Muon-Surrogate Catalyzed Transmutations Of Radioactive Waste Using Recently Discovered Direct Vibrational To Electron Energy Transfer And Transient, Elevated Effective Mass Electron Quasiparticles

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Abstract

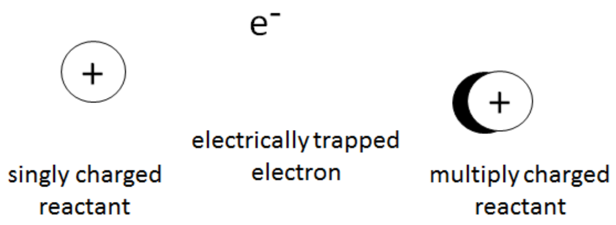
Chemical physics experiments recently revealed a chemical bonding reaction having a strong propensity to transfer most or all the binding energy to a single electron, leaving the bonded product in a low energy or ground state. The same chemical physics predicts the original muon catalyzed fusion observations exactly, published at UC Berkeley circa 1957 and having a nearly identical potential energy diagram. Radioactive reactants are expected to similarly transmute into non-radioactive products when using the recently discovered direct vibrational to electron energy conversion and elevated effective mass electron quasiparticles, referred to as "muon-surrogate electrons" (m_{se}). The reaction permits tailoring a transmutation triggered by chemical means alone.

We create muon-surrogate electrons by using a peculiarity of the electron band structure in nano-meter sized crystallites during simultaneous injection of energy and crystal momentum. This creates transient (10^{-14} sec), moderately elevated effective mass electrons (less than about 50 m_e).

This discovery involves subtle, seldom invoked concepts. A method and device to neutralize radioactive isotope is included.

Background

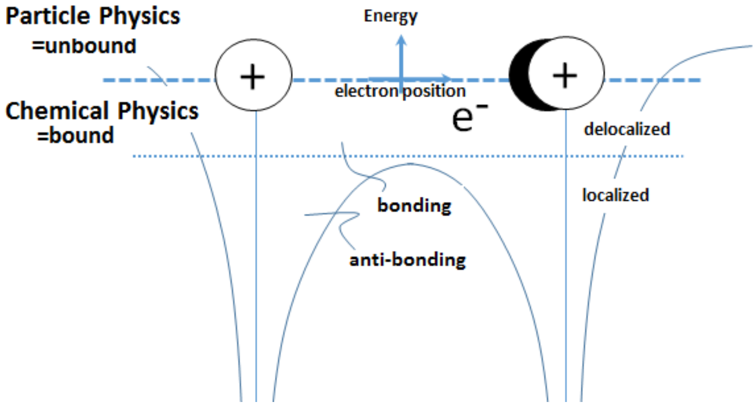
In 1956 Alvarez at UC Berkeley shrank the size of chemical molecular matter by a factor of about 207 using only the "heavy" property of a heavy electron. The heavy electron was a muon living for only about 2 microseconds. He shrank the size of an HD molecule down just enough so that the mass-energy potential ($E=mc^2$, the mass defect) could squeeze the muon, a heavy electron he inadvertently trapped between a reactant proton (H) and a reactant deuteron (D). "Squeezing" means collapsing the wall boundaries of the coulomb quantum well formed by the proton, electron and deuteron. Alvarez could not have known that during the period from about 1999 through 2016, about 50 years later, we would discover that the muon was electronically trapped *between* the proton and deuteron, *not next to* one of them --- subtle. When a trapped mass is squeezed, the energy of squeezing can be transferred entirely to the kinetic energy associated with quantum confinement in a quantum well---novel. To chemical physics, the bonding potential is just another potential, so analysis of the nuclear phenomena was "identical" to the chemical one because the potential energy diagrams were identical.



Tri-body basic reaction in its initial, Rydberg state, a singly charged nucleus and a multiply charged nucleus "far apart" and electrically bound together by the nearly free electron. The transmutation to a new nucleus will be attractive when the reactants weigh more than the product nucleus. The $E=mc^2$ mass-energy difference, "the mass defect," is the energy source.

This reaction mechanically energizes an electron into an unfamiliar form. The form is "quantum confinement energy" (QCE). According to the Heisenberg Uncertainty Principle, QCE is the energy that must be supplied to confine and squeeze any matter or wave into or within a boundary. An electron is placed between two electron-attracting reactants, confining and trapping it to within the quantum well of the molecular boundary. When the reactants are nuclei, their mutual repulsion is weaker than their attraction to the electron between them, so they would converge without limit. Note "between them," indicating the bonding wavefunction, not the anti-bonding.

Chemical physics has known for a century that QCE is a repulsive energy preventing such collapse. The molecule HD is the classic H_2^+ ion of chemistry. "QCE" is the trapped muon-surrogate electron's "T" term, in the Schroedinger equation's Hamiltonian, H=T+V.

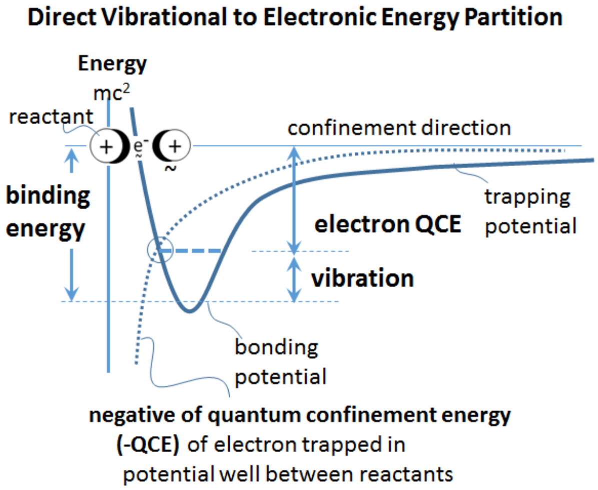


Some particle physicists strongly assert that "coulomb repulsion" dominates. More than a century ago, one of the first and greatest achievements of quantum mechanics was to explain why all matter did not collapse to nuclear densities, because coulomb attraction, the opposite of coulomb repulsion dominates in real matter. A century ago, simple physics showed real chemicals are characterized by coulomb attraction, and a QCE barrier prevents collapse, not coulomb repulsion. There is a barrier, but not a coulomb barrier.

Cold fusion of two positive nuclei is not possible. The two nuclei are never bound. Two-body fusion at less than multi-kilovolt energies is statistically impossible and cannot happen. Consistent with the "direct vibration to the electron energy conversion" discovery, two-body coulomb repulsion is completely confirmed, and cold fusion of two nuclei is impossible. Here, we are describing three-body attraction reactions.

Chemical physics has known for a century that particles in real matter do not have enough energy to eject from the real chemical. In contrast, in particle physics experiments an energetic particle impinging on a foil target always has energy greater than work function and greater than ionization or dissociation energy. It is not bound, and therefore coulomb repulsion applies. When no particle in the real chemical has that minimum energy, the system has a net negative potential, has no net coulomb repulsion, and should attract itself to nuclear dimensions. Wolfgang Pauli and Werner Heisenberg asserted why quantum confinement energy is the only repulsive "force" resisting coulomb collapse in real chemicals, which are "completely bound."

Much of what we need to know about the extremely cold, chemical nuclear transmutations in completely bound chemical systems we can learn from chemical physics. "Completely bound" is one of the subtle elements.



All the chemical physics observations of this three-body reaction use two reactants that can bond together, releasing a net binding energy. In addition, all the reactants chosen in more than dozens of different chemical physics experiments must also be able to attract and trap an electron between them. The reactants N and O, and catalyst/conductor radicals CO and O, H and O and free radicals on catalyst conductor surfaces are examples. The reaction predominantly ejects an electron, and almost always with "too much energy" compared to "only a couple" energy level changes expected, as observed in most chemistry. The basic entity is a simple, almost dissociated three-body entity: two reactants that can bind and a third reactant, an electron, trapped electrically between them, and all three stretched almost to dissociation, always just barely bound. This is a three-particle Rydberg state.

LaRue, Wodtke, Auerbach, White, Huang et al. **(J. Phys. Chem. A 2011, 115, 14306–14314)** reported direct capture of the emitted electron, producing ~1 eV voltages in a Faraday cup. When reacted on a nanometers-thin metal catalyst electrode of a semiconductor diode, Ji, Zuppero, Somorjai, Gidwani et al. reported the ejected electron produced electricity, a 0.68 eV forward voltage across a semiconductor junction. The reaction ejected an electron with a substantial fraction of the chemical binding energy.

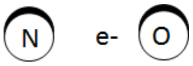
Only reactants that can also bond without the need for an extra electron are candidates. The initial condition begins with the reactants as far apart as possible and the electron with almost but not enough kinetic energy to eject from between them (Rydberg state). This is a highly vibrationally excited initial energy state. During the each contraction phase of the molecular oscillation, the bond energy squeezes and pumps the electron's QCE each time the molecular vibration decreases to its minimum size.

The reaction happens when the minimum confinement size is close-together enough and small enough for the bonding to occur. At the point of bonding, stationary reactants bond, leaving the electron no longer trapped. The bonding can only occur at a vibrational energy level of the two reactants against each other. The bonding energy then has been observed to become divided among the internal vibration of the reactants against each other and the QCE of the ejected electron (plus small recoil).

By combining this reaction with a second discovery, a method to make transient heavy electrons (muon-surrogate electrons, m_{se}), we describe a way to transmute elements into the ground state, producing naturally occurring elements. We ignore the 5-25 MeV QCE generated in the process.

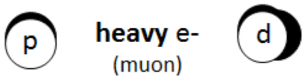
This reaction also accurately describes bonding singly charged nuclei to certain other nuclei, such as in muon catalyzed fusion. A telling, key muon catalyzed reaction observation by Alvarez was precisely the result predicted by chemical physics. The "zero vibration" implies ground state products are formed. "Products in the ground state" have been an enigma for an entire class of observations of hydrogen-electron-nucleus bonding reactions having the reactant-electron-reactant form.

Vibrationally Promoted Electron Emission (VPEE) with chemicals and nuclei



Research in chemical physics and surface catalysis recently revealed a novel reaction where a major fraction of the maximum possible energy was transferred to a hot electron--an "electron spark." Unexpectedly, the resulting exhaust molecule was rather cool, in lower energy states. The starting point was highly energetic. It started stretched out almost to the break point. It could not or should not have become "cold" in one shot. The authors refer to this as "vibrationally promoted electron emission."

The reaction left less or no energy in the bonded reactants. It revealed a reaction propensity for low vibration states, and the ground state. This was unexpected and novel.

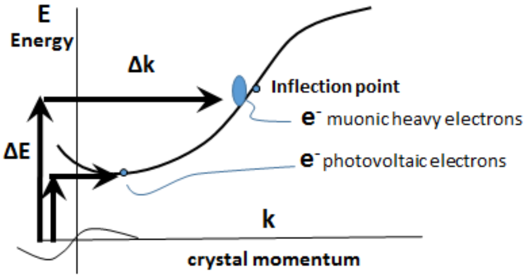


A muon-catalyzed nuclear reaction with the same schematic (same potential energy diagram) produced a similar result: the energy went entirely into an electron spark and the product was in its non-energetic ground state. The muon is also a transient, heavy electron.

How could this reaction be used to produce non-radioactive, ground state products from initially radioactive ones?

Directly Controlling Chemical Reaction Rates

A second discovery showed how to create transiently heavier or lighter electrons ($m_e \neq 1$) in a nano-meters dimension reaction particle.



Effective mass = $\hbar^2/(\partial^2 E/\partial k^2)$
curvature

atom size ~ curvature

Band Structure Diagram, showing simultaneous crystal momentum and energy injection near the inflection point where curvature vanishes and muon-surrogate electrons are formed.

$a_0 = h^2 / (2\pi)^2 k_e^2 m_e$

Bohr radius.

The effective mass of the electron determines the size of all real matter, including the distance between ions, nuclei or reacting chemicals. The useful combination of the two discoveries includes the ability to bring reactants closer, with heavier effective mass, and push them apart with lighter effective mass. Dialing electron effective mass allows dynamic control of chemical reactions at the fundamental level, turning them on and off in predetermined sequences. It also allows initiating reactions between certain reactants in a way that strongly favors the ground state.

Supporting the theory that modifying the electron effective mass can be used to accelerate reactions directly were experiments in Japan and Britain. When a Surface Acoustic Wave (SAW) piezoelectric was used as substrate for catalysis, a dramatic, 4 to ~10,000 times increase in reaction rate and ~50% change in activation energy was observed. See Appendix “SAW Reaction Rate Stimulator.”

The reactants can include nuclei, atoms and molecules. A key observation is that this potential energy diagram for binding chemicals together is the same as for binding nuclei placed together in a real material. The diagram always includes an electron trapped between reactants. The nuclei-bonding potential is similar to many familiar bonding potentials.

Often overlooked, but obvious, the energy source is the relativistic mass-energy potential between reactants and products. It is exactly correct for all reaction and force types at all energies.

This means we only need to pay attention to the chemical physics alone to get the result for both nuclei and chemicals. The only forces are trapping and bonding.

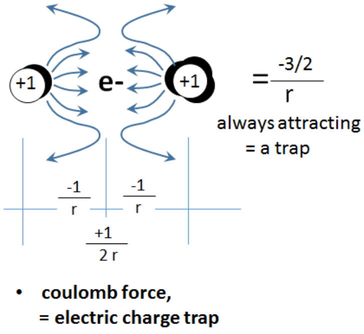
The direct conversion process is entirely described by chemical physics. When we apply it to bonding nuclei together, we expect the transmutation to be in its ground state, most often being born non-radioactive.

VPEE Energizing Quantum Confinement Energy

Nearly every step and every feature of this reaction presents unfamiliarity. This reaction energizes an electron into an unfamiliar form, “quantum confinement energy” (QCE). QCE is the energy associated with the spread in momentum of the Heisenberg uncertainty.

When we convert all the energy available to bind two nuclei together into quantum confinement energy QCE, we deny the reaction branch any energy, and therefore create a non-radioactive, ground state product. QCE took away the binding energy. The ground state is the result.

A “neutralization” of radioactivity is the focus. We ignore the emitted QCE, even though it can be a million times more energetic than chemical energy release.



The H_2^+ ion model shows how to convert vibrational motion into quantum confinement energy QCE. This textbook example starts with an electron between two protons, known as the H_2^+ ion. Chemical physics teaches that this ion should (but doesn’t) collapse to nuclear dimensions. There are no forces to stop the collapse of the protons into the electron. Each proton is energetically attracted to the electron between them. Each proton repels the proton on the other side of the electron with only half the energy and one fourth the force of attraction to the electron.

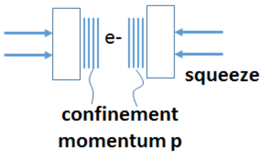
Why does this H_2^+ ion not collapse? It is a stable ion and does not fly apart. Why doesn’t the strong coulomb attraction shrink the ion to nuclear dimensions?

Chemical physics teaches that the electron between the protons is confined to a quantum well defined by the space between the protons. **Heisenberg discovered that when anything is confined within a region of positions, σx, the confined object resists by imparting spread of momentum impulses, σp, to whatever is confining it.**

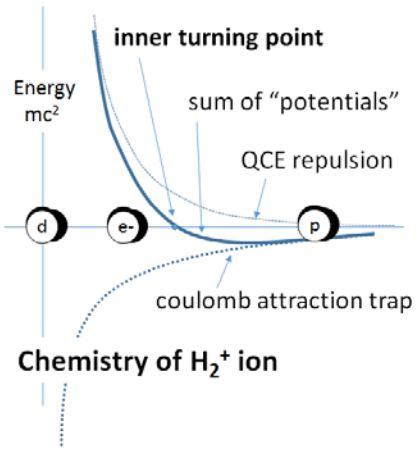
$$\sigma x * \sigma p \geq \hbar /2.$$

Heisenberg uncertainty principle

There is a quantum confinement energy associated with squeezing anything. The squeezing or confinement energy is associated with the spread in momenta. Chemistry students are taught a quick and simple way understand this without solving the Schroedinger equation. Approximating $\sigma x \sim x/2$ and $\sigma p \sim p/2$ allows us to estimate repulsive energy, $E = p^2/2m$ = QCE.



$E = p^2/2m \geq (2\hbar)^2 / mx^2$
= quantum confinement energy
= energy required to confine electron
to a region of size ~ x



The coulomb attraction energy in p-muon-d increases negatively, according to -1.5 / R. The quantum confinement energy increases positively like + 1 / mR^2. Coulomb attraction squeezes and shrinks the size R of the molecule; repulsion increases R.

At normal size R, the attraction is much larger than the repulsion. However, as the size R becomes smaller during a normal vibrating oscillation of the molecule, the repulsion almost suddenly dominates, as in $1/mR^2$.

As soon as the repulsion equals the coulomb attraction, the proton contraction must come to a halt. Coulomb attraction ran out of energy.

The protons are held apart by the electron. Electrons were supposed to attract protons, not repel them. This is subtle.

Figure H_2^+ oscillation

At this "inner turning point" of the oscillation**, all the kinetic energy of the vibration has been pumped into electron quantum confinement energy.** The two stationary protons are then pushed apart by the momentum associated with the QCE. The molecule oscillates. In one sense this is the point where the Born Oppenheimer Approximation "fails" because vibration energy was transferred to electron energy. Instead, we contend the conversion happens because of BOA. BOA lets us approximate that the electron is so low in mass that the reactants are stationary at the inner turning point. The reactants are actually slightly vibrating at the inner turning point.

How can we capture and use the QCE, which means all the energy, and the same time make the exhaust be cold? Add bonding potential energy.

Add Bonding

Certain combination of atoms, molecules and nuclei can also attract and bind themselves into a product when there is no extra electron between them, and in spite of coulomb repulsion. O_2, N_2, NO, CO_2 are some examples. One or two protons and a nickel-62 nucleus, forming a copper-63 or zinc-64 nucleus are other observed examples. Four deuterons and a cesium-133 nucleus forming praseodymium-141 is another observed example.

When we include a bonding potential energy in addition to a trapping potential, we provide the energy to further squeeze the reactants together, which squeezes the electron between them even further. At some point the binding, bonding energy will also run out of energy just as the coulomb potential ran out. The reactants with a binding potential will also stop contracting. The contractions stops at a new, "second" inner turning point.

The reactants can bind when the contraction happens to stop, for example, at a vibrational inner turning point of the bound product. Reactants can only bond into known energy levels, such as vibrational energy levels (simplest case). At the moment the two reactants bind, the electron can no longer be between them. It can no longer push them apart. It still has its energy and has not lost its QCE. Using its QCE to push against the reactants, the electron ejects itself. The reactants are born in a vibrational level of the product formed by the reactants. One expects the result to be a vibrating reactant sharing binding energy with the formerly confined electron.

LaRue documented this energy partition in the 2011 paper. Our model shows how vibrational energy is first pumped into electron quantum confinement energy, and then reactant bonding frees the electron and converts bonding energy into an electric spark.

In the chemical case, two reactants energetically come together and bond, forming a new molecule. In the nuclear case, two nuclei energetically come together and bond, forming a new nucleus. In both cases, the electron trapped between them reversibly removes binding energy. The QCE is part of the energy and the vibrational energy is the other part (minus small recoil).

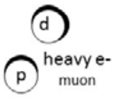
In both cases the bonding energy has been observed to energize and eject the electron trapped between them. The key observation reported by LaRue et al. (Nov 2011) was that the binding energy becomes partitioned between the quantum kinetic energy of the ejected electron, the vibration energy of one reactant against the other, and a relatively small recoil.

Transmuting radioactive elements into non-radioactive elements can be the same type of reaction.

Electron Emission by Muon Catalyzed Transmutations

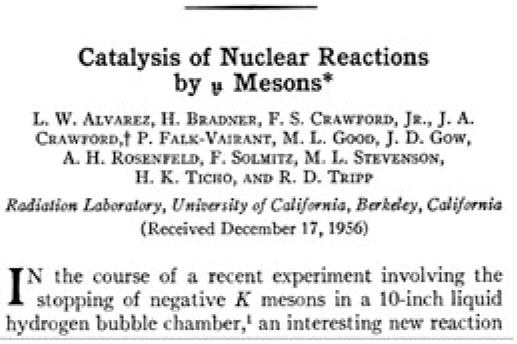
Alvarez used a heavy electron to shrink the size of a hydrogen molecule.

The "size" is the Bohr radius. The stable molecule is HD^+, a proton and a deuteron held together by an electron between them, heavy or not.



The size of the molecule scales as 1 / electron mass. The calculated size was small enough that the proton and deuteron were close enough to tunnel together and undergo fusion.

Alvarez observed "fusion," but the energy went entirely into a muon (heavy electron) spark.



Catalysis of Nuclear Reactions by μ Mesons*

L. W. Alvarez, H. Bradner, F. S. Crawford, Jr., J. A. Crawford,† P. Falk-Vairant, M. L. Good, J. D. Gow, A. H. Rosenfeld, F. Solmitz, M. L. Stevenson, H. K. Ticho, and R. D. Tripp

Radiation Laboratory, University of California, Berkeley, California

(Received December 17, 1956)

In the course of a recent experiment involving the stopping of negative *K* mesons in a 10-inch liquid hydrogen bubble chamber,[1] an interesting new reaction

"Catalysis of Nuclear Reactions by u Mesons" L. W. Alvarez, et al.,
American Physical society Meeting, Monterey, CA, Dec 28, 1956, Phys.Rev. 105,1127 (1957)

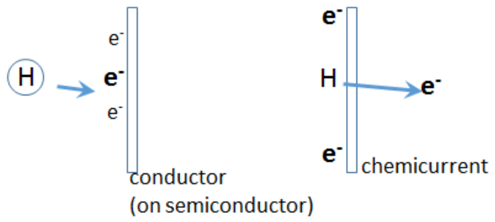
The energy for this type of reaction is well known and was supposed to go into a gamma ray, not the muon.

The muon's only interaction with the p and d, in the HD^+ that would be in any way different from electrons as we know them, was its mass. The hydrogenic material containing the muon was deliberately refrigerated to about 20 K. That deliberately drained all the kinetic energy out of the heavy electron. The muon did not take part in any nuclear reaction. Its only role was to reduce the size of the molecule to make fusion more probable.

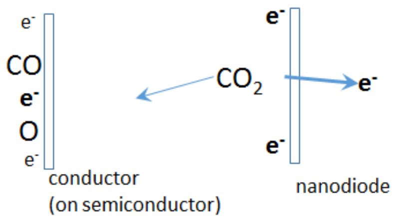
The electrons don't feel any of the proton-deuteron nuclear force at all. The initial muon kinetic energy was insignificant because it was at liquid hydrogen temperature, ~20 Kelvin. Its heavy mass was the property of the muon that made the transmutation reaction possible. More than hundreds of muon catalyzed fusion papers, from 1957 through the present (2016), confirm that only the muon mass was important, and every other property was like that of an electron.

Vibrationally Promoted Electron Emission

Electrons were ejected as a spark in the same way when free radicals contacted a conductor. (Nienhauss 1999)

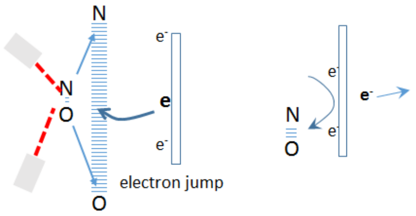


Too much energy went into an electron between the free radical and the conductor surface. The atomic hydrogen free radical does not need the metal electron to bind the hydrogen to the metal surface. A large fraction of the binding energy between the atomic hydrogen atom and the surface metal went into the electron. Nienhaus called it "chemicurrent." Nienhaus (1999)



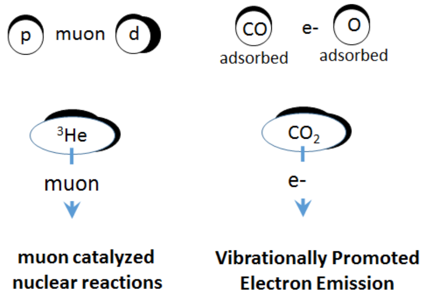
When carbon monoxide and oxygen were adsorbed on a catalyst, to burn them, about half the binding energy was available to form CO_2 gas from adsorbed CO and O. Almost all of this remaining surface catalysis energy went into an electron. A Schottky junction between the very thin metal catalyst and an n-type TiO2 semiconductor developed a 0.68 eV forward voltage. This was far more than a vibrational quantum of energy. Somorjai called it a "nanodiode." Ji, Zuppero et al. (2005), Ji, Somorjai (2005).

A laser method energized an NO molecule to almost its breaking point, making it look like it just formed. Surface catalysis and chemical physics tests produced unexpected, "impossible" large decreases in quantum states. Huang labeled the process "electron jump" and referred to it as "Vibrational Promotion of Electron Transfer." Huang (2000)



When the highly vibrationally excited NO approached a gold conductor, an electron "jumped" from the conductor to the NO molecule, making it NO- Then, unexpectedly, the molecule lost more than half its vibration energy in one bounce off the gold, and it lost the electron. It lost about 5 to 8 vibration quanta and ejected the electron. It should only lose 1, sometimes 2 and almost never 3. It lost 5 to 8--too much vibration energy. On a cesium covered gold surface, some electrons had enough energy to escape and their energy was measured. A single electron had the missing energy. Huang et al, (2000), LaRue et al. (2011)

We noticed that the Alvarez reaction was "identical." And the heavy electron (muon) had the missing energy.



H + trap e- + M → [H bond M] + e- (with K.E.)
CO_{ads} + trap e- + O_{ads} → [CO bond O] + e- (with K.E.)
N + trap e- + O → [N bond O] + e- (with K.E.)
p + trap e- + d → [p bond d] + e- (with K.E.)

All the reactions were of the same type. The $CO_{ads} + O_{ads}$ and the p + d potential energy diagrams are different from the others in that the reactants must tunnel through the QCE barrier to access the binding potential. This promotes "born in the ground state." All but a trace (10^{-8} of reactions) of the products appeared in the ground state.

Iwamura et al. Japan, with deuterons

$2d_2 + 4\,m_{se} + {}^{133}\mathrm{Cs} = {}^{141}\mathrm{Pr}$

$2d_2 + 4\,m_{se} + {}^{88}\mathrm{Sr} = {}^{96}\mathrm{Mo}$

$3d_2 + 6\,m_{se} + {}^{138}\mathrm{Ba} = {}^{150}\mathrm{Sm}$

$3d_2 + 6\,m_{se} + {}^{137}\mathrm{Ba} = {}^{149}\mathrm{Sm}$

$d_2 + 2\,m_{se} + {}^{184}\mathrm{W} = {}^{188}\mathrm{Os}$

$2d_2 + 4\,m_{se} + {}^{182}\mathrm{W} = {}^{190}\mathrm{Pt}$

Violante et al. Italy, with protons

$p + m_{se} + {}^{62}\mathrm{Ni} = {}^{63}\mathrm{Cu}$

$2p + 2m_{se} + {}^{62}\mathrm{Ni} = {}^{64}\mathrm{Zn}$

$p + m_{se} + {}^{64}\mathrm{Ni} = {}^{65}\mathrm{Cu}$

$2p + 2m_{se} + {}^{64}\mathrm{Ni} = {}^{66}\mathrm{Zn}$

We also noticed that claimed reactions by Iwamura in Japan and Violanti, Celani et al. in Italy were of the same type.

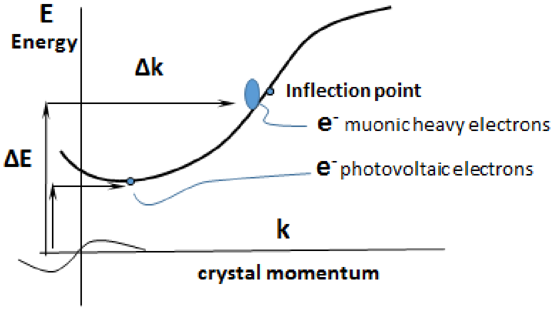
University of Padua, and others in Italy demonstrated proton-nickel reactions. This confirms the chemistry is not dependent on deuterons, corroborating our model.

These reactions, though observed, also reveal that the spin rules appear to be violated. We conjecture some other process must be taking care of spin. In the Mossbauer effect, the lattice absorbs the linear momentum recoil. In what way would the crystal lattice absorb the spin?

Electron Quasi Particles With Transient, Elevated Effective Mass

It is necessary to have a way to initiate the reaction. Heavy electrons are a way.

This defines how to produce a density of muon-like heavy electrons in a proton/electron conductor. The heavy electrons only live just long enough (~10 femtoseconds) to induce nuclear transmutations of a type observed to produce stable, naturally occurring isotopes. Such neutralizing transmutations can occur in radioactive tracers, such as radioactive fission products from a nuclear reactor. The neutralization reactions can be stimulated when one or more muonic, heavy electrons are electrically trapped between reactants.



$$\textbf{Effective mass} = \hbar^2/\underbrace{(\partial^2 E/\partial k^2)}_{\text{curvature}}$$

atom size ~ curvature

The heavy electrons are formed when electrons are energized with particular values of both a crystal momentum and energy, simultaneously and at the same place. The values must place them as near as possible to a special place on the band structure diagram. The place is where the curvature vanishes, at an inflection point.

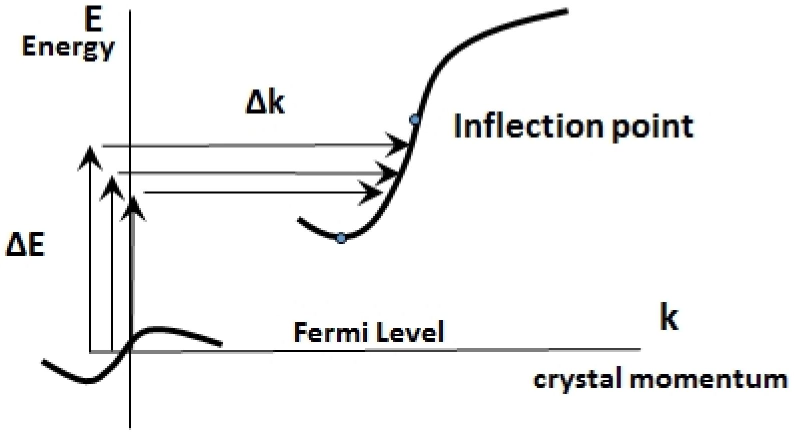
Crystal Momentum Injection

> *"Curvature vanishes at an inflection point."*
>
> *For an instant, chemistry shrinks. Atoms shrink. Molecules shrink*

These concepts are designed to energize electrons to near the inflection point. Crystal momentum injection is key.

When atoms adsorb or desorb from a material surface, on, into or out of the material, they move the atoms of the material, thereby generating a crystal momentum. Adsorption/desorption occurs over a dimension like that of a crystal unit cell, placing crystal momentum in the first Brillouin Zone. The same adsorption or desorption also imparts energy into the same region at the same time, typically of order 1 eV. This injection would provide a spread of short wavelength crystal momenta and of useful electron energies. The issue is the short lifetime and short range of the excitations. Electron lifetime is the mean collision time of the electrons, of order 10 femtoseconds. The range of either electrons or phonons is of order 10 nm or less.

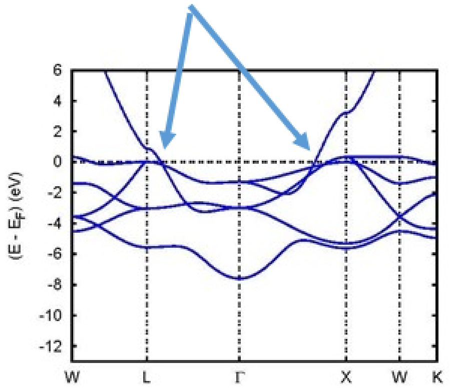
Solid state physics shows that the electron quasi particle in a crystal moves according to a band structure diagram of energy, E, versus crystal momentum, k. The effective mass scales as 1/curvature of the lines.



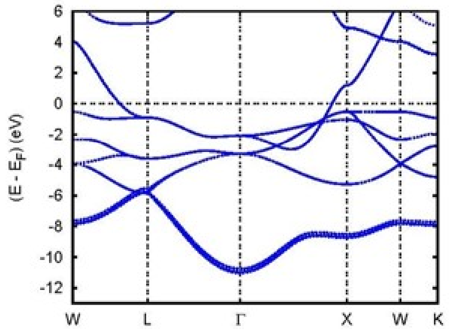
The band structure diagram shows that when the locus of possible electron energies goes “flat,” for example, going from “up” curvature to “down,” the effective mass should diverge, to plus or minus infinity. This is useful because the atom size is proportional to the curvature. Atom size shrinks to nuclear size when curvature vanishes at an inflection point.

This is only valid as long as the electron is ballistic. It’s only ballistic for about 10 femtoseconds (10^{-14} seconds).

Why did we know this, or even care? Silicon photovoltaic semiconductors require crystal momentum and light energy of the right magnitudes to place the photovoltaic electron at the bottom of a valley, not at an inflection point. In silicon photovoltaics, heat provides the crystal momentum and light places the electron in a valley of an excited state of the photovoltaic semiconductor. We simply asked “why only at the valley? Why not an inflection point?”


Inflection point regions near Fermi level (zero electron energy)

Pd



PdH

A band structure calculation for the material where hydrogen moves through the material as if in a delocalized manner, such as in nickel, titanium, zirconium, palladium, vanadium, and a multitude of other chemical materials shows there are always at least two inflection points, and most often very many.

3450 N. E. CHRISTENSEN 14

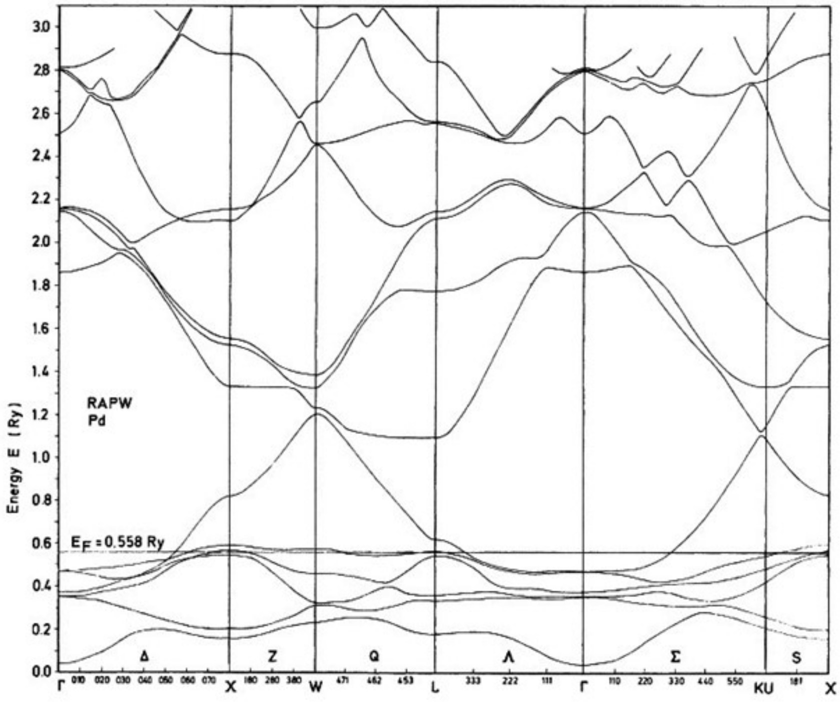


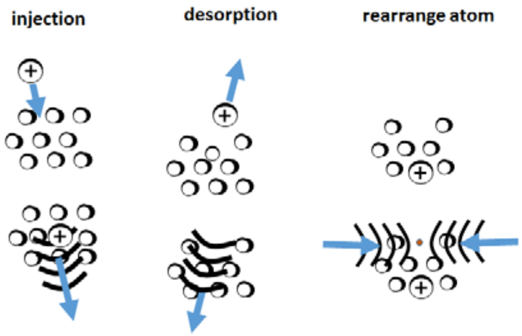
FIG. 1. Band structure of Pd along symmetry lines as calculated by the RAPW method. The fermi level $E_F = 0.558$ Ry above the muffin-tin zero.

The band structure diagrams show inflection points in all the bands. The formidable complexity of these diagrams may be the reason almost no one remembers them or uses them, except in chemistry and semiconductor materials science.

Creating transient heavy, muon-surrogate electrons

To create heavy electrons one must simultaneously add energy E and crystal momentum k to move a Fermi-level electron into a different, special place on the band structure diagram.

To cause VPEE or Alvarez transmutations the required electron energies are often within the range of semiconductor physics, and often with the energy of visible photons (could be from irradiation by solid state LED and lasers). The associated crystal distortions must often be of order smaller than a crystal unit cell. Because these momenta are not compressions or compressive shocks, all the known ways to inject crystal momentum are candidates.

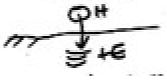


To create heavy electrons suitable for a state transition using multiple tri-particles with a common reactant we chose a glow discharge to inject 400 volt protons into a surface. After thermalizing and becoming bound the protons would simultaneously provide energy, crystal momentum and reactant hydrogen.

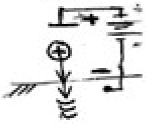
electrolysis

Adsorption, molecular

Adsorbtion, atomic



glow discharge, ionic

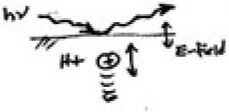


disintegration e-beam

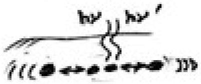
disintegration laser

disintegration thermal

plasmons

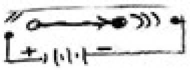


optical phonons



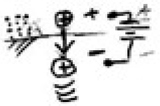
[[add THz waves by using Mearini's technology]]

electromigration



K.E. step, junction

K.E. step, proton electrolyte



The resulting heavy electrons are transient because they lose energy by equally sharing energy after each electron quasi particle collision with other electrons in the crystal, about every 10 femtoseconds (10^{-14} seconds).

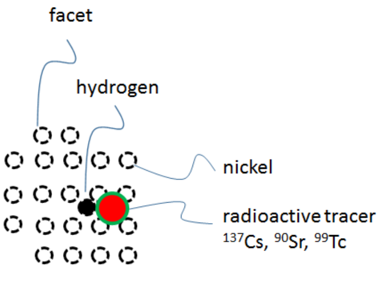
Appendix
Device and Method to Transmute Radioactive Isotopes

"Test Description To Characterize Migration And Disposition Of Radioisotope Tracers and Dopants In Hydrogen-Absorbing Materials After Bombardment By Ionic, Atomic And Molecular Hydrogen"

A Zuppero, W D Jansen, P Crone, C Bishop, T J Dolan, W J Saas
3/8/2017 9:27:39 AM

This Test Description details design of specially designed targets, the proper stimulants for the targets, and the criteria for measuring degree of transmutation. The Test Description concludes with a matrix of tests.

Tailoring Reaction Layer To Consist Of Nano-Particles



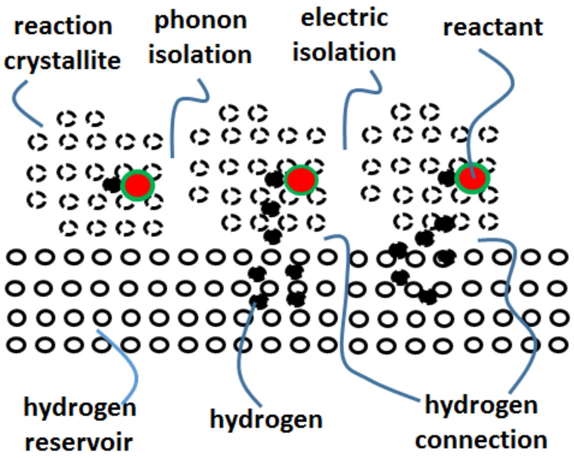
Ideal crystallite

Theory suggests that adding a facet and/or dopants to a nano-crystallite adds a pair of inflection points, where transient heavy electrons are generated.

The optimum crystallite has about 10 nm dimension and many facets.

The optimum geometry isolates each from the others so that electrons and phonons are reflected back into the crystallite. The crystallite is also connected to the reservoir sufficient to allow hydrogen (or deuterium or tritium) to flow into and out of the crystallite.

Theory and observations both indicate using glow discharge to deposit reaction region materials can cause reaction signatures of proton-reactant combinations to become reliable and repeatable. Research Professor Iwamura's recent observations reported from Tohoku University claimed "100% reproducibility." SEM images show their reaction regions have "cauliflower" crystallite structures, presumably providing many facets.

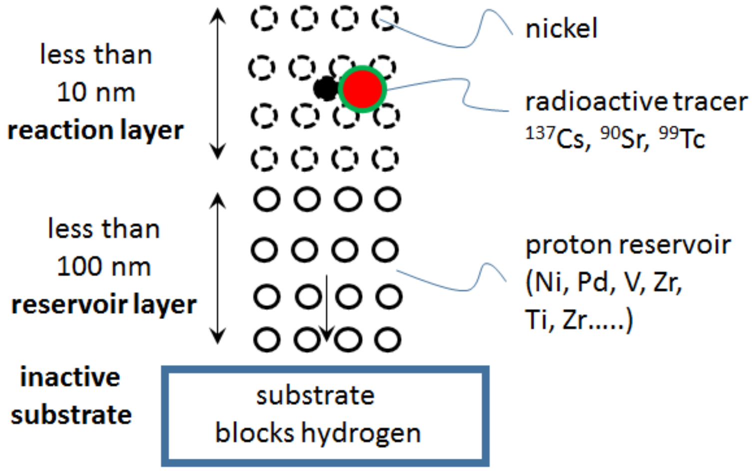


Alloys With Transmutables
The band structure diagram changes with concentration of constituents. Limit the concentration to about 1 monolayer equivalent transmutable isotopes per 10 monolayers of reaction particle

Reaction Particles
Reactions are stimulated in reaction particles small enough to retain electronic and phonon excitations with energies and crystal momentum values near the inflection points of the associated band structure diagram. This size is typically 20 nm or less. Much larger than 20 nm and the excitation damps out. Much smaller than 5 nm causes the band structure diagram to become "digital" or pixilated, limiting the effective mass values.

Preferred Configurations

(1) Ionic Hydrogen injection,
(2) Atomic Hydrogen injection,
(3) Molecular Hydrogen injection,
(4) Reference Targets



Each target consists of a reaction layer, a reservoir layer and an inactive substrate. The reaction depth in a particle is about 9 nm thick. The nominal area is 1 square centimeter. The test target may be an ultra-thin film, a thin film, a wire or other convenient forms, all approximating the ideal. See Appendix C “Background For Depth Of Tracer Implantation Into Reaction Layer.”

Placement of Particles

Particles need not be isolated by a vacuum. Insulator materials isolate conductive particles. Materials with phonon bands having different sound speeds and phonon propagation properties isolate phonons. The particles must have a facet exposed to the source of hydrogen reactant.

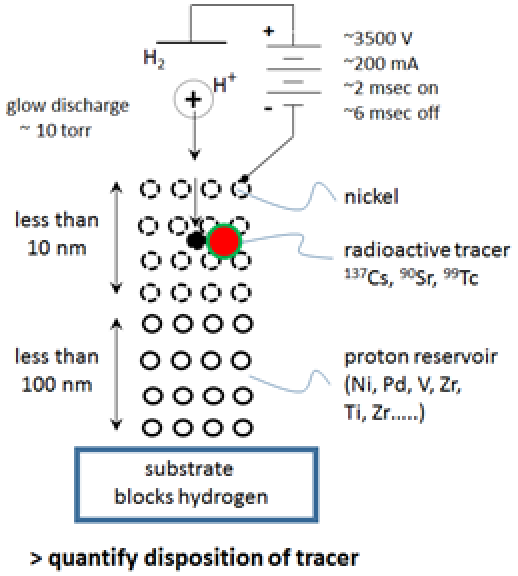
Reaction Stimulation and Filling with Reactant

Fill the reaction particles with the hydrogen reactant (p, d, t) in two ways: 1) inject the hydrogen from the outside, 2) inject from a reservoir. Injecting from the outside can use glow discharge, to inject protons. Injecting can use atomic hydrogen gas. Injection can use the adsorption of molecular hydrogen into the material, as is often associated with solid state hydrogen tanks.

4.1 ionic hydrogen stimulation-- glow discharge stimulator option

Design a glow discharge to accelerate protons from between 100 and 4000 volts, and up to 200 mA, into the target. The glow discharge gas injects hydrogen reactant. Glow discharge also delivers momentum stimulation of the surface using bombardment by the glow discharge gasses, such as inert gasses, hydrogen and deliberately added gasses.

Design a glow discharge with close-spaced electrodes to favor re-deposition of sputtered material. For example, a bipolar sputtering system may be used to continuously sputter away and immediately reform the reaction surface, guaranteeing clusters.



Use a glow discharge to inject protons into the reaction system. Also use the glow discharge to impart momentum to the surface atoms in the test target.

Begin the glow discharge with lowest voltage, which causes the least sputtering and damage.

One experiment injected hydrogen and delivered momentum in two steps, first filling the reservoir into the test target using hydrogen as the glow discharge gas, and then using just an inert gas after filling. In a subsequent set, use a mixture of hydrogen, inert gas contaminant gasses, such as less than 1 part in 1000 of air. Contaminants have been known to have a big effect.

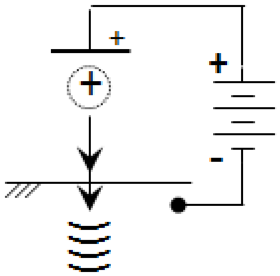
The glow discharge slowly destroys the target by sputtering, and redeposits surface material elsewhere.

Prepare for rapid reaction. At 3500 V and 200 mA, the Russians observed about 10 watts of reaction heat. This reaction rate would neutralize 1 monolayer of ^{137}Cesium in about 10 microseconds--as soon as the switch is turned on.

Many example papers describing prior experiments can be supplied. In a subsequent set of tests, admit gasses such as N2, O2, Ar, H2O (traces of air).

Quantify the integrity of the test target by known methods, such as SEM and TOF-SIMS, noting both physical and isotopic modification of the reaction target.

mimic glow discharge working example



The reaction with highest probability of transmutation duplicates the Karabut (Russian) glow discharge system, substituting their cathode with the Test Target and hydrogen for deuterium. There is no need to include anything related to measuring excess heat or energy.

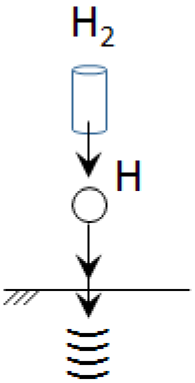
While this should produce reactions in less than 1 second, the high power glow discharge may destroy the sample. Monitor the sample integrity.

Reference papers are available. One example: Karabut, A.B. and E.A. Karabut, “Experimental Results on Excess Power, Impurity Nuclides, and X-ray Production in Experiments with a High-voltage Electric Discharge System”, J. Condensed Matter Nucl. Sci. 8 (2012) 139–158).

4.2 atomic hydrogen stimulation

Design an atomic hydrogen source with a capability to supply about one monolayer of H atoms per second to the reaction surface, about 1E15 atoms/cm^2-sec

Any known means of hydrogen atom bombardment may be used. Atmospheric pressure and higher is preferable. Hot tungsten and atomic hydrogen welder techniques are candidates.



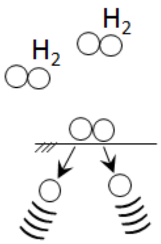
This configuration injects atomic hydrogen. Deposit at least a monolayer per second of atomic hydrogen on the target, ~10^{12} atom per square centimeter per second. In a first test, we suggest using a commercial atomic hydrogen torch at atmospheric pressure and operating far enough away that the 100 nm target does not vaporize when the switch is turned on.

Producing atomic hydrogen is known to be awkward. Almost no detailed data exists to guide us.

Quantify the integrity of the test target by known methods, such as SEM and TOF-SIMS, noting both physical and isotopic modification of the reaction target.

4.3 molecular hydrogen stimulation

Design a chamber for immersion of the target in 200 atmospheres of hydrogen gas for ~200 hours at reaction layer temperatures ranging from 100 C to less than destruct temperature. A thermal gradient from reaction layer to substrate of at least plus or minus tens of degrees C is desirable.



dissociative absorbtion, molecular hydrogen

This configuration injects molecular hydrogen. This is both slow, taking 120 hours in Iwamura's experiments, and inefficient. We estimate the optimum static pressure of hydrogen gas at ~100 Celsius operating temperature to be of order 200 atmospheres. Quantify the integrity of the test target by known methods, such as SEM and TOF-SIMS, noting both physical and isotopic modification of the reaction target.

Reservoir optimum thickness is not known. Some experimental data suggest a workable thickness is of order 100 nm. We observe that a nickel or other hydrogen-storing material beyond the active, 9 nm depth is presumed to be useful, and may even be necessary, as a reservoir of hydrogen. Hydrogen has desorbed from a 2 nm thick palladium foil at about 1/3 the rate that gas would escape from a tiny hole in the Pd.

Reaction plus reservoir thickness from between about 2 and about 100 nm have demonstrated reaction signatures. However, macroscopic foils such as 0.025 mm (0.001 inch) thickness foils, represent such large reservoirs that filling the reservoir has been a serious problem.

use additional means to target inflection points

In a modification of a test, use magnetic fields of order 1 Tesla with B field perpendicular to the reaction surface. Magnetic fields have increased reaction rates, in some cases by an order of magnitude. Calculations show a B field increases effective mass. A magnet with pole face diameter about equal to the reaction surface dimension can be placed under the Test Target.

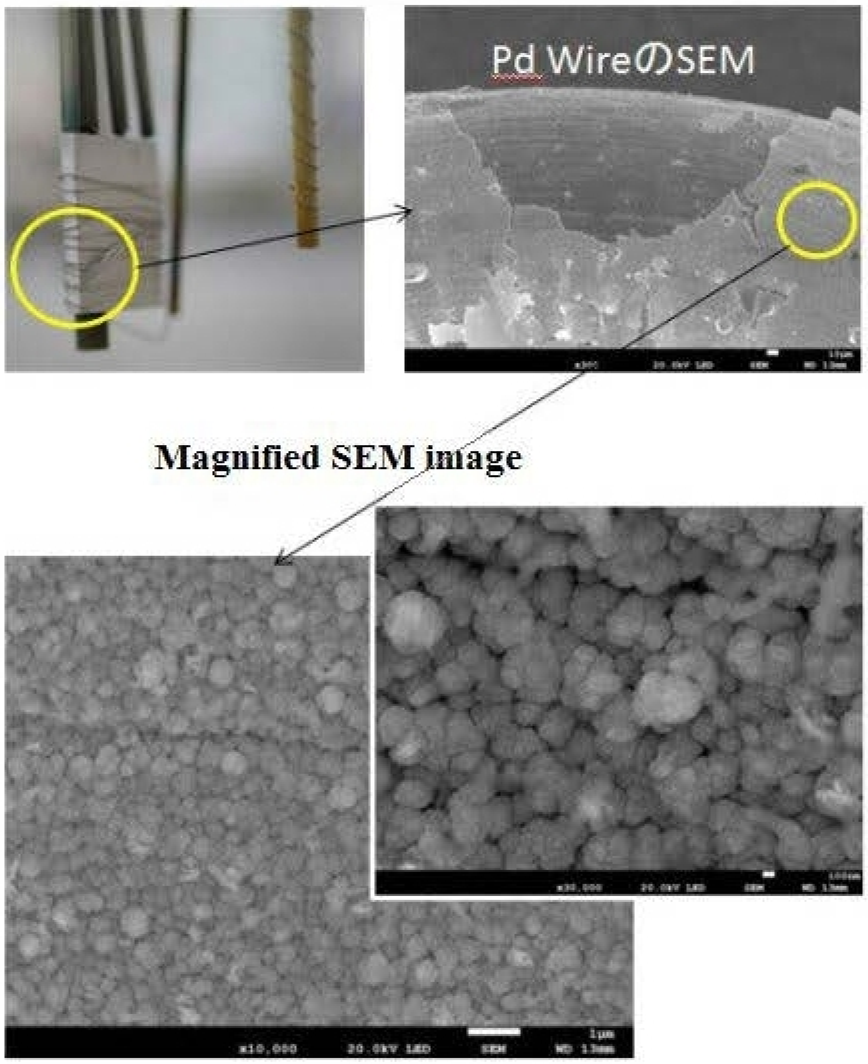
In a modification of a test, shine a visible light laser with intensity of 50 mW/cm^2 on the Test Target. In one test, about 20 times higher reaction rate was realized in a target that had been pre-loaded with (deuterium) hydrogen reactant and irradiated with red laser pointer light.

Reaction Materials

The observed transmutations are predicted to occur in hydrogen-filled, hydrogen-bearing, electrically conducting materials subjected to extreme, transient distortions lasting less than a picosecond and with less than nanometers extent in an isolated crystallite. This type of transmutation has produced predominantly naturally occurring isotopes apparently born in their non-radioactive ground state.

Iwamura has observed transmutation of non-radioactive ^{133}Cs, ^{88}Sr, non-radioactive isotopes. Theory suggests the same transmutation type should be feasible for the radioactive ashes of a nuclear reactor, ^{137}Cs, ^{90}Sr, and ^{99}Tc.

SEM image of a Pd wire after an experiment at Tohoku U.



“After glow discharge treatment, the surface is covered with a film composed of nanoscale particles of palladium and nickel, etc.(Source: Tohoku University, Professor Iwamura)”
from [www.lenr-canr.org/acrobat/**KanekoKcoldfusion**.pdf](www.lenr-canr.org/acrobat/KanekoKcoldfusion.pdf)

Appendix

Depth Of Tracer Implantation Into Reaction Particle

How deep should the radioactive tracers be implanted into the nickel foil?

The value “9 nm” for the limit on implantation is based first on an XPS measurement and then a process like TOF-SIMS in palladium. The depth limit is not known in nickel. This “9” is a best guess. Note Pr concentration in first 1-2 nm is less than 1/2 of Pr just 1 nm deeper. Praseodymium is a signature of reaction. Note also Cs appeared to migrate near the surface.

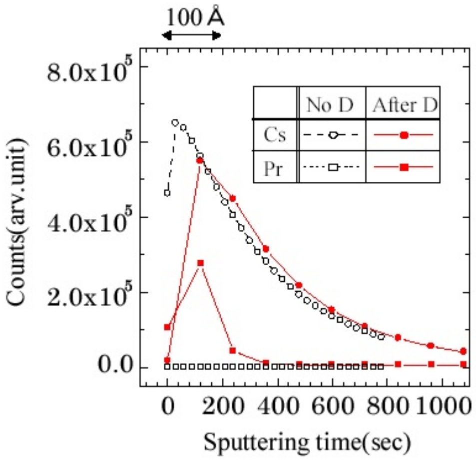


Figure 9 Depth Profiles of Cs and Pr for a Pd complex (Pd /CaO/Pd) sample after D2 gs permeation and a Pd complex (Ps /CaO/Pd) sample without D2 gas permeation. ((Iwamura 2003))

Data suggest any deeper than about 9 nm in palladium is too deep. It is presumed to be of the same order of magnitude in nickel, but this has not been measured. Short wavelength crystal momentum waves die out past about 9 nm, and electron collision length energy dissipates past about 9 nm. The precise values are not known. Iwamura also presented data where salts and hydroxides of reactants were placed on the palladium surface, and reaction signatures were observed, which was puzzling.

Reactions can be quantified in many ways, for example, by analysis of sputtering products as a function of depth and by radioactivity measurements before and after stimulation.

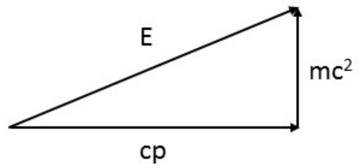
Therefore the nominal Test Target consists of a region of reaction particles and a reservoir layer on a hydrogen blocking material. The reaction layers consists of 9 nm of nickel impregnated with radioactive tracers and in concentrations up to about 10%.

The reservoir layer may be other hydrogen bearing materials such as more nickel, palladium, vanadium, and other materials with similar properties.

Appendix
Rationale For Choosing Nickel

The first and most compelling reason to choose nickel is the electron effective mass. Observations demonstrated hydrogen absorption/injection combined with nickel's inflection points appears to generate electrons with effective masses 50% higher than needed. The second reason is nickel retains hydrogen near the reaction surface better than some alternatives (Pd, V).

One must use relativistic QCE.



relativistic electron quasiparticle

Quantum Confinement Energy

$QCE = E - mc^2$

$mc^2 = m_{eff}\, Eo$

cp = momentum energy,

Eo = electron rest energy

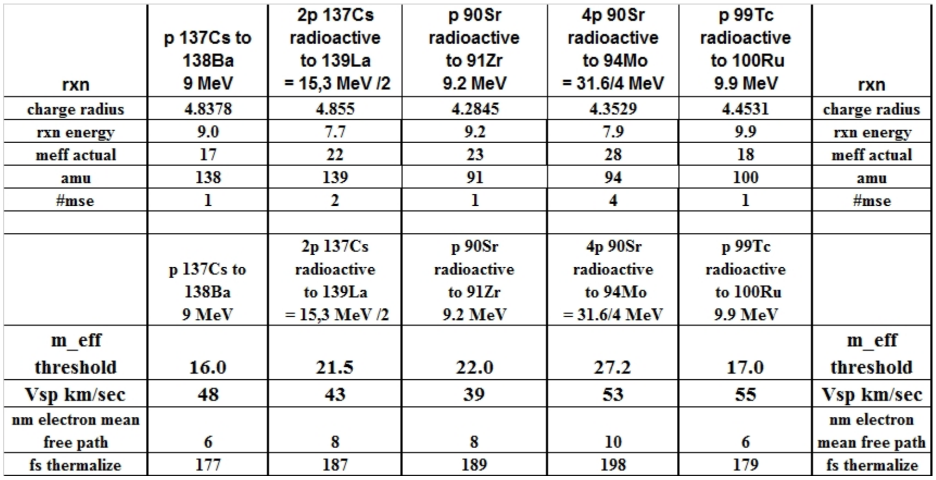
$$QCE = m_{eff}\ Eo \ \left(\left(1 + \left(\frac{cp}{m_{eff}\, Eo} \right)^2 \right)^{1/2} - 1 \right)$$

At non-relativistic momentum, p, this reduces to the familiar QCE = E = $p^2/2m$. At relatively high momentum, it reduces to the familiar E = cp.

In a real material, a real heavy electron is an electron quasi particle. The electron is still thermal, however, because <velocity> = zero, per the Born Oppenheimer Approximation.

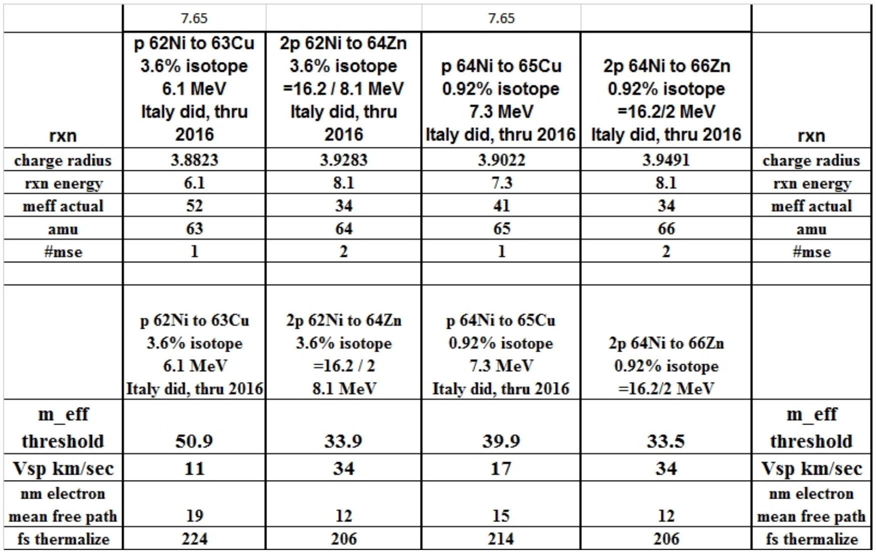
One sets the QCE equal to the binding energy and calculates what minimum m_{eff} is required. This gives the effective mass threshold below which no reaction can occur. The calculated minimum is greater than the minimum because the trapping potential should have been included. Including all potentials will give closer to the confined electron's energy. The QCE will be larger. Then, subtract the trapping potential energy One must also solve the Schroedinger equation for the correct quantum confinement energy, and it will have energy levels one must pay attention to. All of these refinements will lower the difficulty of experimentally achieving it because it permits a larger spread of energies and crystal momenta that will work, farther from the actual inflection point on the band structure diagram. One does not need to cover such a small region of the band structure. All this makes the minimum effective mass a smaller, easier number.

Calculating this more accurate smaller effective mass than what is shown below is planned.



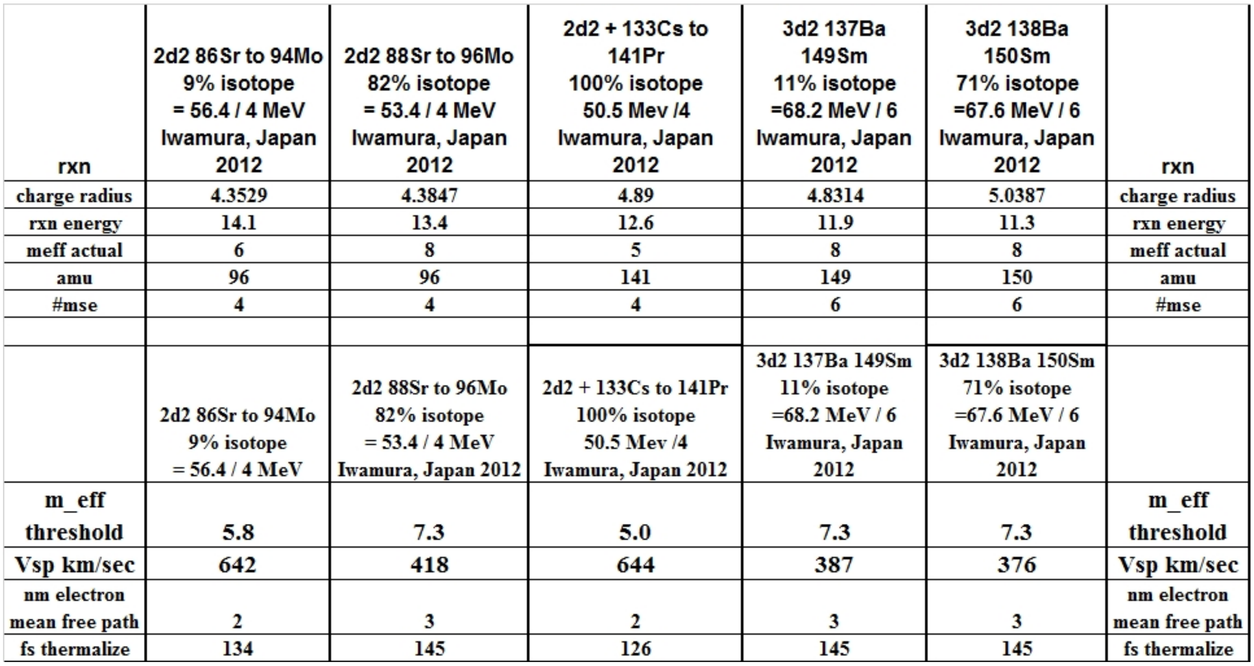
rxn	p 137Cs to 138Ba 9 MeV	2p 137Cs radioactive to 139La = 15,3 MeV /2	p 90Sr radioactive to 91Zr 9.2 MeV	4p 90Sr radioactive to 94Mo = 31.6/4 MeV	p 99Tc radioactive to 100Ru 9.9 MeV	rxn
charge radius	4.8378	4.855	4.2845	4.3529	4.4531	charge radius
rxn energy	9.0	7.7	9.2	7.9	9.9	rxn energy
meff actual	17	22	23	28	18	meff actual
amu	138	139	91	94	100	amu
#mse	1	2	1	4	1	#mse
	p 137Cs to 138Ba 9 MeV	2p 137Cs radioactive to 139La = 15,3 MeV /2	p 90Sr radioactive to 91Zr 9.2 MeV	4p 90Sr radioactive to 94Mo = 31.6/4 MeV	p 99Tc radioactive to 100Ru 9.9 MeV	
m_eff threshold	16.0	21.5	22.0	27.2	17.0	m_eff threshold
Vsp km/sec	48	43	39	53	55	Vsp km/sec
nm electron mean free path	6	8	8	10	6	nm electron mean free path
fs thermalize	177	187	189	198	179	fs thermalize

The minimum effective mass threshold needed to cause a neutralization transmutation in nickel is estimated to be in the range 16 to 27 electron masses.



	7.65		7.65		
rxn	p 62Ni to 63Cu 3.6% isotope 6.1 MeV Italy did, thru 2016	2p 62Ni to 64Zn 3.6% isotope =16.2 / 8.1 MeV Italy did, thru 2016	p 64Ni to 65Cu 0.92% isotope 7.3 MeV Italy did, thru 2016	2p 64Ni to 66Zn 0.92% isotope =16.2/2 MeV Italy did, thru 2016	rxn
charge radius	3.8823	3.9283	3.9022	3.9491	charge radius
rxn energy	6.1	8.1	7.3	8.1	rxn energy
meff actual	52	34	41	34	meff actual
amu	63	64	65	66	amu
#mse	1	2	1	2	#mse
	p 62Ni to 63Cu 3.6% isotope 6.1 MeV Italy did, thru 2016	2p 62Ni to 64Zn 3.6% isotope =16.2 / 2 8.1 MeV	p 64Ni to 65Cu 0.92% isotope 7.3 MeV Italy did, thru 2016	2p 64Ni to 66Zn 0.92% isotope =16.2/2 MeV	
m_eff threshold	50.9	33.9	39.9	33.5	m_eff threshold
Vsp km/sec	11	34	17	34	Vsp km/sec
nm electron mean free path	19	12	15	12	nm electron mean free path
fs thermalize	224	206	214	206	fs thermalize

In nickel, reactions requiring a minimum in the range of about 33 to 51 electron masses have been observed to form copper, zinc and other stable elements. The required effective mass to neutralize radioactive tracers is less than 33 to 51 by a comfortable margin. This means nickel has been observed to sustain or develop the minimum necessary electron quasi particle effective mass.



rxn	2d2 86Sr to 94Mo 9% isotope = 56.4 / 4 MeV Iwamura, Japan 2012	2d2 88Sr to 96Mo 82% isotope = 53.4 / 4 MeV Iwamura, Japan 2012	2d2 + 133Cs to 141Pr 100% isotope 50.5 Mev /4 Iwamura, Japan 2012	3d2 137Ba 149Sm 11% isotope =68.2 MeV / 6 Iwamura, Japan 2012	3d2 138Ba 150Sm 71% isotope =67.6 MeV / 6 Iwamura, Japan 2012	rxn
charge radius	4.3529	4.3847	4.89	4.8314	5.0387	charge radius
rxn energy	14.1	13.4	12.6	11.9	11.3	rxn energy
meff actual	6	8	5	8	8	meff actual
amu	96	96	141	149	150	amu
#mse	4	4	4	6	6	#mse
	2d2 86Sr to 94Mo 9% isotope = 56.4 / 4 MeV	2d2 88Sr to 96Mo 82% isotope = 53.4 / 4 MeV Iwamura, Japan 2012	2d2 + 133Cs to 141Pr 100% isotope 50.5 Mev /4 Iwamura, Japan 2012	3d2 137Ba 149Sm 11% isotope =68.2 MeV / 6 Iwamura, Japan 2012	3d2 138Ba 150Sm 71% isotope =67.6 MeV / 6 Iwamura, Japan 2012	
m_eff threshold	5.8	7.3	5.0	7.3	7.3	m_eff threshold
Vsp km/sec	642	418	644	387	376	Vsp km/sec
nm electron mean free path	2	3	2	3	3	nm electron mean free path
fs thermalize	134	145	126	145	145	fs thermalize

Palladium, popular and the most well-known proton + electron conducting host material (like nickel) apparently achieved effective masses up to about 10. However, the reactions used deuterons, not protons. The LaRue-Alvarez tri-body attraction reactions in palladium using deuterium with natural cesium, strontium and barium only required effective masses between about 5 and 8. Effective masses between 5 and 8 are apparently far more achievable than 30 to 50. However, our tests are based on data we presume required at least m_eff above about 30 to transmute nickel. We have no basis to presume palladium has achieved the minimum m_eff. Therefore, we reject palladium as the host lattice material.

The second reason for our preferring nickel may be the reason LaRue-Alvarez reactions using protons in palladium have not been affirmed--and theoretically should have been observed. Our experiments observed that protons and deuterons can both leave the first few nanometers of palladium almost as fast as a pinhole leak in a vacuum system. Hydrogen and deuterium diffuse through palladium orders of magnitude faster than through nickel. This means hydrogen leaves too quickly. It leaves the region where the crystal momentum and energy have not damped out, in the first few nanometers. This leaves too few protons for reactions.

For example, we tested for pinhole leaks in a 2 nm palladium foil on top of a copper electron microscope grid. Used as a membrane to hold off one half an atmosphere of air against a vacuum on the other side, the 2 nm Pd layer did not leak, down to the sub-torr pressure level.

When we used deuterium instead of air, the vacuum could not be maintained on the other side. In a different test, hydrogen diffused 50 times faster than deuterium through mm-thick palladium foils at room temperature.

Nickel also absorbs hydrogen in quantities approaching 1 per nickel atom. Nickel is a moderate proton and electron conductor. Other materials also absorb that much hydrogen, such as palladium and vanadium, and to a lesser degree titanium and many others. Fast hydrogen absorption and slow hydrogen desorption have been a key feature of materials desired for the “first wall” encountered by fusion products and fuels in a fusion chamber. Such first-wall materials are sometimes referred to as “superpermeable” materials.

Nickel tends to more easily absorb hydrogen and far less easily desorb. Various experiments described in the literature have used nanometers-thick layers of nickel on palladium, empirically verifying LaRue-Alvarez reactions when used.

Appendix

SAW Reaction Rate Stimulator

N. Saito et al. / Applied Surface

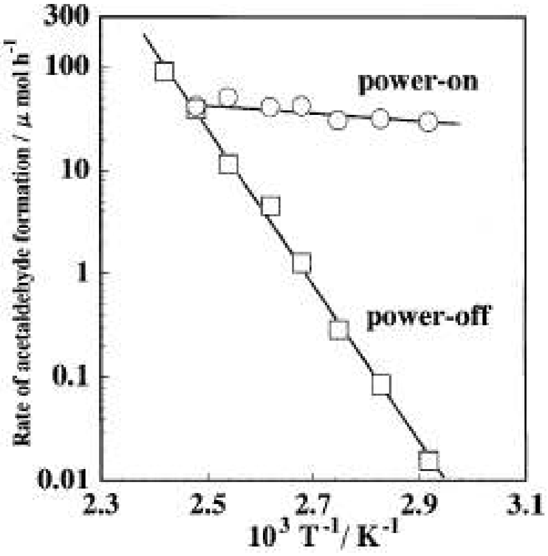


Fig. 4. Effects of resonance oscillation on temperature dependence of catalytic reaction. Rf-power = 3.0 W, fr = 3.4 MHz. (○) Power-on, (□) power-off.

“Anomalous enhancement of catalytic activity over a Pd thin film by the effects of resonance oscillation generated on a ferroelectric”
Saito, Nobuo; Yuzuru Ohkawara, Yukihisa Watanabe, Yasunobu Inoue
Applied Surface Science 121 / 122 1997, pp 343– 346

We were studying surface reactions at UC Berkeley related to VPEE. We read that a 100 nm thick catalyst was placed on top of a surface acoustic wave generator (SAW). Reactants were on top of the catalyst. When the surface acoustic waves did not energize the catalyst, “power-off” in the figure, the downward slope of the curve means the reactions experience an energy barrier, referred to as activation energy, and both the activation barrier and the reaction rate was normal. When the waves were turned on, “power-on” in the figure, the reaction rate was almost the same as at high temperature, where “1/T” is smaller. The slope was small, meaning the activation energy was low. How could that happen?

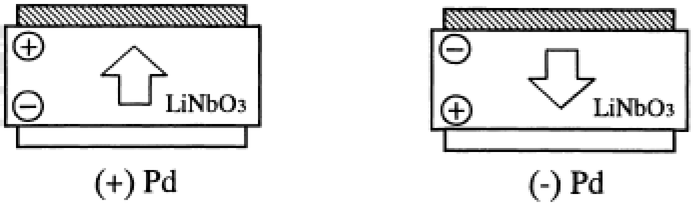
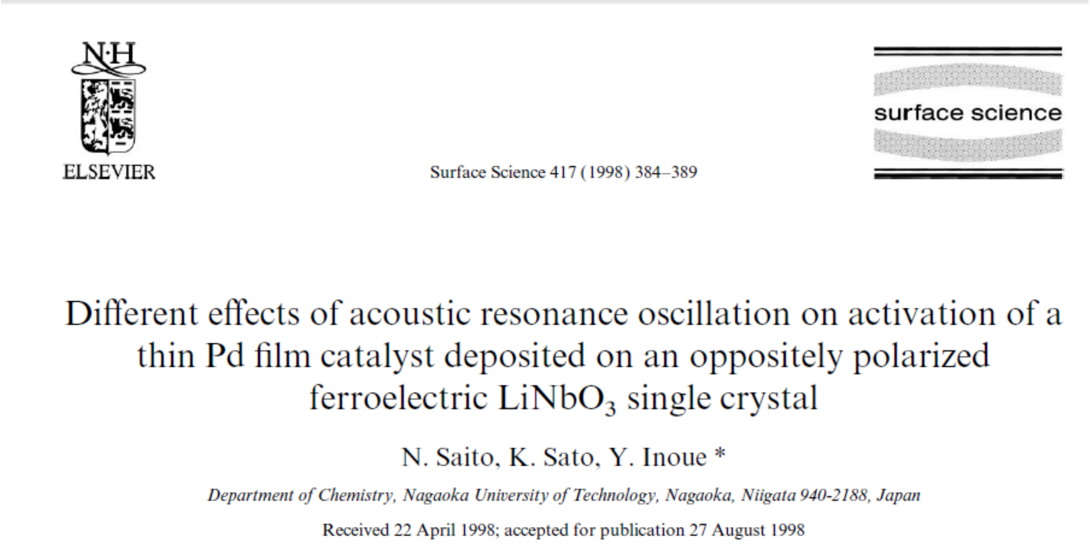


Fig. 1. Structures of Pd thin film catalysts deposited on a positively and a negatively polarized ferroelectric z-$LiNbO_3$ substrate: shaded box, Pd; empty box, Al.

The curious and confounding observation was that the SAW waves were too weak to change anything on the small scale of the 100 nm catalyst. The SAW was too weak to do anything familiar, such as squeezing. Nobody knew why this reaction rate acceleration happened.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Different effects of acoustic resonance oscillation on activation of a thin Pd film catalyst deposited on an oppositely polarized ferroelectric $LiNbO_3$ single crystal

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“Different Effects Of Acoustic-Resonance Oscillation On Activation Of A Thin Pd Film Catalyst Deposited On An Oppositely Polarized Ferroelectric LiNBO3 Single-Crystal”

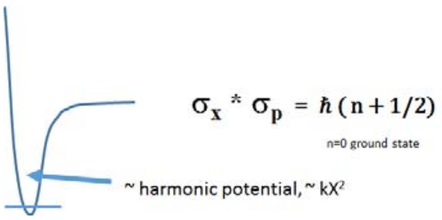
A huge acceleration of reaction rate was unexplained. We suspected the insertion of crystal momentum was related, but did not then know how or why.

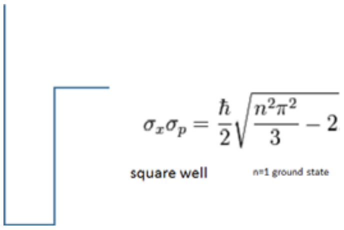
Appendix

Quantum Confinement Barrier like Coulomb Barrier

The relative placement and values of the trapping and bonding potentials separate the observed data into two groups: 1) trapping and bonding potentials overlap, and 2) bonding potential forbidden by QCE, mandating tunneling to access the bonding potential.

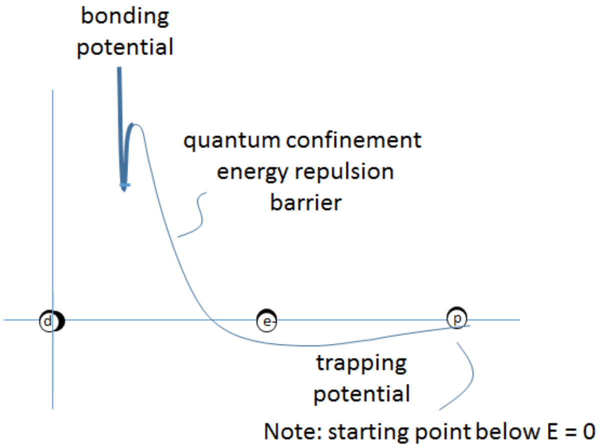
The NO- experiments reported by LaRue et al. () had the bonding potential range overlapping the trapping potential (group 1). The sequence of observed vibration states and emitted electron energies reflects the energy levels as a function of energy “quantum number”.



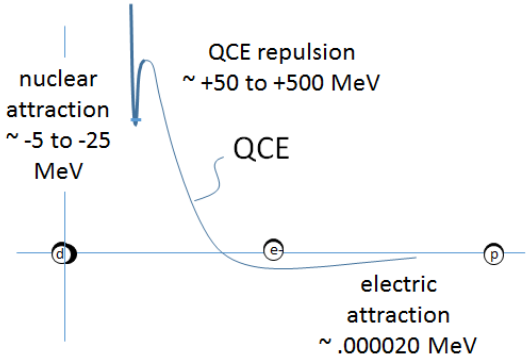


One notices that the “greater than or equals” of the Robertson-Schroedinger (Heisenberg) Uncertainty Relation is removed when the Schroedinger equation is solved. The value of QCE is the T term in the Hamiltonian at an inner turning point of the bonding vibration.

In the case of p-muon-d and of CO_{ads}-mse-O_{ads} the repulsive QCE becomes greater than the bonding potential as the confinement dimension decreases. This means the bonding potential can not be accessed classically. It can only be accessed by tunneling (group 2). The tunneling barrier is like $+1/mX^2$.

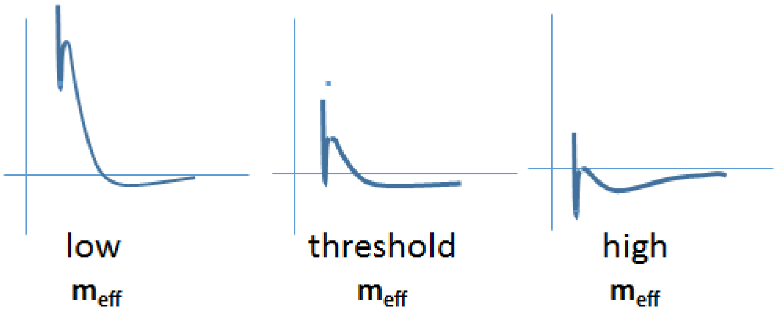


Note that the starting point is below the zero energy. This means the reactants can’t have enough energy to penetrate the barrier because they must be below zero energy, and would tunnel to nowhere. This means there are no stable states formed by the bonding potential. This is why we are here and not at nuclear dimensions.



The electron does not weigh enough. The $+1/mX^2$ term is always too large at any small dimension where nuclear bonding has an effect.

This strictly forbids cold fusion. It does not matter that an electron is between the reactants and that the configuration is tri-body. There are no stable states.



When we increase effective mass, m, the repulsion decreases. At some threshold effective mass, the ground state of the bonding potential decreases to below zero energy, making it accessible to tunneling, but not classically accessible.

This is the threshold effective mass we calculate and use as a guide for the reaction. We notice that the muon is also not heavy enough to allow classical access to the nuclear bonding. The ~207 me of the muon would need to be the ratio of hydrogen atom Bohr radius to the nuclear potential range, ~ 52E-12 meters/ 2.7E-15 meters, ~ 19,000 times heavier than an electron, not ~207.

At the extreme where the QCE is much less than the vibration energy at a high nuclear potential quantum number, then QCE is not dominant and the reaction is not drained of excess energy. This would place the reaction into the normal, expected reactions for hot fusion.

A d-d tri-body reaction appears to be of this class, as does t-d tri-body reaction. One expects well-known branches to be accessed, with well-known observed energetic reaction products. This is the more familiar muon catalyzed fusion.

Also note that the QCE curve represents a pseudo-potential. One must solve the Schroedinger equation to evaluate QCE.

A method to evaluate the QCE pseudo-potential calibrates the system at a bonding vibrational turning point. This is an interesting, approximately solvable student exercise.