Goal: Predict transmutations

We hypothesize that we can make some electrons heavy by crystal momentum injection, and that the heavy electrons can catalyze nuclear reactions, similar to muon catalyzed fusion reactions.
Topics

Vibrationally promoted electron emission
Three-body particle model
Kinetic energy of confinement (KEC)
Coulomb potential
Threshold effective mass
Heavy electron production
Gamow tunneling through KEC barrier
Example -- Muon catalyzed fusion
Molecular Chemistry Three-Body Reaction

\[ \text{N} \quad \text{e}- \quad \text{O} \]

\[ \text{N} \rightarrow \text{e}- \leftarrow \text{O} \]

*molecular binding + coulomb potential*

\[ (((\text{N e- O}))) \quad \text{vibrationally excited molecule} \]

\[ \text{NO}(\nu) \quad \text{e-} \rightarrow \]

*“Vibrationally Promoted Electron Emission”* (LaRue, 2011)
Nuclear Three-Body Particle Model

\[ \text{Coulomb potential + nuclear binding} \]

“Reactant” R: Ni, Pd, Ti, Cs, Ba, W, ...

“Fuel” f: H, D, T, Li, ...

electron attracts f and R
Hamiltonian

\[ H = T_i + T_e + V_e + V_{\text{nuc}} \]

- \( T_i = \text{total ion energy} \)
- \( T_e = \text{electron energy = thermal + KEC} \)
- \( V_e = \text{Coulomb potential energy} \)
- \( V_{\text{nuc}} = \text{nuclear binding energy} \)
Squeezing $x$ increases momentum $p_x$
Robertson-Schrödinger equation

\[\sigma_p^2 \sigma_x^2 = (\hbar/2)^2 K(n)\]  
\[\sigma_p^2 = \langle p^2 \rangle - \langle p \rangle^2 \approx p^2\]  
Assume \(\sigma_x^2 \approx x^2\)

\[T_e = p^2/2m \approx (\hbar/2)^2 K(n) / 2mx^2\]

\(T_e\) is called “Kinetic Energy of Confinement (KEC)“, limits the attainable \(x\).
1-D particle model needs checking by 3-D wave function calculations.
Three-Body Coulomb Potential

\[ V_e = \frac{e^2}{4\pi\varepsilon_0} \left[ \frac{Qq}{x} - \frac{Q}{r} - \frac{q}{(x-r)} \right] \]

If \( q=1 \), then

\[ V_e = - \frac{e^2}{4\pi\varepsilon_0 x}(1 + 2Q^{1/2}) \quad \text{attractive} \]
Potentials vs. Separation Distance

(arbitrary units)
Inner Chemical Turning Point

\[ H = \mathcal{T}_i + T_e + V_e + V_{\text{nuc}} = 0 \]

\[
(\hbar/2)^2 \frac{K(n)}{2mx^2} - \left(\frac{e^2}{4\pi\varepsilon_0 x}\right)(1 + 2Q^{1/2}) = 0
\]

\[ x = 4\pi\varepsilon_0 \frac{\hbar^2}{8me^2(1 + 2Q^{1/2})} \]

If \( Q=1 \) and \( m=m_0 \), then \( x \approx 2.2 \text{ pm} \).
Threshold effective mass

\[ H = T_e + T_i + V_e + V_{\text{nuc}} \leq 0 \quad \text{at } x=a \]

\[ \left(\frac{\hbar}{2}\right)^2 \frac{K(n)}{2ma^2} - \left(\frac{e^2}{4\pi \varepsilon_0 a}\right)(1 + 2Q^{1/2}) - V_{\text{nuc}} \leq 0 \]

Solve for \( m \).

Typically \( m \geq 10 - 30 \ m_o \)
Threshold effective mass

\[ H = T_e + T_i + V_e + V_{\text{nucl}} \leq 0 \]

at \( x = a \) (nuclear force radius)

Virtual resonance state

Normal electron, \( m = m_o \)

\( V_{\text{nucl}} \)

KEC

\( m \) above threshold

Chemical initial state at \( x = b \)

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Dolan & Zuppero, MIT Colloquium
Tunneling through KEC barrier

tunneling b to a → virtual resonance state inside nucleus
binding energy → ejected electron $T_e$ and compound nucleus $T_i$

How can we make electrons heavy?
Band Structure Diagram

Lattice gives electrons high inertia

Effective electron mass \( m = \frac{\hbar^2}{(\partial^2 E / \partial k^2)} \)

Band structure of PdH

Inflection points
Heavy electrons have been known for many years

1962 data

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<th>Metal</th>
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Momentum Stimulation Methods

gas adsorption/desorption
electrolysis
x-ray and gamma ray impact
particle impact (p, d, α, ...)
glow discharge bombardment
laser beams
THz waves
phonons
heating
shock waves

10 nm crystal phonon lifetime ~ 3 ps
Heavy electron lifetime ~ 10 fs
Tunneling probability $P$ through KEC barrier

$$P = \exp(-2G)$$

Gamow integral

$$G = (2m)^{1/2} \int_{a}^{b} [E(x) - E_o]^{1/2} dx / \hbar$$

$$[E(x) - E_o] = [T_e + V_e + T_i - E_o] \approx [T_e + V_e]$$

In most of the interval $(a,b)$ $T_e \gg V_e$

$$G \approx (2m)^{1/2} \int_{a}^{b} dx \left[ \hbar^2 \frac{K(n)}{8mx^2} \right]^{1/2} / \hbar \quad \text{overestimates } G$$

$$G \approx \left( K(n)^{1/2}/2 \right) \ln(b/a) \quad K(n) \approx 1$$

$$P = \exp(-2G) \approx \exp[-\ln(b/a)] \approx a/b$$
Model applied to muon catalyzed fusion

\[ p + d \rightarrow ^3\text{He} \quad \text{(Alvarez 1956)} \]

\[ Q = q = 1, \quad a = 3.16 \text{ fm} \quad b \approx 160 \text{ fm} \]

Estimated threshold mass \( m \approx 138 \text{ m}_o \)

Actual muon mass \( m_\mu \approx 207 \text{ m}_o \) adequate

Estimated tunneling probability \( P \approx 0.02 \)

Values depend on assumptions about \( b \) and \( \sigma_x^2 \), but this example illustrates use of the model.
Research Needs

• Include relativistic effects
• Check these estimates by solving the Schrödinger equation
• Use density functional theory to study the model
• Calculate the distribution of heavy electrons near inflection points
• Calculate the reaction rates and compare them with data
• Design experiments to test the model
Summary

Molecular chemistry analogue - VPEE

Electron pulls ions closer

KEC limits approach

Momentum injection moves electrons near inflection points

Heavy electrons reduce KEC $\rightarrow$ closer approach

Tunneling through KEC barrier $\rightarrow$ binding, electron ejection

Example: muon catalyzed fusion

Next: Anthony Zuppero will discuss more example cases.
Electron Stimulation

Inject crystal momentum and energy