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Framework for Understanding LENR Processes, Using Conventional Condensed Matter Physics

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Outline

I Background:

- Broken Gauge Symmetry and Long-Range Interactions in Conventional Condensed Matter
- Many-Body Collisions in Conventional Condensed Matter at Low and Finite T

II Many-Body Collision Theory that Includes Localized/Delocalized Nuclear Reactions

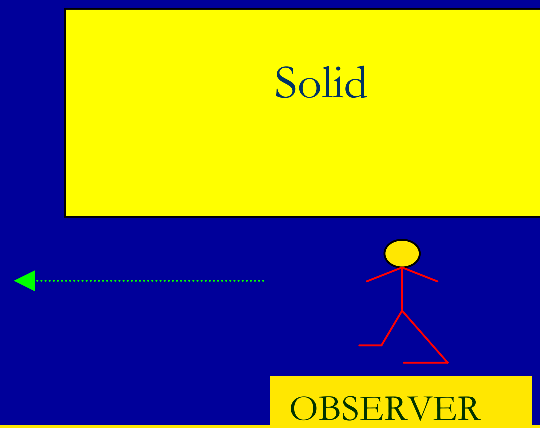
III LENR's Through Broken Gauge Symmetry Model, and Relationship to Other LENR Theories

IV A Plausible Triggering Mechanism: Zener-ionic Breakdown

V Concluding Remarks

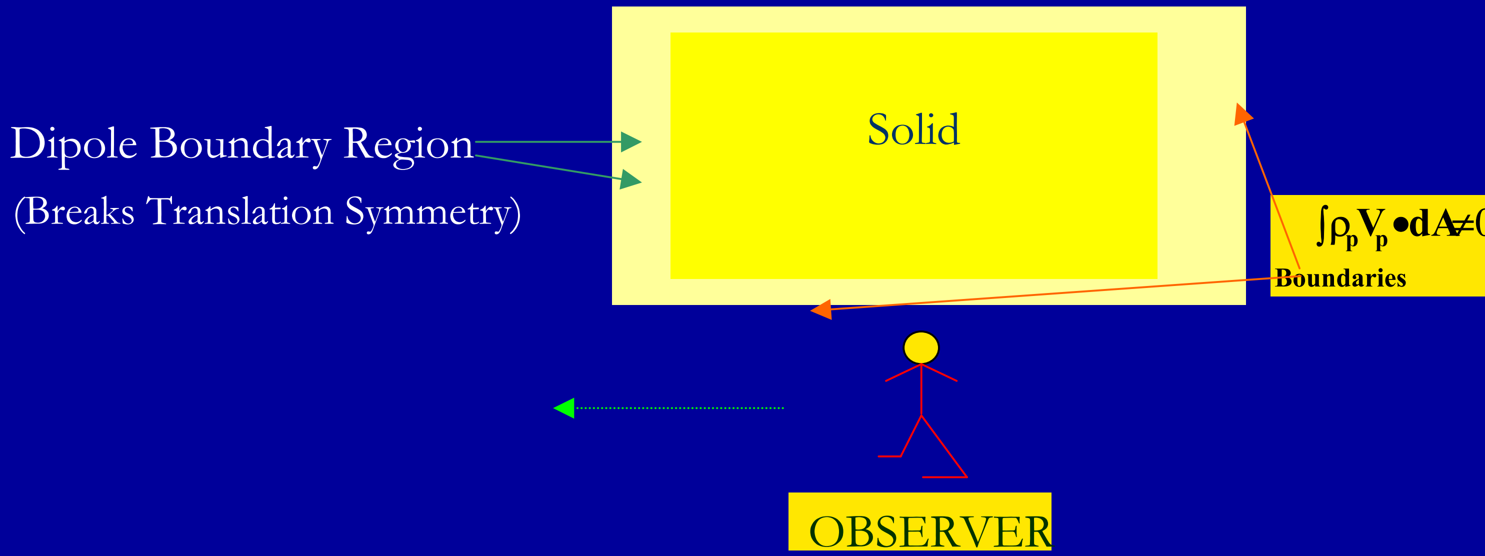
Background: Coherent Solid State Wave Properties Result from a Symmetry

A Neutral Solid *<u>"Does not Know"</u>* if it is in Motion or at Rest



- At Rest, Center-of-Mass (CM) Wave Function $\Psi = 1$
- If in Motion, $\psi(\mathbf{R}_{cm}) \equiv e^{i\frac{\mathbf{P}_{total} \bullet \mathbf{R}_{cm}}{\hbar}} = \prod_{j} e^{i\frac{\mathbf{P}j \bullet \mathbf{r}_j}{\hbar}}$ ← Momentum Shared Instantly Everywhere
- Q. M. doesn't say if solid or observer is in Motion → Form of Galilean Relativity
- P = MV can be varied continuously → Coupling to Many Processes
- This is Basis of Semi-Conductors, Transistors, and Computers
- Idea, which is Foreign to Nuclear Physicists, involves details about E.M.: mv=p-e/cA
- To be Stable: Ground State Must Have Smallest Overlap With Outside Processes
- Energy Reduced by Loss of Symmetry (Broken Gauge Symmetry)

Background: Relative Motion of "Bulk" (Neutral Solid) Fixed by Surface (Dipole) Collisions and Heating



- **Dipole Layer Causes Collisions: Particles Acquire Charge**
- **Particles Acquire Finite Lifetime τ Outside Neutral Solid (in Dipole Regions):**

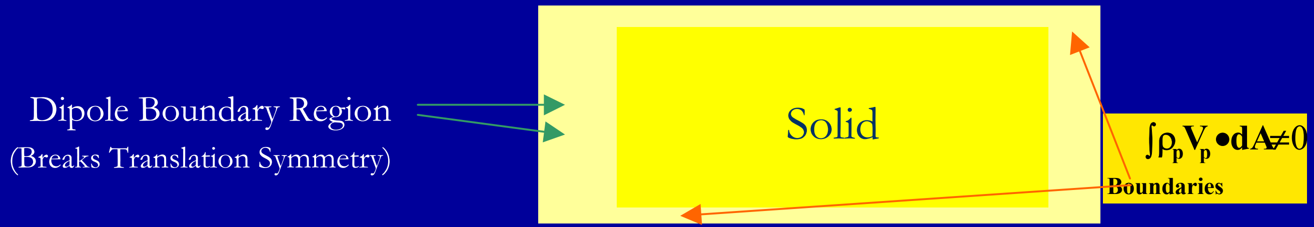
$$\frac{1}{Lifetime} \equiv \frac{1}{\tau} \equiv \int d^{3n}r \lim_{t\to\infty} \frac{\partial \left|\Psi_E^{\,+}(t) - (\Psi_E^{\,+}(-t))^*\right|^2}{\partial t} = \frac{2\pi}{\hbar}\left\langle \Psi_E^o \middle| V\delta(E-H)V \middle| \Psi_E^o \right\rangle \neq 0$$

Ψ_E^o = **Wave Function Without Dipole Boundary Region**

V = **Change in Potential From Dipole Boundary Region**

H = **Total Hamiltonian Including Dipole Boundary Region**

Background: Collisions and Heating at Finite Temperature T



- **Dipole Layer Initiates Collisions ⟹ Bulk/Surface Coupling: Phonons**
- **Can Treat Heating Using Complex Potential $V_{eff}^{\pm}$ (R-Matrix Theory):**

$$\mathrm{Real}(E - H_o - V_{eff}^{\pm})\Psi_{Bulk}^{E} = 0, \qquad \frac{1}{\tau} = \frac{1}{\hbar} * \left\langle \Psi_{Bulk}^{E} \middle| i(V_{eff}^{+} - V_{eff}^{-}) \middle| \Psi_{Bulk}^{E} \right\rangle$$

$$V_{eff}^{\pm} = V + V \frac{1}{(E - H_{exact} \pm i\varepsilon)} V$$

- **Problem is Formidable**
  - $V \equiv V(\Psi_{exact})$ ⟹ **Requires Models for** V **and** Ψ_{exact}
  - **Treats Problem Locally: Boundary Conditions Implicit**
- **Alternative Treatment (Generalized Multiple Scattering Theory)**
  - **Treats Problem Non-Locally, With Explicit Boundary Conditions**
  - **Provides Solution, Directly (V not needed), in Different Regions of Space**
  - **Applies Rigorously at T=0, Reaction Rate Defines Hierarchy of Processes**
  - **Includes Coherence (from Galilean Invariance of Bulk States) at T=0**

Background: How Collisions Become Non-Local in Generalized Multiple Scattering Theory

- **Lifetime τ in "Forbidden" Regions Useful for Identifying "Individual Collisions":**

$$\frac{1}{\tau}=\frac{2\pi}{\hbar}\left\langle \Psi_E^o \middle| V\delta(E-H)V \middle| \Psi_E^o \right\rangle \equiv \frac{2\pi}{\hbar}\sum_f \left|\left\langle \Psi_E^o \middle| V \middle| \Psi_E^f \right\rangle\right|^2 = \frac{2\pi}{\hbar}\sum_f \left|\left\langle \Psi_E^o \middle| \vec{T}-\overleftarrow{T} \middle| \Psi_E^f \right\rangle\right|^2$$

$V = V_o - V_f$
$V_o =$ **Potential: No Collisions**
$V_f =$ **Potential: With Collisions**
$\Psi_E^o =$ **Wave Function: No Collisions**
$\Psi_E^f =$ **Wave Function: with Collisions**

- **V Re-Expressed in terms of "Directed" Kinetic Energy Operators** $\vec{T}$ **(** $\equiv \Psi_E^{o*}\vec{T}\Psi_E^f = \sum_i -\frac{\hbar^2}{2m}\Psi_E^{o*}\left((\nabla_i - \frac{ie}{c}A_f(r_i))^2\Psi_E^f\right)$, $\mathbf{A_f}$ **= "Vector Potential A with Collisions") and** $\overleftarrow{T}$ **(** $\equiv \Psi_E^{o*}\overleftarrow{T}\Psi_E^f = \sum_i -\frac{\hbar^2}{2m}\left((\nabla_i + \frac{ie}{c}A_o(r_i))^2\Psi_E^{o*}\right)\Psi_E^f$, $\mathbf{A_o}$ **= "Vector Potential A without Collisions"):**

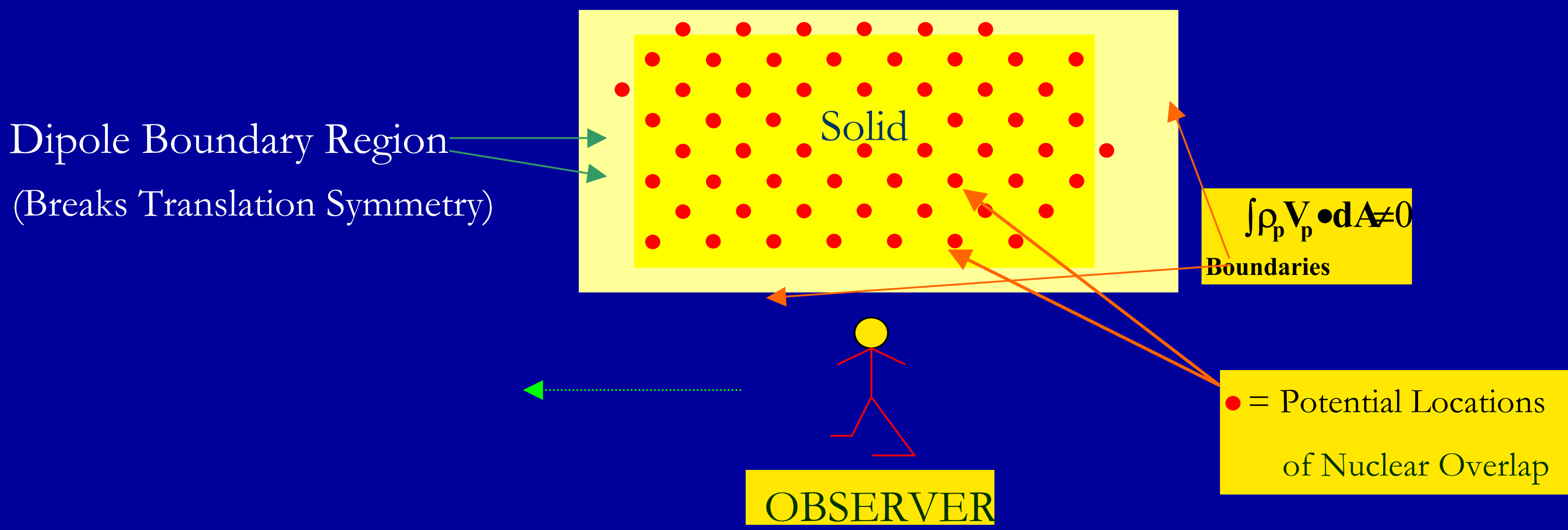
$$\frac{\partial\left\langle \Psi_E^o(t) \middle| \Psi_E^f(t)\right\rangle}{\partial t} = \frac{1}{i\hbar}\int d^{3n}r\left(\Psi_E^{o*}(\vec{T}-\overleftarrow{T}+V_f-V_o)\Psi_E^f\right)=0 \Longrightarrow \int d^{3n}r\left(\Psi_E^{o*}(\vec{T}-\overleftarrow{T})\Psi_E^f\right)=-\int d^{3n}r\left(\Psi_E^{o*}(V_f-V_o)\Psi_E^f\right)$$

- **Lifetime τ: Defined by current *J(r$_i$)*, Change in A** $(\equiv \Delta\mathbf{A} = \mathbf{A_f} - \mathbf{A_o})$, **Average A (** $\equiv \frac{1}{2}(\mathbf{A_f}+\mathbf{A_o})$**) and changes in Momentum (Cusps, Accompanied by Changes in A) at Locations of Collisions**

$$\left\langle \Psi_E^o \middle| \vec{T}-\overleftarrow{T} \middle| \Psi_E^f \right\rangle = -\int d^{3n}r\,\Psi_E^{o*}\left(\sum_i \frac{q_i}{c}\Delta A(r_i)\bullet J(r_i)\right)\Psi_E^f$$

$$-i\hbar\left(\sum_{\text{i= Collision Locations}} \int \Psi_E^{o*} d^2r_i \bullet \frac{1}{m_i}\left(P(r_i)-\frac{q_i A_{ave}(r_i)}{c}\right)\Psi_E^f\right)$$

Generalization: Collisions and Heating With Nuclear Reactions

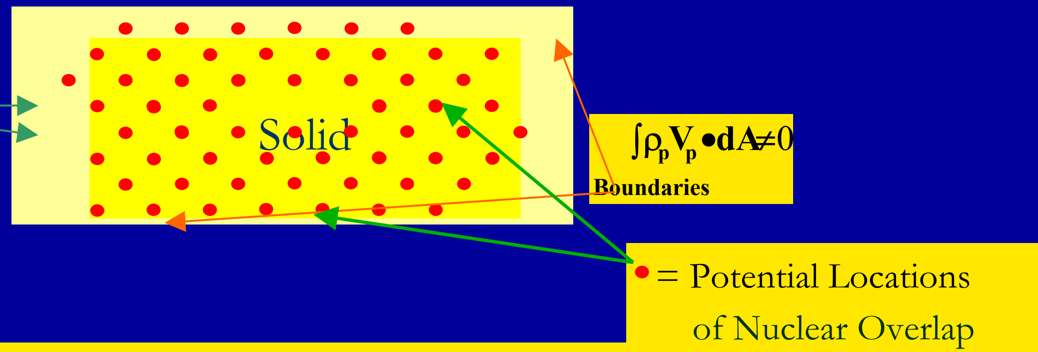


- Collisions Alter Charge : Can Include Locations Where Nuclear Overlap Occurs
- Particles Acquire Finite Lifetime τ Outside Solid (Including Dipole and Nuclear Regions):

$$\frac{1}{Lifetime} \equiv \frac{1}{\tau} \equiv \frac{2\pi}{\hbar} \left\langle \Psi_E^o \middle| V\delta(E-H)V \middle| \Psi_E^o \right\rangle = \frac{2\pi}{\hbar} \sum_f \left| \left\langle \Psi_E^o \middle| \vec{T} - \overleftarrow{T} \middle| \Psi_E^f \right\rangle \right|^2 \neq 0$$

Rigorous (Non-Local) Temperature T=0 Limit Associated with Galilean Invariance of Bulk

Dipole Boundary Region
(Breaks Translation Symmetry)



$$\frac{1}{\tau} = \frac{2\pi}{\hbar} \sum_f \left| \left\langle \Psi_E^o \middle| \vec{T} - \overleftarrow{T} \middle| \Psi_E^f \right\rangle \right|^2$$

- **Bulk Can't Tell if it is in Motion or at Rest:**
  - **In Ground State Bulk Region,** $\Delta A(r_i) = 0$; $A_o(r_i) = A_f(r_j) =$ **Constant.**

$$\Rightarrow \left\langle \Psi_E^o \middle| \vec{T} - \overleftarrow{T} \middle| \Psi_E^f \right\rangle \Big|_{Bulk} = -i\hbar \left(\sum_{\text{i= Collision Locations}} \int \Psi_E^{o^*} d^2 r_i \bullet \frac{1}{m_i} \left(P(r_i) - \frac{q_i A_o}{c}\right) \Psi_E^f \right)$$

*** Bulk Contribution Entirely From "Collisions" (Cusp Locations, of Nuclei)**

- **Ground State has Minimal Overlap With Excited States**
  - **In Bulk Region,** $\int d^{3n} r \left(\Psi_E^{o^*} (\vec{T} - \overleftarrow{T}) \Psi_E^f \right) = -\int d^{3n} r \left(\Psi_E^{o^*} (V_f - V_o) \Psi_E^f \right)$ **is Minimized**

$\Rightarrow$ **Bulk Region Ground State "Moves" Rigidly, Relative to Dipole Region**

*** Bulk Contribution Balanced by Collisions and Changes in A in Dipole Region**

*** Lowest Lying Excitations Occur Through UmKlapp Processes in which**

$$\oint_{\substack{Dipole\\Boundary}} d\vec{l} \bullet \Delta A(r_i) = \oint_{\substack{Dipole\\Boundary}} d\vec{l} \bullet \frac{c\hbar G}{q_i}, \quad \vec{G} = \text{ Reciprocal Lattice Vector of Bulk Lattice}$$

Relationship to Other Theories

- **Dipole/Nuclear Heating Picture is Low Temperature T Resonant Process**
- **At Higher T, Other Finite Lifetime τ Processes Apply:**

$$\frac{1}{Lifetime} \equiv \frac{1}{\tau} \equiv \int d^{3n}r \lim_{t\to\infty} \frac{\partial \left| \Psi_E{}^{+}(t) - (\Psi_E{}^{+}(-t))^{*} \right|^2}{\partial t} = \frac{2\pi}{\hbar} \left\langle \Psi_E^o \middle| V\delta(E-H)V \middle| \Psi_E^o \right\rangle \neq 0$$

$\Psi_E^o =$ **Initial Wave Function(s) (Boltzmann Averaging May Apply)**

$V =$ **Change in Potential From All Processes**

$H =$ **Total Hamiltonian Including All Processes**

- **Schwinger (1989): V from Coherent Phonons**
- **Hagelstein (~2000): V from Coherent Phonons/Multi-Nucleon (SU(N) Coupling)**
- **Kim ~(2000): V from Coherent Bose Einstein Condensate in Trap**
- **Li (~2000): V from Empirical Coherent Process (in d+d→^{4}He, using d+t→^{4}He + n)**

Triggering: Zener-Ionic Breakdown in Nano-Scale PdD

Variant of "Zener- Electronic Breakdown"

Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, Vol. 145, No. 855 (Jul. 2, 1934), 523-529.

523

A Theory of the Electrical Breakdown of Solid Dielectrics.

CLARENCE ZENER, H. H. Wills Physics Laboratory, Bristol.

(Communicated by R. H. Fowler, F.R.S.—Received December 27, 1933, Revised March 1, 1934.)

- Highly Polarized Nanoscale (60nm) Crystal, Long-Range Fluctuation ($PdD_{1+/-\delta}$; $\delta \sim 0.0003$)
- Induced Fermi Energy Electron Electric Field $\Delta\vec{E} \sim \text{Volt/cm} = 10^{-8}\,\text{Volt}/A$
- "Flat" Dispersionless Ion Band States (like an Insulator) $\int_{non-bulk} d^3x \left\langle \Psi \middle| J(x) \middle| \Psi_{GS} \right\rangle \leq\sim \frac{0.01\,eV}{|\Delta\vec{E}|\,t}$
- All d's in Ion Band State Degenerate; Induced $\Delta\vec{E}$ Forces Momentum P of all Deuterons to Change Coherently: $\Delta P(t) = e\Delta\vec{E}t$
- When $\Delta P(t) = \frac{2\pi\hbar n}{a}$, Resonant Tunnelling (Bloch Oscillation) Takes Place
- Explains Incubation ("Triggering") Time: 60nm size takes 0.03ms; 6μm-5 minutes; 60μm - 80 h

VI Concluding Remarks

• The Ion Band State Theory is limiting case, of a more general many-body problem associated with Broken Gauge Symmetry, in which momentum is transferred instantly to many locations, at once. Most coherent process occurs at ionic insulator- ionic conductor transition.

• Implicit in this limit are important coherent effects, involving Energy Band states, Phonons and other quasi-particles, that form the basis of the Ion Band State theory.

• Five important points that haven't been emphasized previously are:

1. The special role of electronic structure in the Ion Band State picture;
2. The relationship of Ion Band States to H and/or D Phonons.
3. The relationship between LENR's, initiated from Ion Band States, and "Lattice Recoil;"
4. At T=0, only a relatively small (nano-scale) crystal is required for nuclear reactions to be initiated by Ion Band States, and
5. At finite T, in finite size crystals, different Ion Band States become coupled to each other and to resonant processes in which energy, momentum, and charge are transferred from ordered regions to disordered regions.

• Reactions in the Ion Band State theory (and its many-body, Broken Gauge Symmetry generalization), and in the theories by Schwinger, Hagelstein, Kim, and Li, are explained by Coherent Processes, in which heat, from energy, momentum, and charge, associated with nuclear processes, is produced slowly, in "Forbidden Regions" through "Selective" forms of Resonant Interactions, involving many particles, throughout the solid.