# TUNNELING BENEATH THE $^{4}$He* FRAGMENTATION ENERGY

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At ICCF-14, we presented the means whereby the repulsive Coulomb barrier between hydrogen (deuterium) nuclei is reduced in length, perhaps by orders of magnitude. This mechanism, involving optical phonons and electric fields (internally or externally generated) in a lattice that induce the formation of $H^{-}H^{+}$ ($D^{-}D^{+}$) pairs, increases the tunneling probability by more than 100 orders of magnitude. It has additional major consequences.

The lattice constraints and collision processes force the ions into a temporary, but cyclic, 1-D configuration that greatly deepens the electron ground-state potential well. The tightly-bound and energetic electron pair (a local-charged Boson - the lochon) becomes more than strong screening, it becomes a binding force between the nuclei. Thus, the Coulomb-barrier height is reduced as well as its length. With this greatly enhanced barrier-penetration probability, the energy level of nuclei with reasonable tunneling probability drops from the multi-100 keV range down into the eV range.

The $^{2}$He (diproton) and first excited state of helium-4, $^{4}$He* (unable to decay via gamma radiation) are above the fragmentation energy (i.e., they are more likely to fragment than to exist for long or to decay to the ground state). Normal tunneling is into these resonant states (excited or fragmentation levels). With the ability of low-energy nuclei to tunnel from an appropriate lattice, the possibility of lower-energy excited compound nuclei becomes real. If, with the lochon, the helium-2, or excited helium-4 nucleus, does not have sufficient energy to fragment, and gamma decay is highly forbidden, how does it shed the excess energy? It is proposed that this condition is the basis for the experimental observations of CMNS.

Depending on the actual energy of the excited (compound) nuclei, the decay process could include fragmentation, or not. This accounts for the observations in CMNS of excess heat, in both p-p and d-d reactions, and the observations (or absence) of tritium, $^{3}$He, neutrons, and $^{4}$He in the d-d reaction. This variation (unpredictability) of results, heretofore the stumbling block to acceptability of CMNS, is now perhaps the greatest validation of its existence. Furthermore, the proposed mechanism accounts for observed “transmutation,” something that we didn’t accept for a long time.

The key to the mechanism is the lochons, which during the collision process attain significant energy from the nuclear Coulomb potential (many keV; but, being tightly bound in ground states, they do not radiate). During the fusion process, they would divide and can perhaps attain energies in the MeV range from coupling with the nucleons accelerating in the nuclear potential (and these electrons would radiate - bremsstrahlung). This collision/radiation process lasts until: 1) the neutral entity ($^{2}$He* or $^{4}$He*) drifts into a neighboring nucleus in a transmutation process; 2) one (or more) of the nuclear electrons combines with a proton ($p + e \Rightarrow n + \nu$); or, 3) diproton fragmentation or the $^{4}$He ground state is reached. Thus, all major observed CMNS processes are explained. (Levels and observability of the Bremsstrahlung and neutrinos must still be determined.)

# Tunneling Beneath the $^4$He* Fragmentation Energy

(Annotated Presentation)

A. Meulenberg
and
K. P. Sinha

This presentation is an attempt to respond to a challenge presented by Akito Takahashi 2 years ago.

## Abstract

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## Abstract (cont.)

Depending on the actual energy of the excited (compound) nuclei, the decay process could include fragmentation, or not. This accounts for the observations in CMNS of excess heat, in both p-p and d-d reactions, and the observations (or absence) of tritium, 3He, neutrons, and 4He in the d-d reaction. This variation (unpredictability) of results, heretofore the stumbling block to acceptability of CMNS, is now perhaps the greatest validation of its existence. Furthermore, the proposed mechanism accounts for observed “transmutation,” something that we didn’t accept for a long time.

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**Our ICCF-14 Goal: to provide an understandable, standard-physics basis and condition set for overcoming the D-D <u>Coulomb barrier</u>**

**Partially achieved via solid-state physics**

**(some questions about input parameters)**

**Our ICCF-15 Goal: to provide an understandable, standard-physics basis for explaining observed LENR <u>results</u> (hopefully consistent with prior model)**

**Needs analysis of both atomic and nuclear physics**

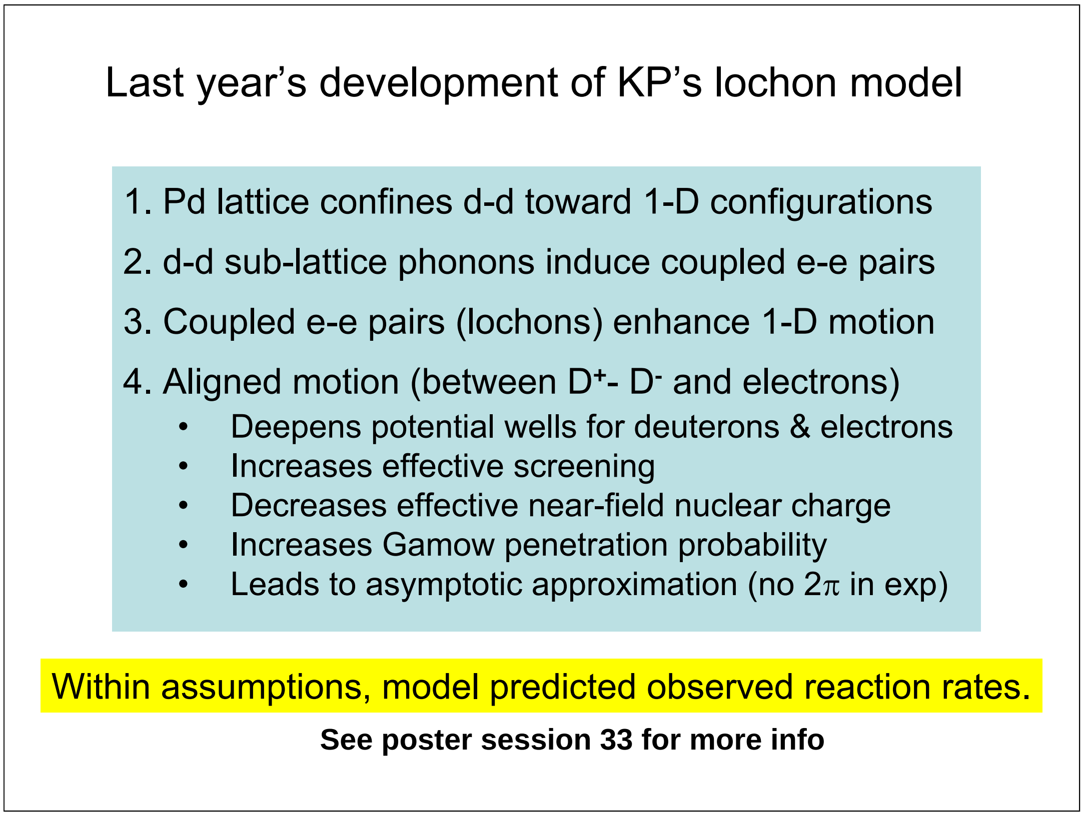
Last year KP provided a quantum mechanical description of the first part of what I'll try to describe today. I doubt that 5% of the whole CMNS group could understand what he described (even if they had studied it). And less that ½ of that group could comment on its validity. Perhaps 6 people out of the 5% heard the presentation or read the paper.

I might be in the part of the 5% that can understand what KP described, but cannot comment on its validity. I'm looking for another person who heard or read and <u>understands</u> what he said.

Today, as an introduction to the next "Step," I will give my description of what

I think is the physics behind KP's QM that says we can penetrate the Coulomb barrier.

Those who understand QM (and many others) will likely find that my explanation makes no sense to them. On the other hand, I hope that it makes <u>some</u> sense to 50% of the people here and that it helps to bring the theoreticians and experimentalists closer together.



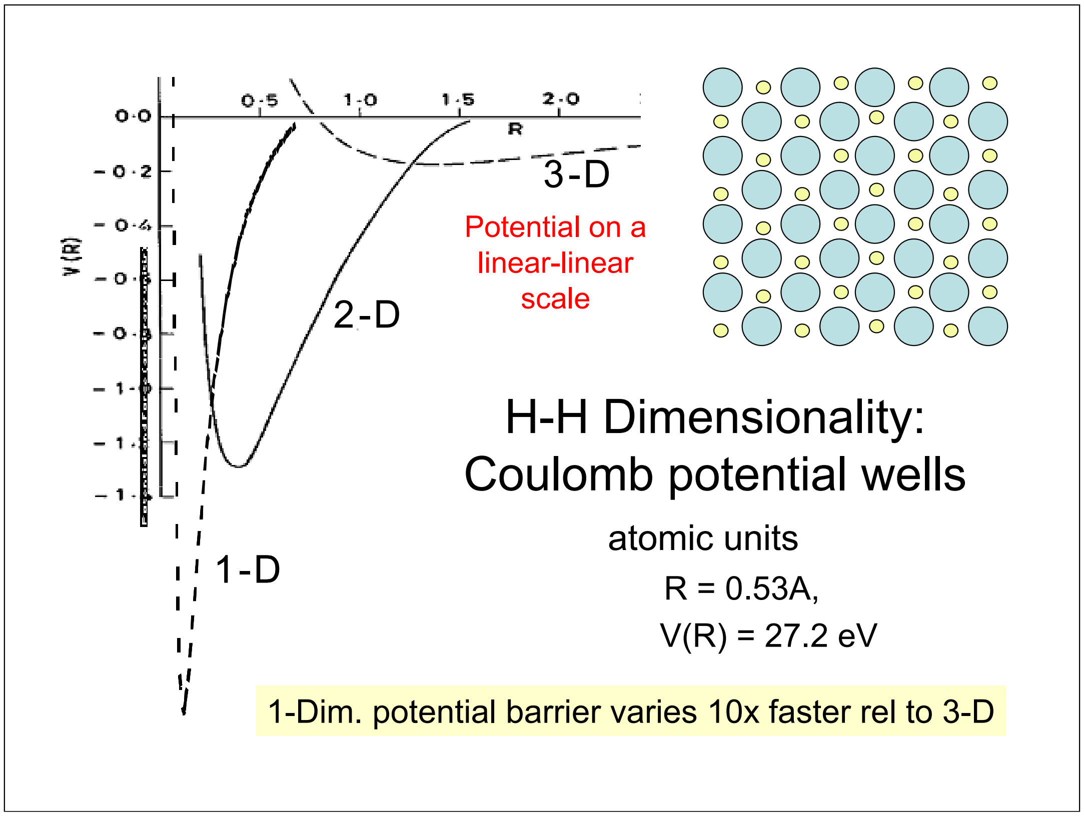
## Last year's development of KP's Iochon model

1. Pd lattice confines d-d toward 1-D configurations
2. d-d sub-lattice phonons induce coupled e-e pairs
3. Coupled e-e pairs (Iochons) enhance 1-D motion
4. Aligned motion (between $D^+$- $D^-$ and electrons)
    - Deepens potential wells for deuterons & electrons
    - Increases effective screening
    - Decreases effective near-field nuclear charge
    - Increases Gamow penetration probability
    - Leads to asymptotic approximation (no $2\pi$ in exp)

Within assumptions, model predicted observed reaction rates.

**See poster session 33 for more info**

1. 1-D process during collision only (lattice breaks symmetry of isotropic Coulomb potential of isolated atoms)
2. phonons produce mechanical and electric fields
3. optical phonon-induced motion of deuterons:
    - between Pd atoms gives 2-Dim confinement (saddle potential)
    - Allows point-to-point (1-Dim) “encounters” between deuterium atoms at 1e13 to 1e14 times/sec.
4. Attractive $D^+$- $D^-$ potential “focuses” motion (to 1-D) and breaks symmetry of 2-D confinement



Potential on a linear-linear scale

## H-H Dimensionality: Coulomb potential wells

atomic units

R = 0.53A,

V(R) = 27.2 eV

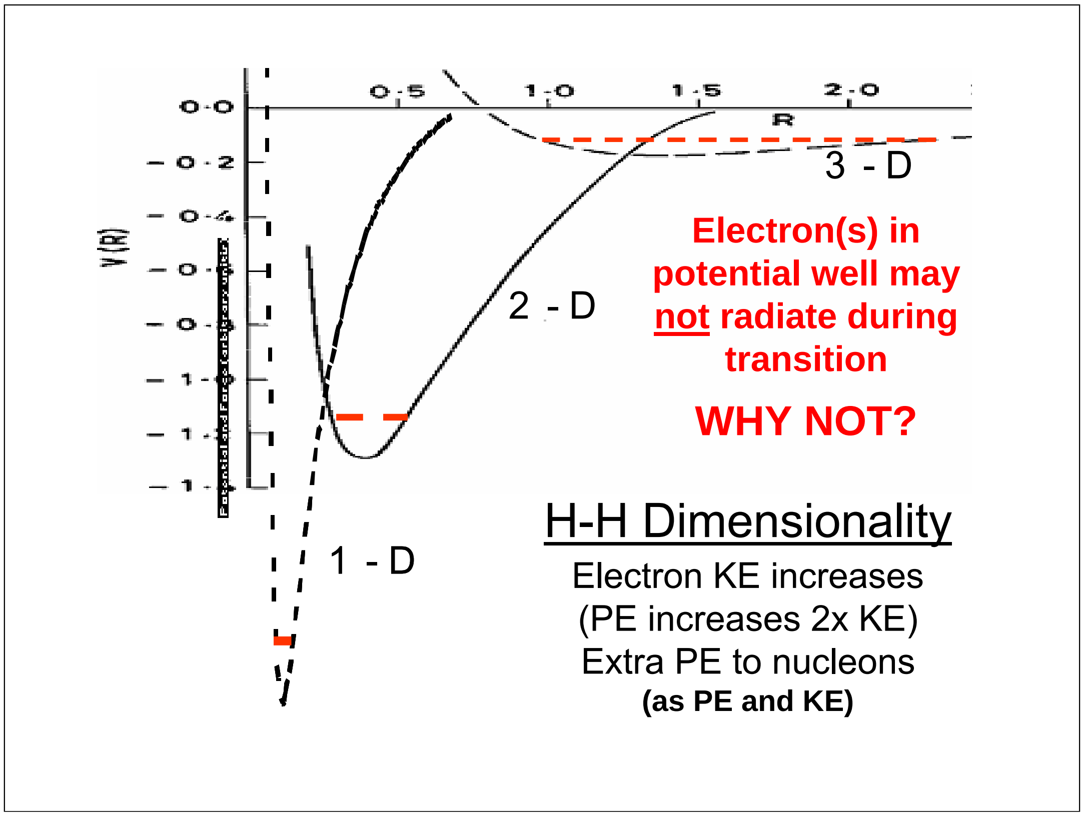
1-Dim. potential barrier varies 10x faster rel to 3-D

- This figure is only to indicate the effects of dimensionality.
- Atomic potentials are influenced by the Coulomb interaction,

  this figure hints at the electron-potential-well evolution (3-D to 1-D).
- The D-D sublattice phonons in PdD have a “multilinear” symmetry.

  A linear defect site is a better candidate for the model
- The picture presented is for a H2 molecule only during the collision process.

  It assumes a fully-loaded PdD matrix.



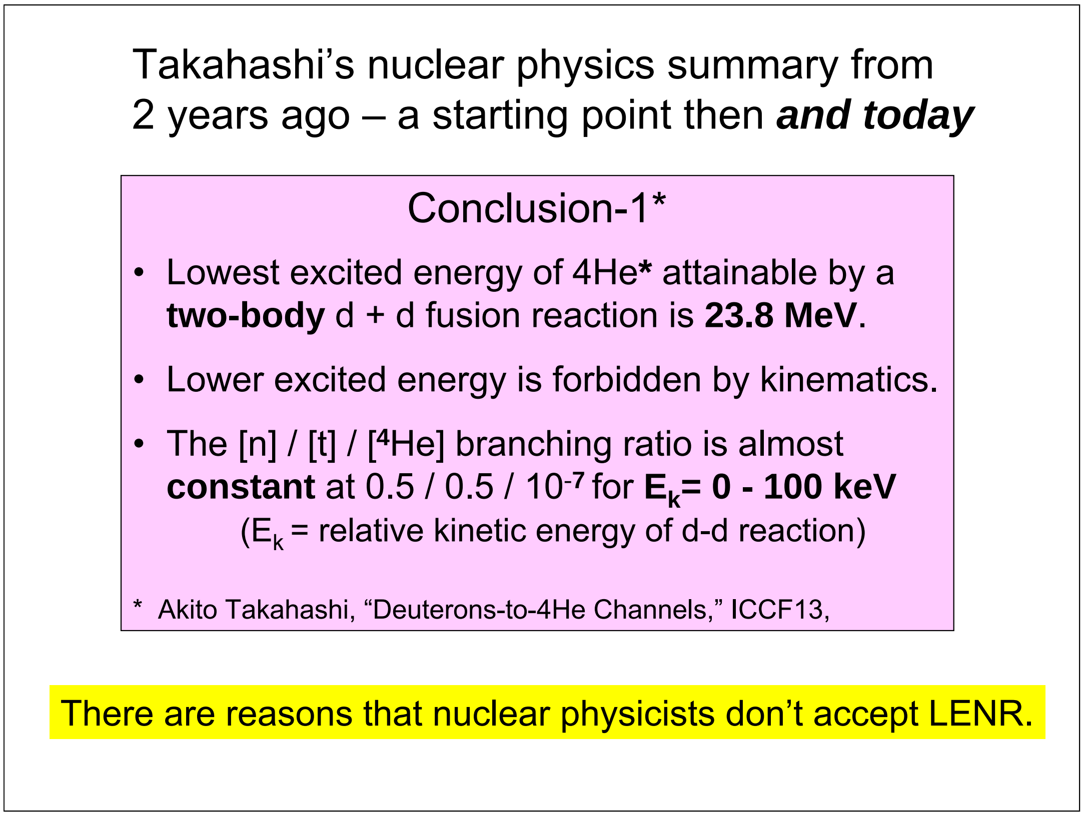
**Electron(s) in potential well may not radiate during transition**

**WHY NOT?**

## H-H Dimensionality

Electron KE increases
(PE increases 2x KE)
Extra PE to nucleons
**(as PE and KE)**

1. As the deuterium is “pressed” between the Pd atoms, its electron is given KE
   - its wave function and orbit shrink.
   - If it cannot shrink fast enough, its energy exceeds the dropping $H_2$-energy levels
   - It can move into & radiate from the higher (*l* = 1) levels to the new ground level.
2. But, as a neutral “molecule”,
   - There is a probability for the electrons to both be on the same nucleus
   - The electrons actually do work as the nuclei come together
   - Doing work allows them to move deeper into the Coulomb well.
   - Use Born-Oppenheimer approximation, (Frank-Condon Principle doesn’t hold).
3. The “deep” electrons are energetic; they provide super-strong screening.
4. These deep electrons answer my main concern in KP’s Lochon model.
5. For future reference, this is a 4-body collision



## Takahashi’s nuclear physics summary from 2 years ago – a starting point then ***and today***

### Conclusion-1*

- Lowest excited energy of 4He***** attainable by a **two-body** d + d fusion reaction is **23.8 MeV**.
- Lower excited energy is forbidden by kinematics.
- The [n] / [t] / [$^4$He] branching ratio is almost **constant** at 0.5 / 0.5 / $10^{-7}$ for **$E_k$= 0 - 100 keV**
  ($E_k$ = relative kinetic energy of d-d reaction)

* Akito Takahashi, “Deuterons-to-4He Channels,” ICCF13,

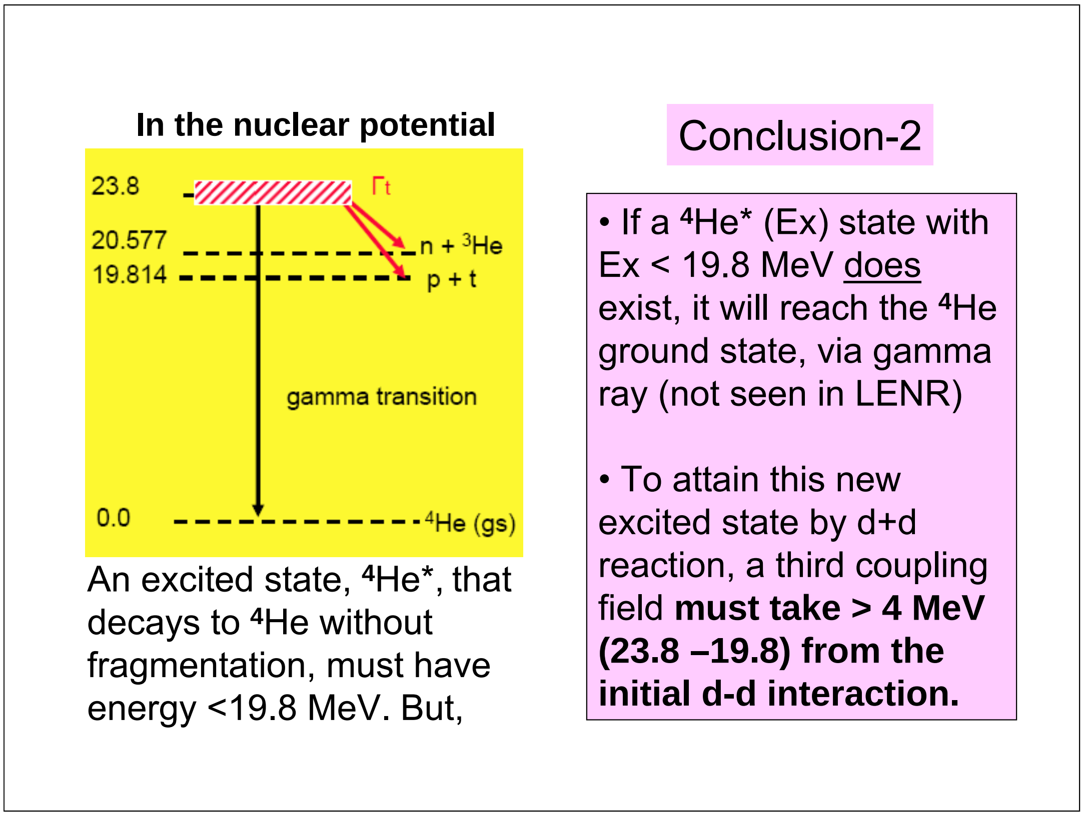
There are reasons that nuclear physicists don’t accept LENR.

•23.8 MeV is the mass difference between 2 deuterons and an alpha particle (or 2 deuterium atoms and a 4He atom)

•Since the alpha cannot have more kinetic energy than the 2 deuterons, the total energy of the excited state must be > 23.8 MeV

•As seen next, any state with E>23.8 MeV is well above the fragmentation levels.

•Note that he put in “two-body” reaction. This becomes important in the following discussion.



**In the nuclear potential**

An excited state, $^4$He*, that decays to $^4$He without fragmentation, must have energy <19.8 MeV. But,

## Conclusion-2

- If a $^4$He* (Ex) state with Ex < 19.8 MeV <u>does</u> exist, it will reach the $^4$He ground state, via gamma ray (not seen in LENR)

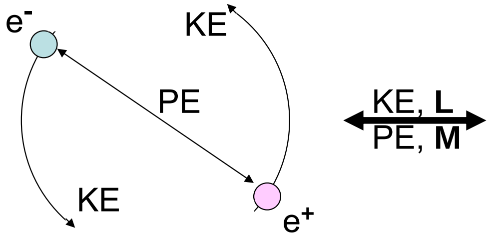
- To attain this new excited state by d+d reaction, a third coupling field **must take > 4 MeV (23.8 –19.8) from the initial d-d interaction.**

•To alter the fragmentation ratios (to those observed in LENR experiments), another mechanism must be postulated.

- •No other decay channels have been observed
- •Therefore, there must be a means of getting below the 20.6 and 19.8 MeV fragmentation energies – or find another mechanism.

## The Lochon model

1. => high probability of penetrating d-d Coulomb barrier. But,
2. **does it allow $^4$He* with E < 23.8 MeV?**



Electron-positron pair

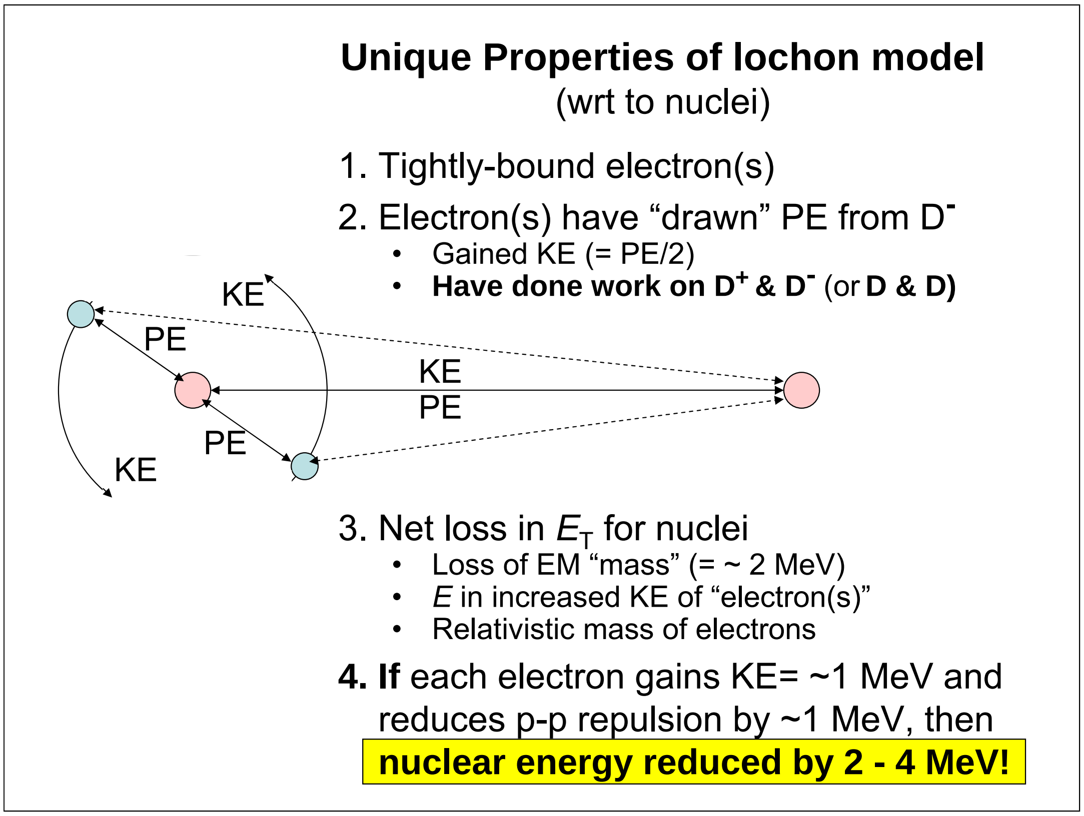
**Mass, charge, EM field**
**Angular momentum**
**Energy (KE & PE)**

1 – 3 photons

**EM field**
**No mass, No charge**
**Momentum (ang & lin)**
**Energy (KE? & PE?)**

**To answer 2. we start by looking at electron-positron annihilation.**

- electron positron pair “annihilate.” All mass & charge are gone. All *E* is in photons.
- KE and PE are defined at/after annihilation? No! Field energy is.
- Extend to case where electron & proton “join.”
  - Proton & electron field is reduced. Most normal charge-field mass is gone! Where?
  - Dipole field grows. Electron and proton are no longer distinct.
  - relativistic field grows.

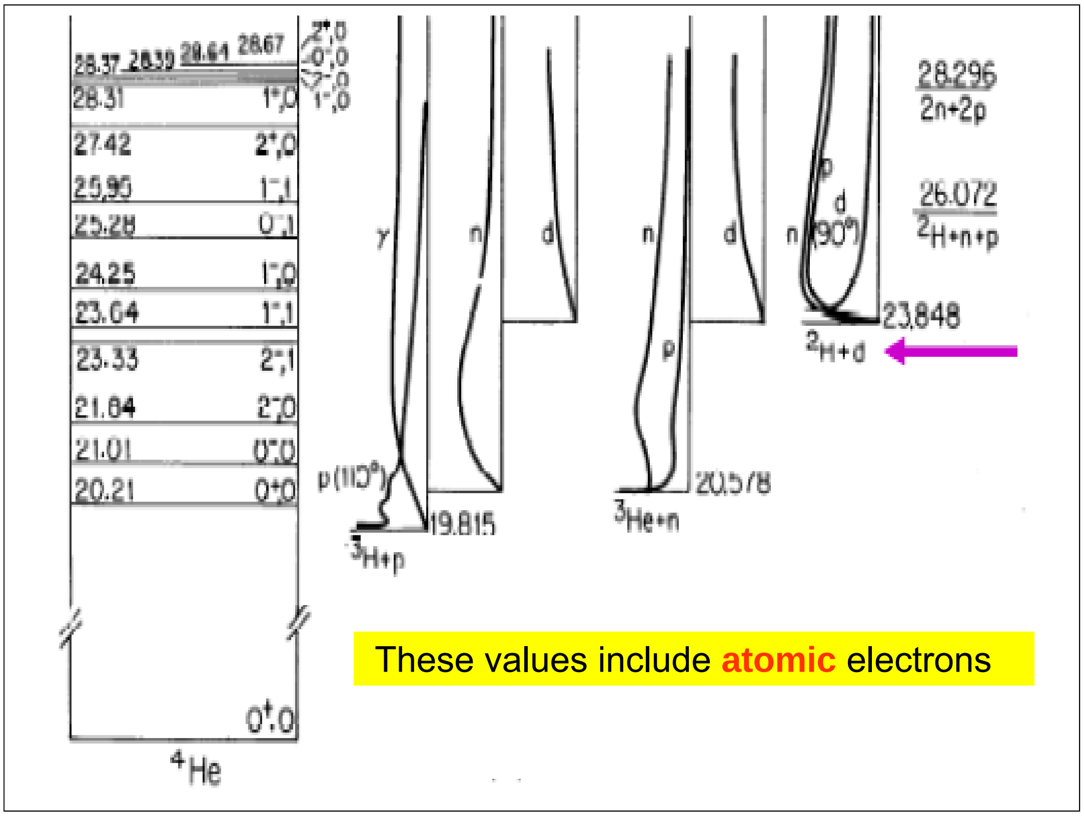


## Unique Properties of lochon model

(wrt to nuclei)

1. Tightly-bound electron(s)
2. Electron(s) have “drawn” PE from $D^-$
   - Gained KE (= PE/2)
   - **Have done work on $D^+$ & $D^-$** (or **D & D)**
3. Net loss in $E_T$ for nuclei
   - Loss of EM “mass” (= ~ 2 MeV)
   - *E* in increased KE of “electron(s)”
   - Relativistic mass of electrons
4. **If** each electron gains KE= ~1 MeV and reduces p-p repulsion by ~1 MeV, then **nuclear energy reduced by 2 - 4 MeV!**

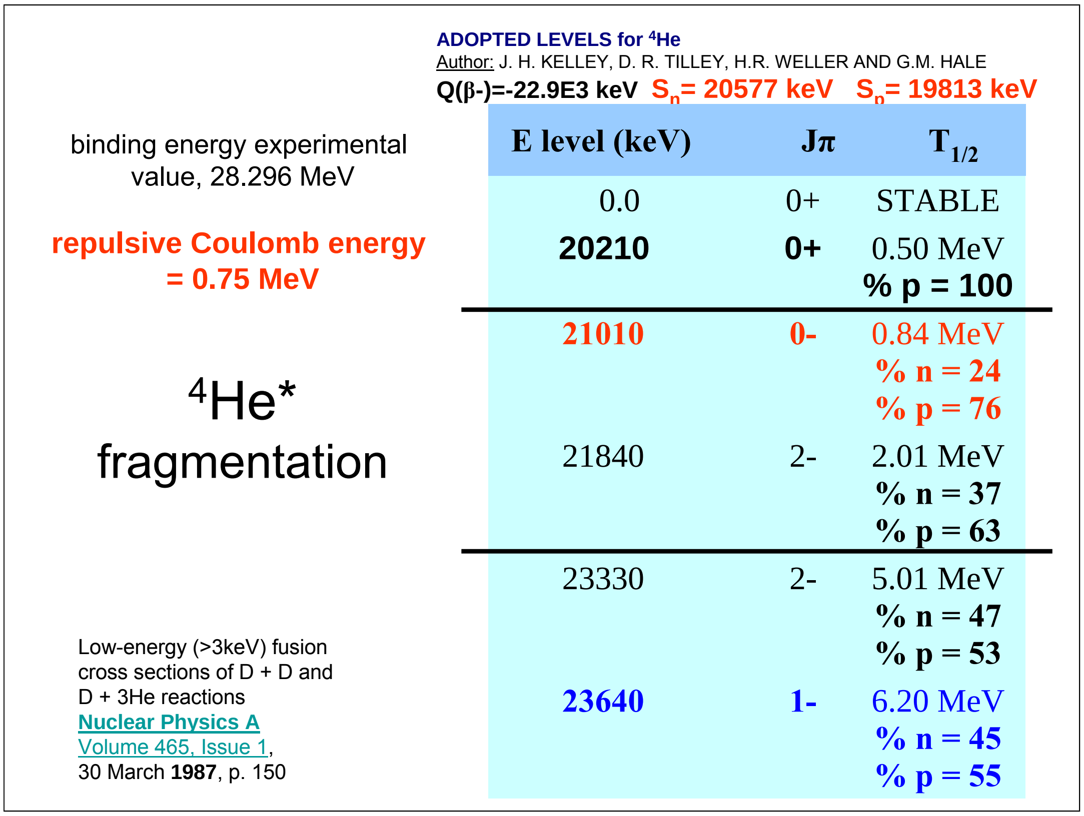
1. 2 electrons (tightly bound) give > barrier penetration power of the D+ D- combination than 1 electron.
2. If the electron pair (a local charged boson = Lochon) is still bound during fusion, then
   - p-p Coulomb repulsion is decreased and the deuteron wave functions overlap more closely.
   - deuterons spend more time in the nuclear potential well, hence have lower average energy.
   - $^4$He* energy would likely be less than 20 MeV, thus no fragmentation is possible.
3. If one of the electron pair is ejected before fusion is complete, then p-p Coulomb repulsion is increased and the $^4$He* energy would likely exceed 20 MeV, thus p+t production is still possible.



These values include **atomic** electrons

- Normally incident deuteron energy exceeds 23.8 MeV
- Substitution of tightly-bound electrons for the atomic electrons means that the electric-field energy and the p-p Coulomb repulsion is reduced – thus, both the input energy & $^4$He* energy levels are reduced
- Another portion of the proton energy is bound up in the electron’s KE. Therefore, *E* (D+D) goes down.

The nucleon energies may total less than 19.8 MeV!



**ADOPTED LEVELS for $^4$He**

Author: J. H. KELLEY, D. R. TILLEY, H.R. WELLER AND G.M. HALE

**Q(β-)=-22.9E3 keV** **$S_n$= 20577 keV** **$S_p$= 19813 keV**

binding energy experimental value, 28.296 MeV

**repulsive Coulomb energy = 0.75 MeV**

$^4$He* fragmentation

| E level (keV) | Jπ | $T_{1/2}$ |
|---|---|---|
| 0.0 | 0+ | STABLE |
| **20210** | **0+** | 0.50 MeV<br>**% p = 100** |
| **21010** | **0-** | 0.84 MeV<br>**% n = 24**<br>**% p = 76** |
| 21840 | 2- | 2.01 MeV<br>**% n = 37**<br>**% p = 63** |
| 23330 | 2- | 5.01 MeV<br>**% n = 47**<br>**% p = 53** |
| **23640** | **1-** | 6.20 MeV<br>**% n = 45**<br>**% p = 55** |

Low-energy (>3keV) fusion cross sections of D + D and D + 3He reactions
**Nuclear Physics A**
Volume 465, Issue 1,
30 March **1987**, p. 150

At the higher energies (23,640 & 23,330 keV), the fragmentation ratio (p/n) is close to 50/50.

As the $^4$He* energy approaches 20.6 MeV, the neutron/$^3$He path becomes inaccessible.

This gives a path to understanding the LENR “signature” of varying p & n production rates.

## Consequences of sub-fragmentation excitation: 1

(via tightly-bound electrons)

1. Energy levels lowered by reduced Coulomb repulsion
    - ($0^+$, 0) and ($0^-$, 0) levels now lower than 20 MeV
    - Resonance tunneling into sub-fragmentation levels
    - These lowered states are from high-*E* electrons
2. Transition condition
    - Nuclear potential “traps” d-d near their lowest PE
    - Energy is highly variable because of electron’s positions
    - Electrons at max KE, max coupling, & min field energy**?**
    - Electrons “share” nuclear potential (via near-field)**?**
3. Long-lived state(s) below 19.8 MeV?
    - No fragmentation
    - No energetic-gamma to ground state
      0 => 0 transitions highly forbidden
    - No electron or nucleon angular momentum

The electron-reduced nucleon energies total less than 19.8 MeV - relative to charge-modified ground state!

Resonant tunneling into electron-lowered nuclear states (now below 19.8 MeV).

Transition condition could exist all the way to ground state.

Some metastable states could exist in the electron-modified nucleus

## Consequences of sub-fragmentation excitation: 2

(via tightly-bound electrons)

1. Energy levels lowered by reduced Coulomb repulsion
2. Transition condition
3. If, long-lived state(s), then
   - Only metastable resonances (fs lifetimes?)
   - Tightly-bound electrons upset resonances
   - Not typical nuclear levels
4. New decay modes dominate
   - Decay modes via tightly-coupled electron(s)
   - Internal conversion (energetic electron ejected)
   - Pair production (real vs virtual)
   - Electron capture & pep reaction (neutrons produced)**?**

Normal nuclear resonances have protons and neutrons. Now there are protons, neutrons and meta-neutrons (protons w tightly-bound electrons).

Protons radiate energy via the tightly-bound, highly-energetic, electrons. The proton-modulated electron-frequency matches the Pd inner-electron frequencies. Electron frequency is like a "carrier-wave."

In internal conversion, the electron may couple to the excited state and take the energy of the nuclear transition directly, without an intermediate gamma ray being produced first, and therefore need not change angular momentum or electric moment. (0 => 0 transition possible)

The kinetic energy of the emitted electron is equal to the transition energy in the nucleus (multi-MeV range), minus the binding energy of the electron (MeV range).

*Internal conversion is favoured when the energy gap between nuclear levels is small, and is also the primary mode of de-excitation for 0+ → 0+ (i.e. E0) transitions (i.e., where excited nuclei are able to rid themselves of energy without changing electric and magnetic moments in certain ways) with insufficient energy to decay by pair production. It is the predominant mode of de-excitation whenever the initial and final spin states are the same, but the multi-polarity rules for nonzero initial and final spin states do not necessarily forbid the emission of a gamma ray in such a case.*

Low-energy transitions favored because electron & proton deBroglie frequencies match. Thus, as excited nucleus approaches ground state, electron ejection becomes more probable.

e capture: In this case, one of the orbital electrons, usually from the K or L electron shell (K-electron capture, also K-capture, or L-electron capture, L-capture), is captured by a proton in the nucleus, forming a neutron and a neutrino.

Electron capture & pep reaction not likely in D-D because Q of 4H or D+2n is too high.

## Consequences of sub-fragmentation excitation: 3

(via tightly-bound electrons)

1. Energy levels lowered by reduced Coulomb repulsion
2. Transition condition
3. Long-lived state(s),
4. If, new decay modes dominate, then
5. Neutral nucleus (short-lived)
   - No far-field Coulomb potential
   - Quasi-neutral body
   - Dipole (and higher) potential - decays as $1/r^n$ with $n > 2$
   - High internal energy (nucleons & relativistic “electrons”)
   - Electrons as “exchange” medium w lattice
6. Pd electrons transiting nucleus pick up energy
7. “Fat neutron” drifts into neighboring nuclei => transmutation
   - Source of radiation, heat, & “life after death”

Radiation from proton/electron dipole is low (despite relativistic velocities and high acceleration of charge) because the dipole moment is so small (only femtometers).

Field coupling from proton/electron dipole is short range. Therefore, energy exchange only with electrons passing very close to nucleus.

## Summary

- Lochon Model (w full QM description) provides for Coulomb barrier penetration & full fragmentation
- Extension of Lochon Model provides for “fusion” with partial or no fragmentation.
- fusion at sub-fragmentation energy permits heat-only decay to $^4$He (via tightly-bound electrons)
- fusion at sub-fragmentation energy (with lochon) permits transmutation via neutral, energetic, “nucleus”

Extension of Lochon model provides for reduction of proton potential (field) energies during the D-D collision process.

Extended model provides basis for all major LENR experimental observations.

# End

**See more below about tunneling probabilities in Lochon model**

.

## Sub-picometer Range

- deuteron pair within 100 fm, => different tunneling regime
- 2 electrons attached, but in Bohr-like orbits => attractive potential beyond 0.01A (= 1 pm, hence not < 100 fm)
- 2 electrons attached (assuming classical electron radius in "classical" orbits) => attractive potential beyond 10 fm.
  - **not in equilibrium (std QM states not valid)**
  - **Born-Oppenheimer approximation (Assume nuclei fixed, calc. $e^-$ orbits point-by-point) =>**

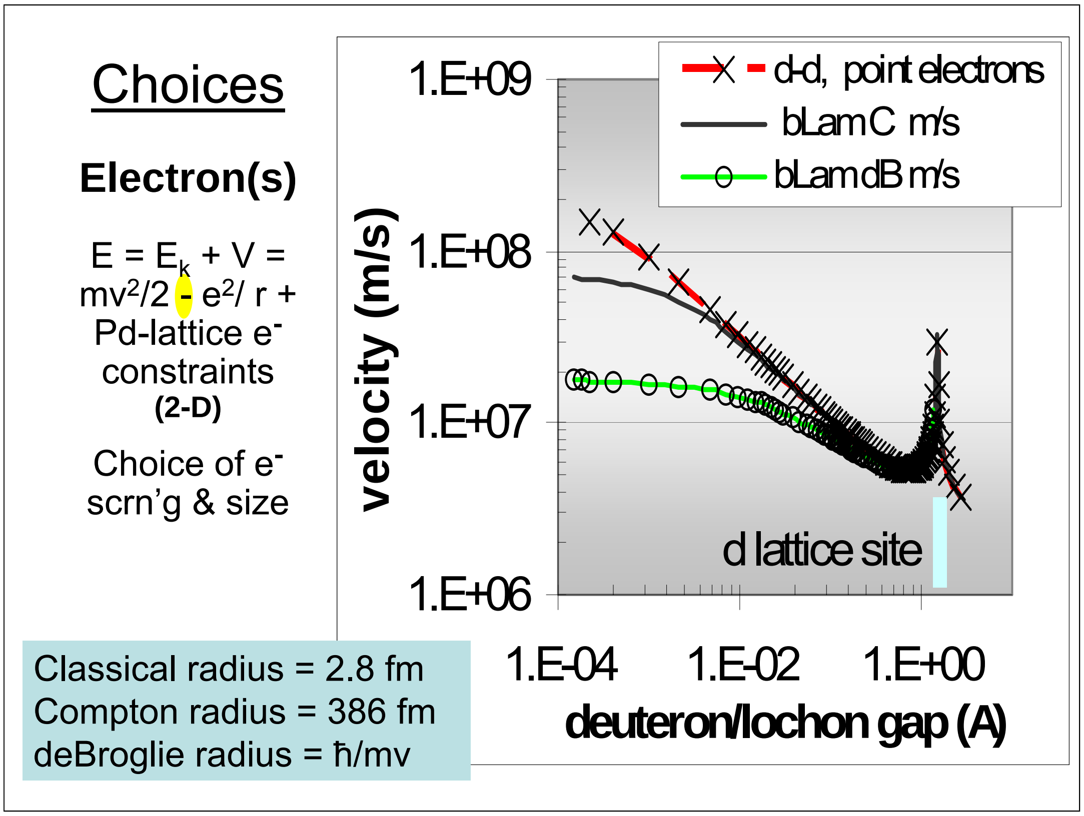
**separates electron from atomic action.**

Determination of tunneling regime is critical to both probability and nature of fusion.

Attachment of electron(s) during process is not well defined – but most important.

Equilibrium values (QM eigenstates) do not pertain to this situation. Must use different model. http://en.wikipedia.org/wiki/Born-Oppenheimer_approximation

Events/conditions during this transition period, determines nature of fusion process.



## Choices

**Electron(s)**

$E = E_k + V = mv^2/2 - e^2/r +$ Pd-lattice $e^-$ constraints **(2-D)**

Choice of $e^-$ scrn'g & size

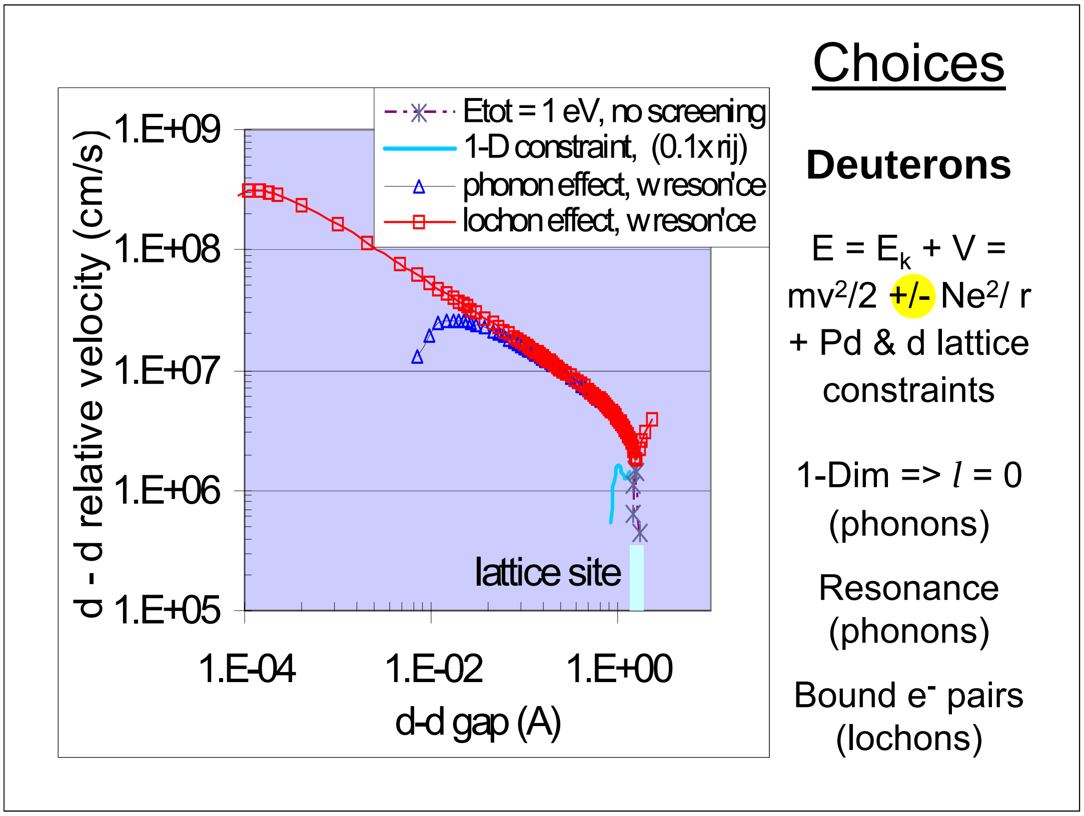
Classical radius = 2.8 fm
Compton radius = 386 fm
deBroglie radius = ħ/mv

I had mentioned that last year's results raised some questions about input parameters.

The realistic "size" of an electron and its screening length was one.

- There are 3 characteristic sizes generally used. They vary by many orders of magnitude.
- The speed of an electron, during an encounter with a nucleus, varies by an order of magnitude depending on which is assumed.

Only the extremely-small classical radius gave the high probability of LENR. How do we rationalize use of this value? Our poster paper gives the details of why that is realistic.



## Choices

**Deuterons**

$E = E_k + V =$
$mv^2/2 \pm Ne^2/ r$
+ Pd & d lattice
constraints

1-Dim => $l = 0$
(phonons)

Resonance
(phonons)

Bound $e^-$ pairs
(lochons)

Four scenario in figure:

1. just the phonon induced motion – no screening effects total E < 1 eV
2. longitudinal optical-phonon mode forcing deuterons between Pd atoms (= 2-D & 1-D multilinear)
3. resonance between deuterium and Pd sub-lattices
4. phonon-induced electric field separates charges to form $D^+ D^-$ resonant pairs.

Note that without the charge separation, we stop at 0.01A = 1000 fm = 1 pm. But, this is still considered a good tunneling distance.

If the lochon (or at least one of the electrons) remains attached to a deuteron, the Coulomb field is attractive (or not repulsive). With the lochon assumption, the deuteron pair are approaching each other with several hundred eV at 1 pm – and are still accelerating.

What happens in the sub-picometer range is critical to the LENR model.