Heavy Electron Catalysis of Nuclear Reactions

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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

N e- O

N → e- ← O

molecular binding + coulomb potential

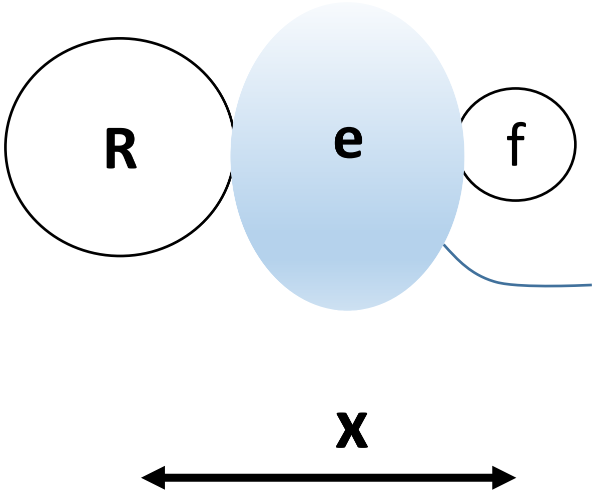
(((N e- O))) *vibrationally excited molecule*

NO(ν) e- →

"Vibrationally Promoted Electron Emission" *(LaRue, 2011)*

Nuclear Three-Body Particle Model

Coulomb potential + nuclear binding



"Reactant" R:
Ni, Pd, Ti,
Cs, Ba, W, …

"Fuel" f: H, D, T, Li …

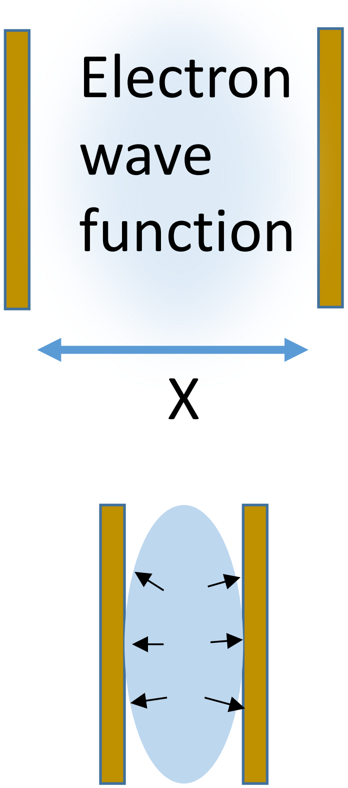
electron attracts
f and R

Hamiltonian

$H = T_i + T_e + V_e + V_{nuc}$

T_i = total ion energy
T_e = electron energy = thermal + KEC
V_e = Coulomb potential energy
V_{nuc} = nuclear binding energy

Squeezing x increases momentum p_x



Robertson-Schrődinger equation

$\sigma_p^2 \, \sigma_x^2 = (\hbar/2)^2 \, K(n)$ ground state $K(n) \approx 1$

$\sigma_p^2 = \langle p^2 \rangle - \cancel{\langle p \rangle}^2 \approx p^2$

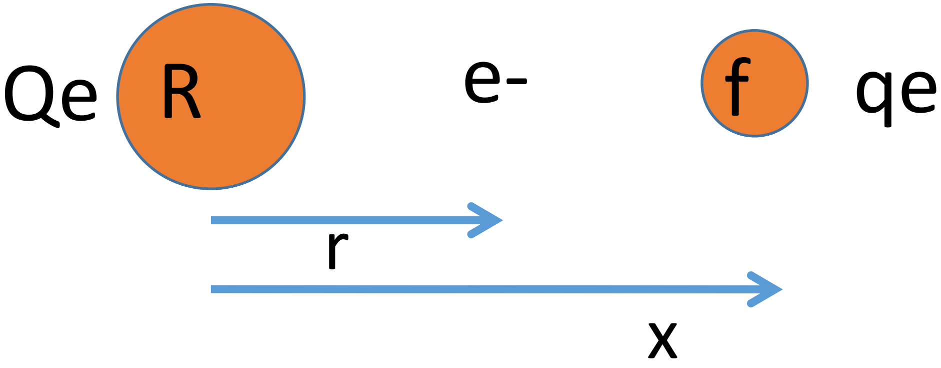
Assume $\sigma_x^2 \approx x^2$

$T_e = p^2/2m \approx (\hbar/2)^2 \, K(n) \, / \, 2mx^2$

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



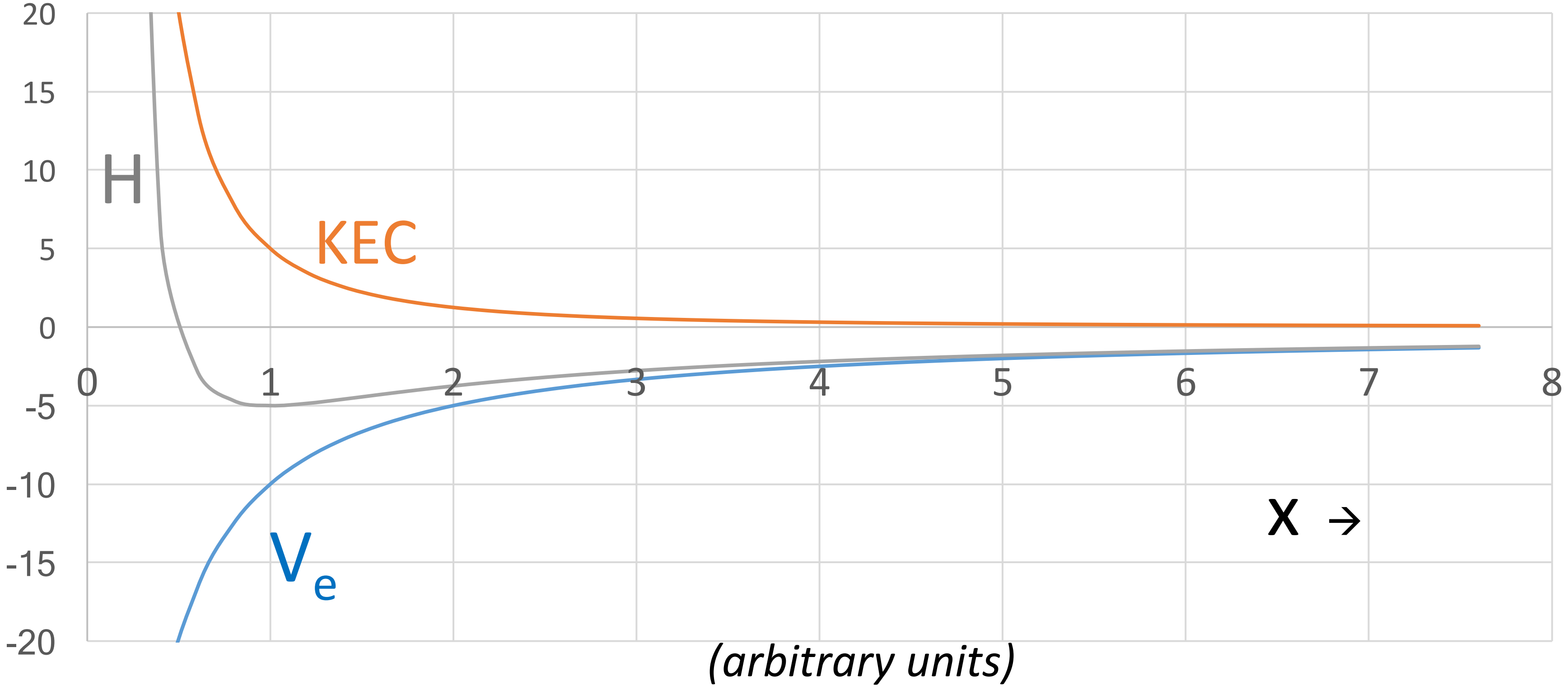
R-f repulsion *e-R attraction* *e-f attraction*

$$V_e = (e^2/4\pi\varepsilon_o)\,[\,Qq/x \quad - Q/r \quad - q/(x-r)\,]$$

If q=1, then

$$V_e = -\,(e^2/4\pi\varepsilon_o x)(1 + 2Q^{1/2}) \quad \text{attractive}$$

Potentials vs. Separation Distance



Inner Chemical Turning Point

$$H = \cancel{T_i} + T_e + V_e + \cancel{V_{nuc}} = 0$$

$$(\hbar/2)^2 K(n) / 2mx^2 - (e^2/4\pi\varepsilon_o x)(1 + 2Q^{1/2}) = 0$$

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

If $Q=1$ and $m=m_o$, then $x \approx 2.2$ pm

Threshold effective mass

$H = T_e + \cancel{T_i} + V_e + V_{nuc} \leq 0$ at x=a

$(\hbar/2)^2 K(n) / 2ma^2 - (e^2/4\pi\varepsilon_o a)(1 + 2Q^{1/2}) - V_{nuc} \leq 0$

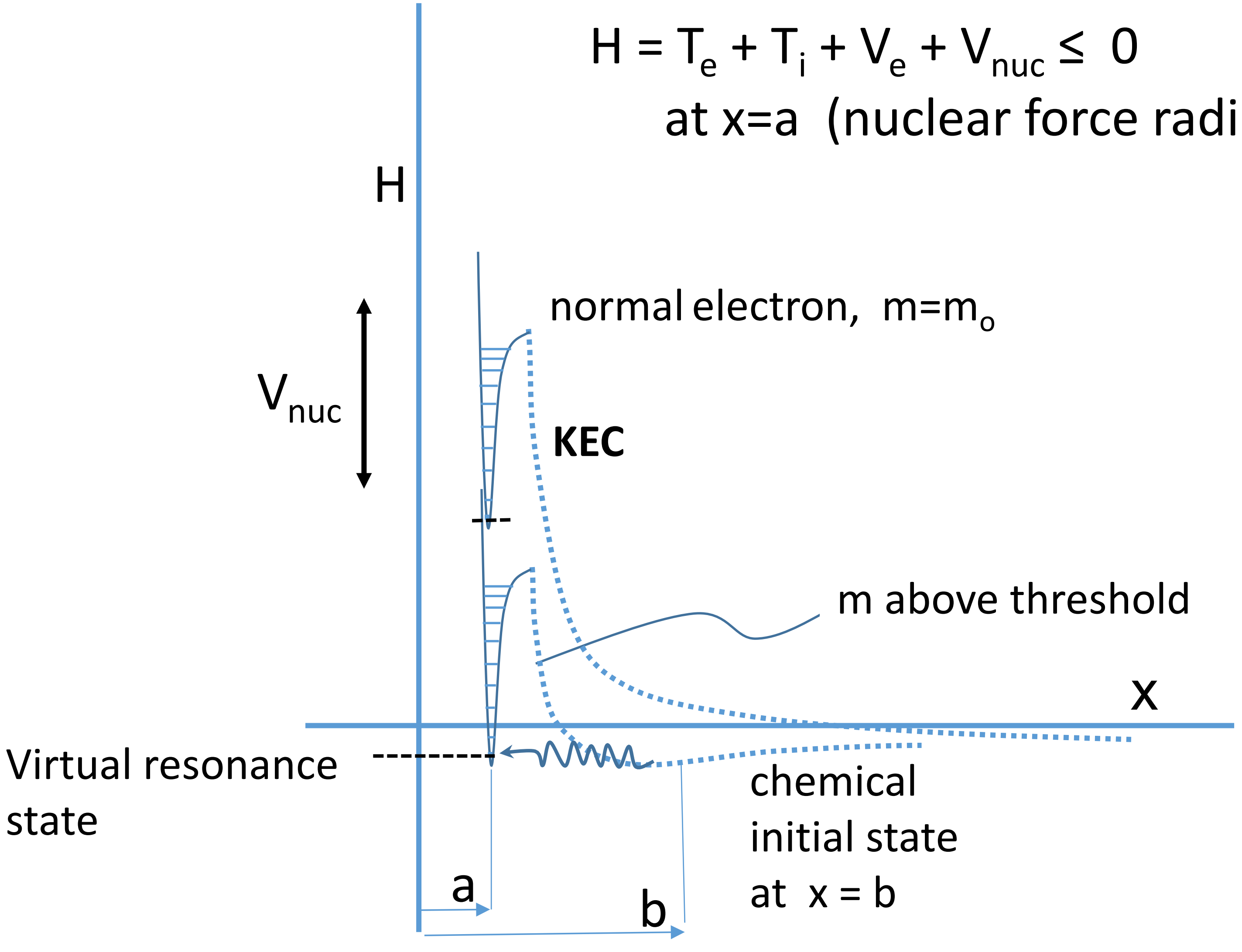
Solve for m.

Typically $m \geq 10 - 30\ m_o$

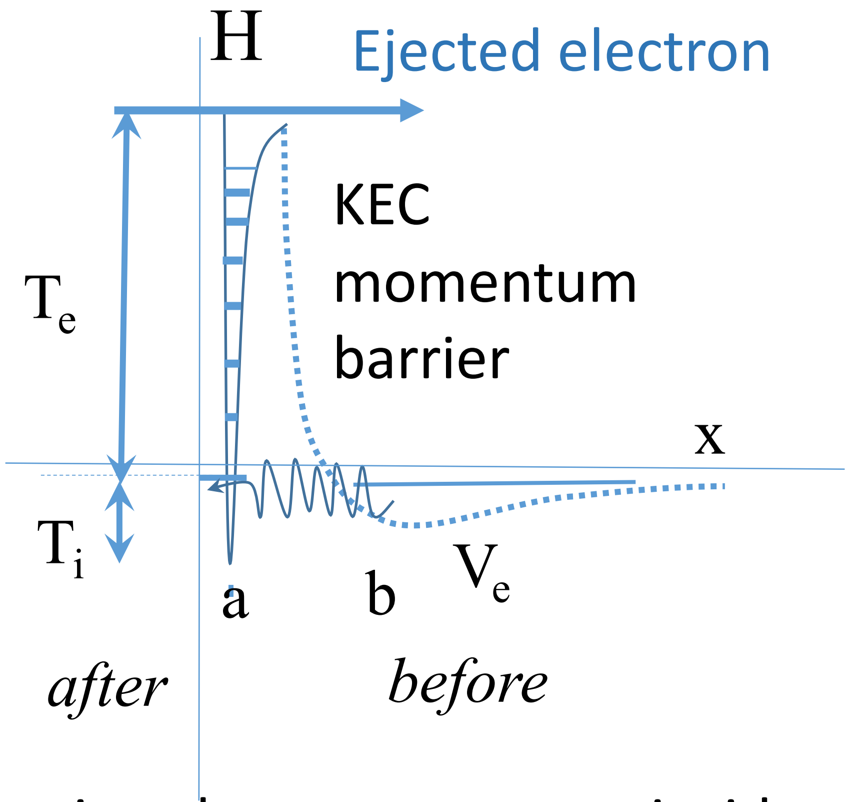
Threshold effective mass

$H = T_e + T_i + V_e + V_{nuc} \leq 0$

at x=a (nuclear force radius)



Tunneling through KEC barrier



tunneling b to a → virtual resonance state inside nucleus

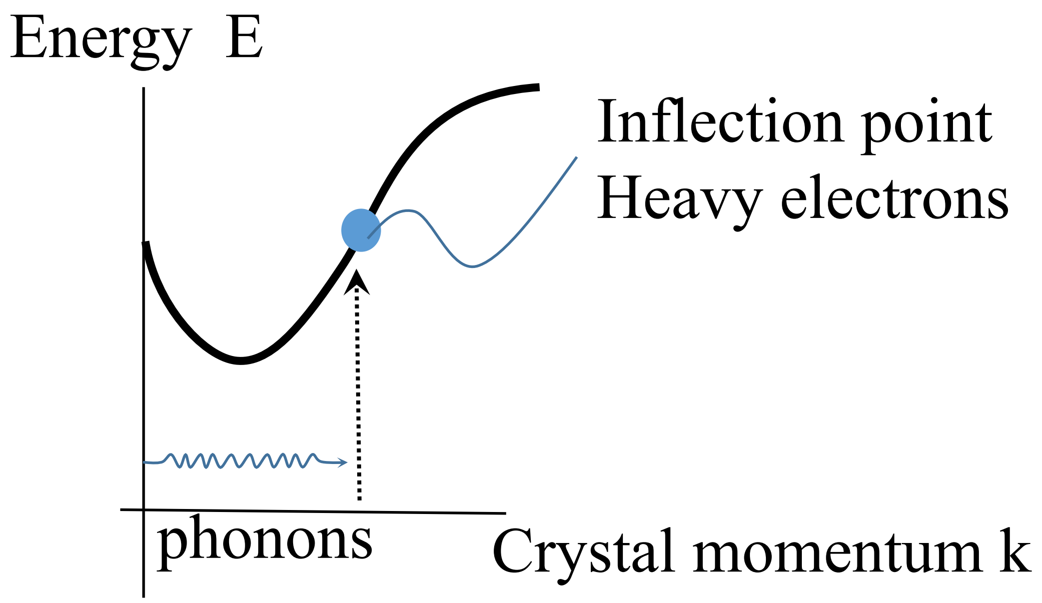
binding energy → ejected electron T_e and compound nucleus T_i

How can we make electrons heavy?

Band Structure Diagram

Lattice gives electrons high inertia

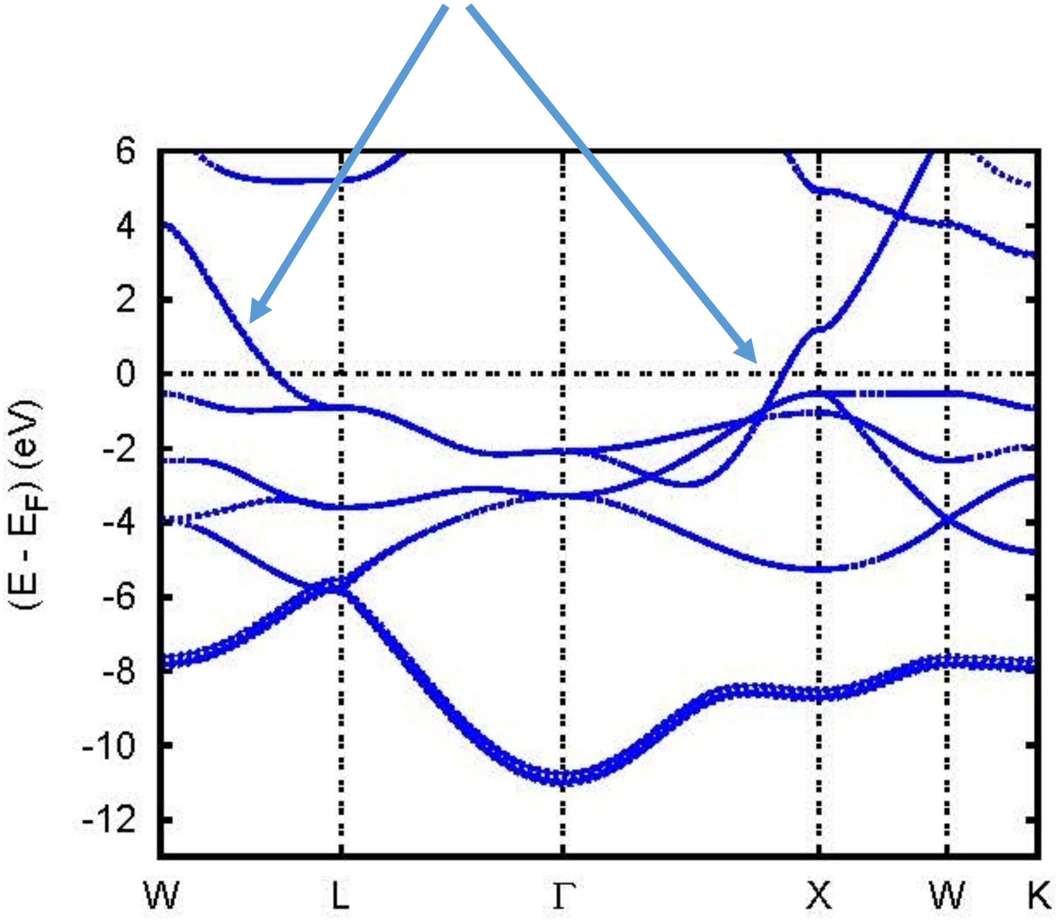
Effective electron mass $m = \hbar^2 / (\partial^2 E/\partial k^2)$



Charles Kittel, Introduction to solid state physics, 8th Edition, Wiley, 2005, p.198

Band structure of PdH

Inflection points



Heavy electrons have been known for many years

1962 data

Metal	m/m_o
Cu	1.5
Al	1.6
La	4.3
a-Fe	12
Pt	13
Co	14
Pd	27
Ni	28

Charles Kittel, Introduction to solid state physics, Second Edition, Wiley, 1962, p 259.

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

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

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

$G \approx (2m)^{1/2} \int_a^b dx \, [\hbar^2 K(n)/8mx^2)]^{1/2} / \hbar$ overestimates G

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

$P = \exp(-2G) \approx \exp[-\ln(b/a)] \approx a/b$

Model applied to muon catalyzed fusion

$p + d \rightarrow {}^3He$ (Alvarez 1956)

$Q = q = 1$, $a = 3.16$ fm $b \approx 160$ fm

Estimated threshold mass $m \approx 138\ m_o$

Actual muon mass $m_\mu \approx 207 m_o$ adequate

Estimated tunneling probability $P \approx 0.02$

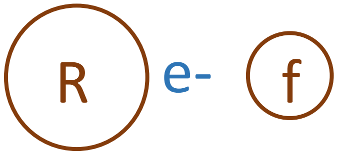
Values depend on assumptions about b and σ_x^2,

but this example illustrates use of the model.

Research Needs

- Include relativistic effects
- Check these estimates by solving the Schrődinger 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 → closer approach

Tunneling through KEC barrier → binding, electron ejection

Example: muon catalyzed fusion

Next: Anthony Zuppero will discuss more example cases.

Electron Stimulation

Inject crystal momentum and energy