 6 more deuterons had been added (^{141}Pr, Mo, Sm, Ti, Os, and Pt). The reaction fits the heavy electron model for "*shrinking* of the size of chemistry" and of the VPEE process to bind the reactants into ground state product nuclei.

Reaction rates are based on an elevated effective mass, *evanescent* electron *wavefunction density* when a chemical electron with scatters from the nuclear region between the reactants. The elevated residence time of the heavy electron between the attracting reactants (which must include the electron to be attractive) allows the reactants to converge to the smaller size of the product nucleus. The electron is scattered when it collides with the converging reactant nuclei, and appears either as an ejected electron or as electron energy within the nuclear product, typically inducing fission-like emissions.

Appendix A. Relevant Chemical Physics Experiments

Chemical physics discovered a fundamentally new type of reaction during the 2000s. Figure 8 shows the energy of a fuel (f) and a reactant (R) binding together by molecular attraction is transferred directly to an electron (e^-) passing between them.

Key experiments at UC Berkeley and UC Santa Barbara demonstrated direct conversion of the chemical binding energy into the kinetic energy of a single electron. The observed reaction seemed to violate the Born–Oppenheimer Approximation. It is now accepted that vibrational energy can transfer directly into a single electron's kinetic energy.

Hellberg observed both 1–2 eV electrons and photons when "f" comprised chlorine molecules, Cl_2, which adsorbed on "R", a potassium K surface [29]. The merged "molecule," "fR," was Cl_2–K or Cl–K. The 1–2 eV electron received

almost all the energy available. The Cl_2 on the K surface was only expected to lose energy by vibrational decay or photon emission, one quantum at a time, not all at once. Instead, the reaction ejected a single energetic electron taken from the K surface when the two came in contact. The two potentials attracting the fuel and reactant together include the electron coulomb bonding and the Cl_2-K attraction's binding potential [29].

Figure 9 shows how Nienhauss provided hydrogen radicals, H, to a 6 nm thin Ag silver surface [30]. The H was supposed to form a bond with the silver and slowly lose energy to thermal electrons one vibrational quantum at a time. Instead, an electron from the silver was ejected with energy above the Schottky barrier ($\sim$ 0.6 eV). The silver formed a Schottky barrier diode with the silicon underneath it. The electron energy must have been $\geq$ 0.7 eV, because Nienhauss measured a short circuit current across the diode. The expected energy was much lower, in the 1 meV range for phonons and thermal range (0.026 eV), for electrons [30].

As shown in Fig. 10, Huang reported energizing an NO molecule using a laser to stretch the molecule to nearly its breaking point [31]. A free N radical was placed just close enough to a free O radical for them to bind and become a highly vibrationally excited NO molecule. When the molecule contacted the gold vacuum chamber walls, the NO molecule suddenly lost most of its vibration energy to a single electron that jumped on the NO molecule from the gold, and then immediately ejected with "too much energy." The prevailing theory had expected that the energy went into the thermal bath of electrons [31].

Ji, Zuppero, Somorjai and Gidwani reacted carbon monoxide CO with an oxygen radical O on a 2 nm thin Pd catalyst on an n-TiO_2 semiconductor substrate (Fig. 11). Prof. Somorjai declared that they observed an "impossible"

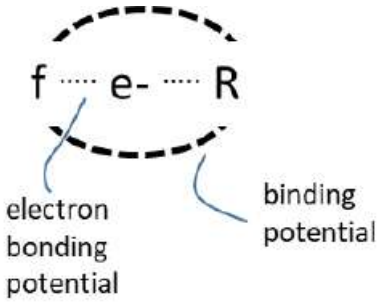

Figure 8. At the moment a sufficiently heavy electron forms a three-body with attracting reactants f and R that can bind, prompt binding may occur and the electron may be ejected with most of the energy.

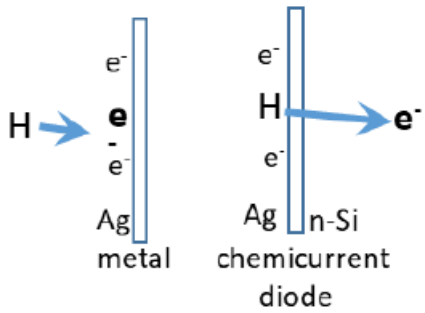

Figure 9. A fuel radical H adsorbs on a reactant "molecule", a conducting Ag metal substrate, energizing and ejecting an electron with the H-metal binding energy.

forward voltage across the diode of 0.68 eV, about half of the available $\sim$ 1.5 eV from the CO and O adsorbed on the catalyst. This confirmed that a single electron, not a thermal bath, received the energy [32].

LaRue and White reported direct observation of the electron energy (Fig. 12), confirming a partition of binding energy between an NO vibration and the electron energy. They confirmed that the energy was deposited into *a single electron*. The key observation was electrons with the entire binding energy, upsetting the prevailing theories. This was a new effect, which they called *"Vibrationally Promoted Electron Emission" (VPEE)* [1].

Appendix B. Effective Electron Quasi-particle Mass at Nuclear Dimensions

We apply our simple chemical binding model to the nuclear case for binding nuclei such as p and d together into helium-3. The trapped electron repulsive momentum (derived from "kinetic energy of confinement") increases to very high values when the confinement parameter σ_x (representing ion separation distance) is small, according to the HUR, so the ion separation remains at many picometers, while the nuclear force range x_n is only a few femtometers. If we could make some electron quasi-particles heavier, then their repulsive momentum would be reduced, and the ion

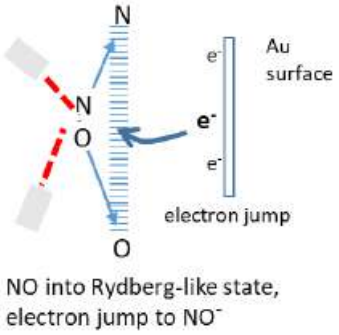

Figure 10. A laser excited an NO molecule to a high vibration state (nu 12) as it collided with an Au conducting chamber surface where an electron attached to the NO, was energized by the NO vibration energy, and the electron was promptly ejected with a major fraction of the vibration energy.

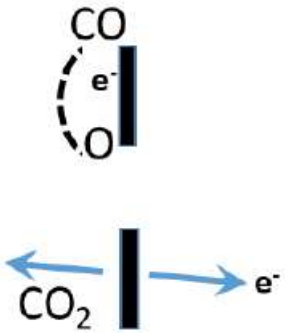

Figure 11. Fuels CO and O adsorbed on a thin catalyst surface formed CO2 gas, energizing an electron between them with sufficient energy to surmount the Schottky barrier between the catalyst and a semiconductor under the catalyst.

separation would decrease. The separation distance would still be far greater than x_n, but it might be possible for part of the quasi-particle wave function to tunnel into the x_n region, if the total attractive potential exceeded the repulsive momentum there. This condition defines the required heavy quasi-particle mass threshold $m_{\rm th}$(Eq. (5)).

The key issue is whether the effective electron mass can actually be increased and effective at nuclear dimensions. We hypothesize that the crystallite lattice might cause the electron wavefunction to have oscillations with relatively high slope and curvature, even if it does not form a bond between f and R. The transition state does not need a bond. We would need the slope and curvature of a wavefunction segment to be locally above the global variance limits of the Robertson–Schrődinger equation (Eq. (3)). The slope of the wavefunction is the momentum operator, $p = (\hbar/i)\mathrm{d}\psi/\mathrm{d}x$ and the quantum kinetic energy is the curvature, $E = (\hbar/i)^2(\mathrm{d}^2\psi/\mathrm{d}x^2)/2m$. Our concept would produce a wave function with elevated slopes and curvature like quantum well states in conducting layers like those studied by the groups of Chiang and of Matsuda [33,34]. Such electron quantum well states might impart momentum and energy as if electron effective mass in the region between the f and R were either reduced or elevated. Researchers studying electrons in few-atom quantum well monolayers theoretically predicted and experimentally observed a Fabry–Perot interferometer-like modulation of the electron wavefunction near boundaries of crystallites, before it damped out deeper into the crystal [33,34]. Each peak in the modulation could locally affect electron momentum.

Chiang notes that the crystal acts like a multiple-reflection periodic array, similar to the multiple reflections of light in a Fabry–Perot etalon. Chiang experimentally explored a one-dimensional equivalent of a 3D Fabry–Perot etalon formed by crystallite conducting atom layers. The electron wave function replaces light in the equations.

Multiple reflections of the delocalized electron quasi-particle wavefunction from the crystal ions are one way to look at the Bloch theorem. The Bloch equation for a crystallite is:

$$\Psi_m(kr) = \frac{1}{\sqrt{N}} \sum_n a_m(R_n, r)\, \mathrm{e}^{ik\cdot R_n}. \tag{B.1}$$

The R_n is the vector from electron to the nth ion, r is the vector electron position, k is the crystal momentum, the $\Psi_{\rm m}$ is the electron wavefunction. The form of the wave function is like that of a 3D Fabry–Perot etalon, with periodic spacing terms. Limiting the range of "n" to include only a region within a radius equal to the collision mean free path of the electron imposes a limit on the wavefunction, resulting in an envelope. The electrons outside the electron ballistic mean free path are assumed to be not interacting.

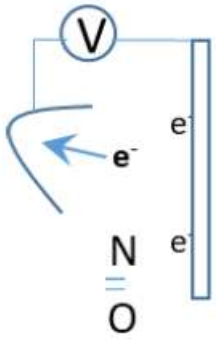

Figure 12. After a highly vibrationally excited NO molecule contacted a conducting surface and energized an electron, it was ejected into an electron detector with as much as the entire binding energy.

One purpose of the electron quantum well work in conducting films by Chiang, by Matsuda, and by Paggel [35] is to precisely define the band structure (energy vs. crystal momentum). The band structure diagram, which can constructed using the Bloch conditions, represents a solution of the wave equation, given the "non-interacting" condition. Thus, we believe that using the "effective mass" given by Eq. (6) is a valid shortcut to evaluating the momentum and energy transfer properties of a transient heavy electron in a crystallite. The $a_{\mathrm{m}}()$ terms in Eq. (A1) cause multiple peaks to develop within the envelope. The slope at each peak is steeper than for a normal electron, changing the momentum operator $p = \hbar/i\mathrm{d}\psi/\mathrm{d}x$. Each peak represents an electron quasi-particle density, but has a slope somewhat proportional to the number of reflections from periodic crystalline nuclei. The slope and curvature relate to the effective mass.

Chiang provides a guiding approximation for each peak: $\psi(z) \propto \sin(n\pi z/d)$, where n is an integer quantum number, z distance into the quantum well film and d is the film thickness. The associated momentum is $p \propto \mathrm{d}\psi/\mathrm{d}z \propto (n\pi/\mathrm{d})\cos(n\pi z/d)$ could be large in very thin films at high n. Chiang provides an example, 24 monolayer envelope with multiple peaks. The slope of Ψ at the peaks is roughly *n* times that of a normal electron (Chiang Eq. (3)).

The elevated effective mass electron is valid at a chemical dimension σ_x . The envelope determines the confinement dimension σ_x, which is always at chemical dimension. The electron quasi-particle cloud centroid is at chemical dimensions, but a small, evanescent portion may tunnel to nuclear dimensions x_n if the effective mass exceeds the threshold value m_{th}. We have estimated m_{th} and the tunneling probabilities for several LENR cases [3]. When the electron effective mass exceeds m_{th}, the system can undergo prompt collapse down to the size of the compound nucleus, ejecting one or more electron quasi-particles with high energies ($\sim$5 MeV per nucleon reacted).

Thus, we believe that the chemical physics model of vibrationally promoted electron emission may be adapted to heavy electron catalysis of LENR transmutations.

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