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Commercializing a Next-Generation Source of Safe Nuclear Energy

Low Energy Nuclear Reactions (LENRs)

**Weak Interactions and Collective Effects Explain LENRs
in Condensed Matter Systems**

High-Level Historical and Technical Overview



*"Energy, broadly defined, has
become the most important
geostrategic and geoeconomic
challenge of our time."*

*Thomas Friedman
New York Times, April 28, 2006*



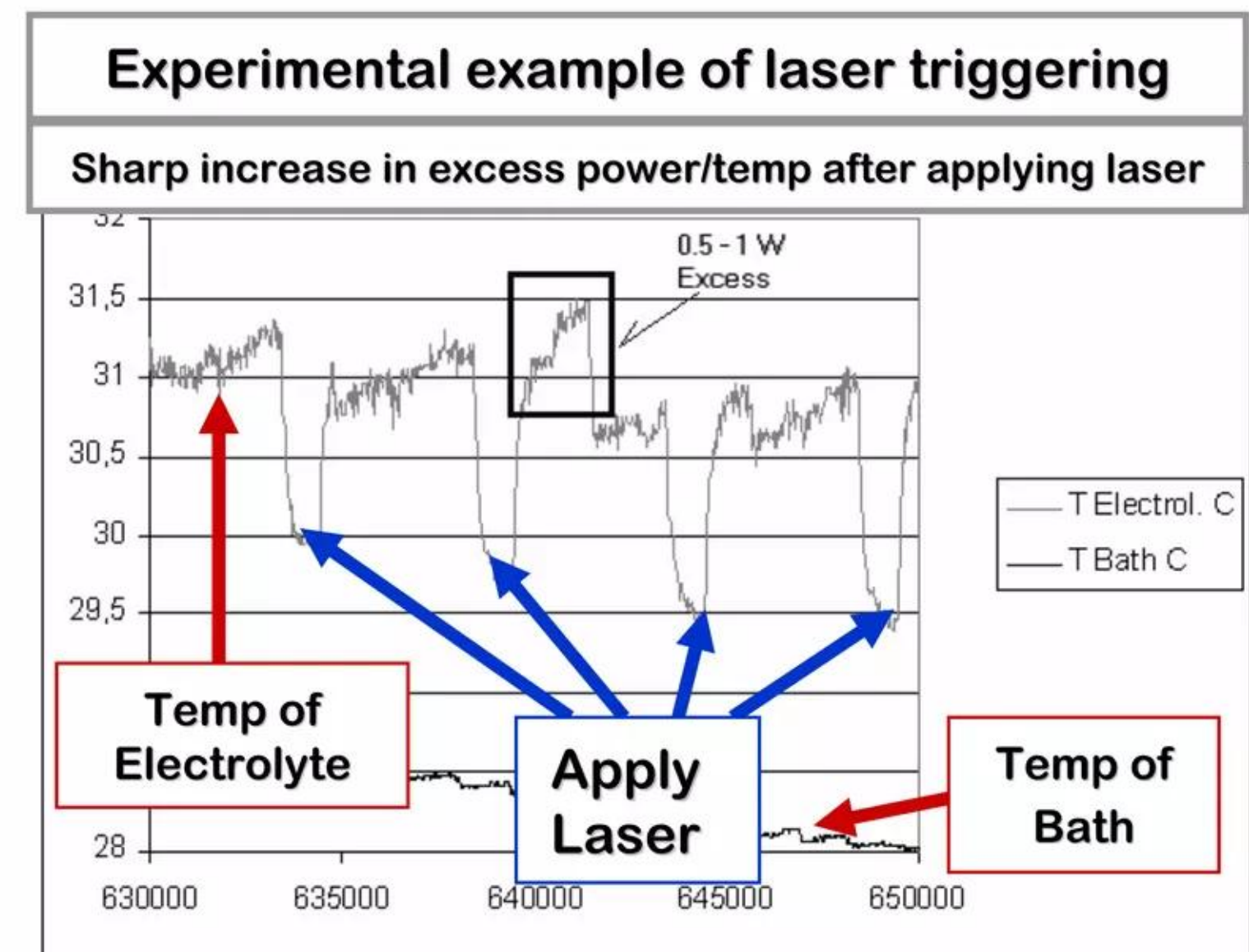
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LENR researchers have observed experimental anomalies

Since 1989, certain researchers in LENRs have documented genuine anomalies that occur in various types of heavy and light hydrogen (e.g., D₂O and H₂O) experimental systems, all involving 'heavily-loaded' metallic hydrides:

- ✓ Electrical current-, laser-, RF-, and pressure-driven triggering of different types of nuclear effects
- ✓ Calorimetrically measured excess heat effects – wide range of values from just milliwatts to tens of Watts in some cases
- ✓ Production of helium isotopes; rarely detect tritium (unstable H isotope)
- ✓ Production of a broad array of different stable isotopic transmutation products (i.e., different elements)
- ✓ Production of modest fluxes of MeV-energy alpha particles and protons as well as some minuscule fluxes of low energy X- and gamma ray photons (no fluxes of 'hard' MeV energy gammas)

In 1831, Michael Faraday was pilloried as a charlatan by fellow scientists when he claimed that he could generate an electric current simply by moving a magnet in a coil of wire. Stung by those vicious accusations, Faraday said, "Nothing is too wonderful to be true if it be consistent with the laws of nature."



Source: Violante et al (ENEA – Italy), Asti Conference, 2004

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March 23, 1989: P&F announce discovery of “cold fusion”

- On March 23, 1989, Pons and Fleischmann, using a Pt anode and Pd cathode with D₂O (heavy hydrogen) in a current-driven electrolytic cell, naively suggested that a D-D “cold fusion” process caused their reported anomalous excess heat results
- Some critics argued that ‘light’ water control experiments should be performed; if no excess heat were detected, it would help bolster the case for P&F’s D-D fusion hypothesis
- Unfortunately, a number of other researchers, including Pons himself, detected excess heat in subsequent light water (H₂O) electrolytic cells, casting doubt on P&F’s D-D fusion idea

P&F’s LENR D-D fusion paradigm quickly encountered problems because excess heat was also detected in light water experiments

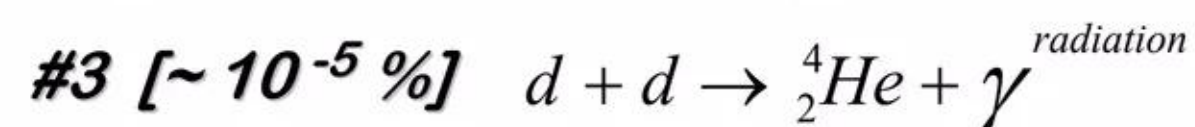
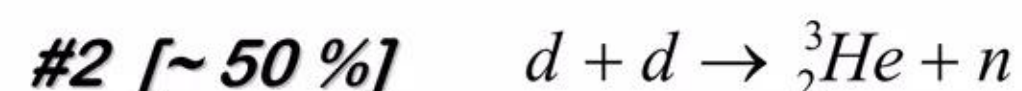
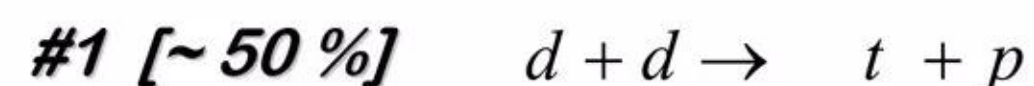
“At the April 17, 1989, news conference, Pons addressed an issue which has caused disquiet ... the lack of a direct comparison between an electrolytic cell containing heavy water and one containing ordinary water. Pons tantalized his audience by indicating that results from just such a comparison suggested an ‘unexpected’ production of heat in the ordinary cell.” Nature 338 April 27, 1989, pp. 691, “Hopes for nuclear fusion continue to turn cool”

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P&F observe ^4He , but no other 'normal' D-D fusion products

- P&F's claimed helium-4 observations questioned by other scientists
- From 1989 through early 2000s, other LENR researchers (esp. McKubre at SRI and Miles at USN-China Lake) continue to improve and correlate Pd-D loading, ^4He and heat measurements; yet they still cannot demonstrate large fluxes of tritium, protons, ^3He , neutrons, or γ -radiation that would be commensurate with measured excess heat according to well-accepted knowledge about branching ratios of D-D fusion reaction
- "Cold fusion" theorists (e.g., Hagelstein, Chubbs) develop theories of LENRs invoking 'new physics' to explain the discrepancy with D-D branching ratios
- As of 2009, still no believable evidence that D-D fusion branching ratios change substantially at low energies

Well accepted 'normal' D-D fusion reactions produce products in three branches with ~ 1:1 ratio between 1-2:



At the April 17, 1989, news conference, "Pons announced a new piece of supporting evidence: mass spectroscopy of the gases evolving from a working fusion cell revealed the presence of ^4He in quantities consistent with the reported energy production, if all deuteron-deuteron fusions produce ^4He rather than tritium [t] and a proton [p] or ^3He and a [energetic] neutron [n]." Nature 338 April 27, 1989, pp. 691, "Hopes for nuclear fusion continue to turn cool"

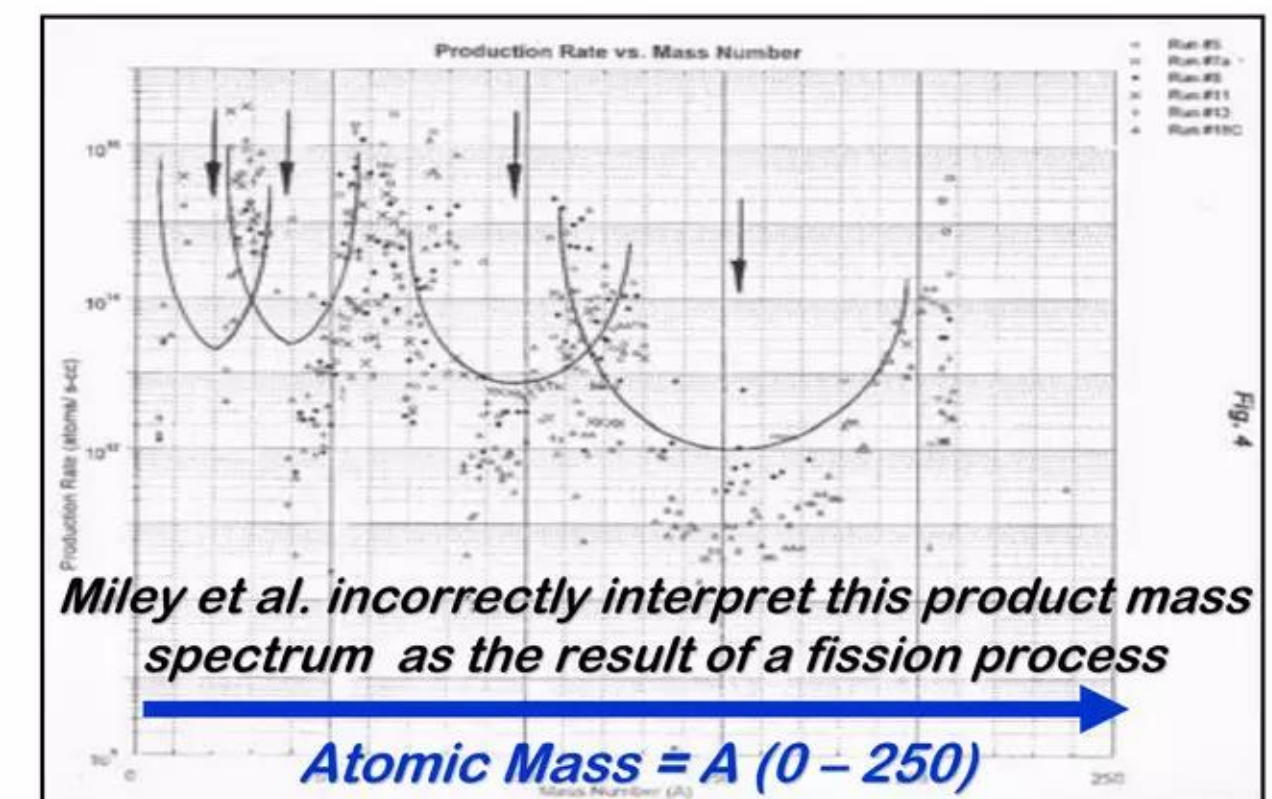
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1996: Miley reports anomalous light water transmutations

- Reports of transmutations seen in LENR experiments began to surface in the early 1990s; this work was done in Russia, the U.S., and especially Japan
- In 1996, Prof. George Miley at U. of Illinois first reported well-documented observations of a bewildering array of transmutation products (different stable elements) seen in a series of important experiments with light water P-F type electrolytic cells using Ni cathodes
- LENR researchers working with heavy water systems did not believe the transmutation results reported by Japanese/Miley et al. because could not reconcile them with D-D fusion paradigm

Miley observed a distinctive 5-peak mass spectrum of stable transmutation products comprising a wide variety of elements not initially present in light water electrolytic cells

Tadahiko Mizuno (Japan) subsequently observed very similar multi-peak mass spectrum, only in heavy water LENR electrolytic cells



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2002: Lipson reports MeV protons/alphas in light water

- In March 2002 at Midwest regional APS meeting, Prof. Andrei Lipson (Inst. Phys. Chem. – Moscow) et al. report unambiguous detection of small fluxes of ~ 1.7 MeV protons and 13.5 ± 2.5 MeV alpha particles (^4He nuclei) using CR-39 plastic detectors in P-F type H_2SO_4 light water electrolytic cells with thin-film Pd/Ni cathodes; evidence for novel nuclear processes taking place in system
- Very high energy 14 - 16 MeV alpha particles observed in Lipson et al.'s experiments are quite distinctive and very anomalous - cannot be produced by prosaic chemical or nuclear processes or the decay of known heavy alpha-emitting isotopes
- Lattice Energy LLC supported the work

In later experiments using CR-39 detectors, small fluxes of protons and alpha particles with \sim same energies were also observed by Lipson, Karabut, and others in a number of very different types of LENR experiments that included Ti- D_2O glow discharge cells, laser irradiation of TiD_x and TiH_x targets, and controlled deuterium desorption from Pd/PdO: D_x heterostuctures

According to Widom-Larsen theory, large fluxes of ultra low momentum neutrons produced in well-performing LENR systems can create new types of unstable, extremely heavy-mass isotopes that rapidly alpha-decay.

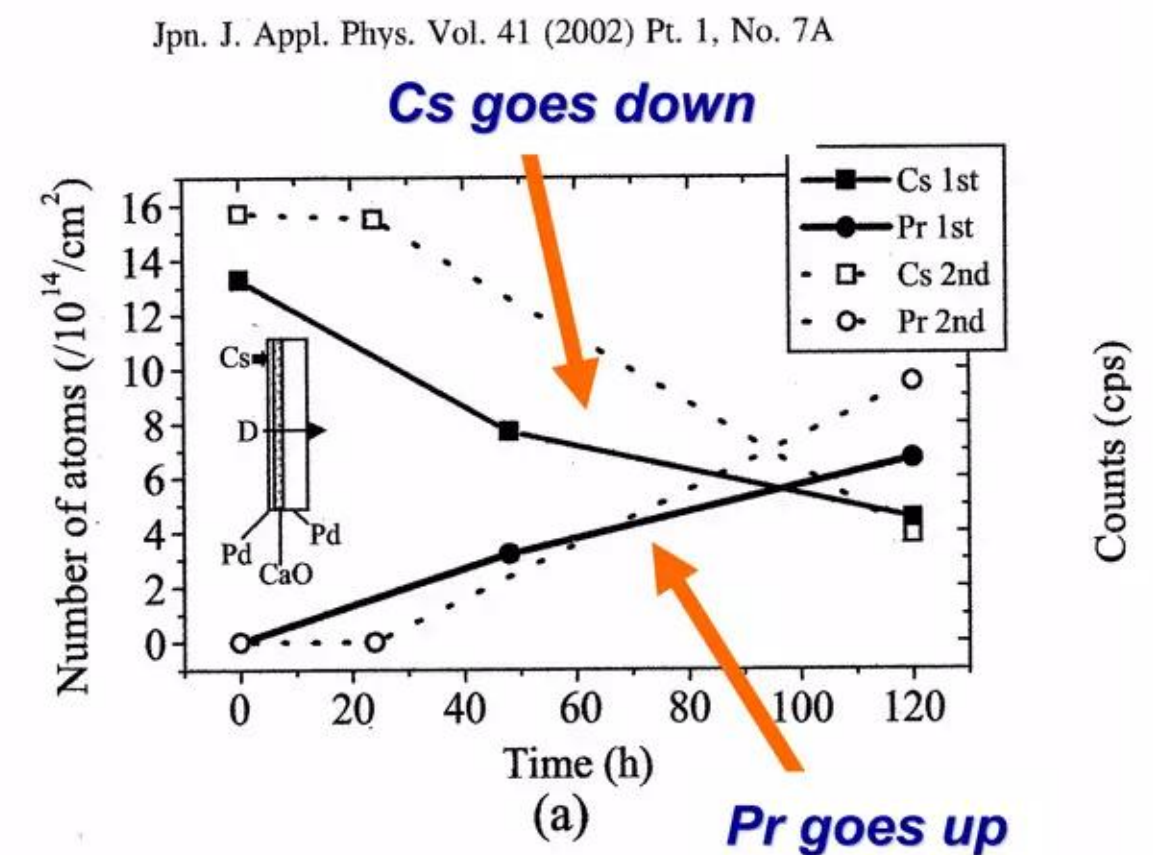
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2002: Iwamura et al. report important transmutation results

- In May 2002 at ICCF-9 in Beijing, China, Dr. Yasuhiro Iwamura and colleagues at Mitsubishi Heavy Industries (Japan) first report expensive, carefully executed experiments clearly showing transmutation of selected 'target' elements to other elements
- Experiments involved permeation of D_2 gas under 1 atm pressure at $343^\circ K$ through a Pd:Pd/CaO thin-film structure with Cs and Sr 'target' elements placed on outermost Pd surface
- Results showed that Cs was transmuted to Pr and Sr was transmuted to Mo
- Invoked EINR model (1998) to explain it

Iwamura et al, Advanced Technology Research Center, Mitsubishi Heavy Industries, "Elemental Analyses of Pd Complexes: Effects of D2 Gas Permeation", Japanese Journal of Applied Physics 41 (July 2002) pp. 4642

Widom-Larsen theory can easily explain these results



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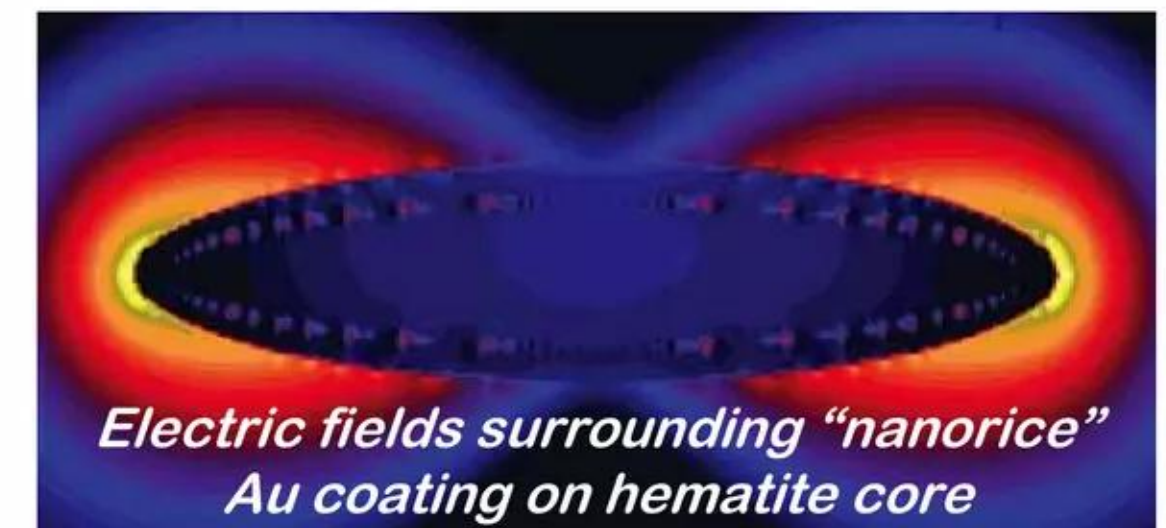
2003: Letts and Cravens report laser triggering of LENRs

- In August 2003, Dennis Letts, an amateur scientist, and Dr. Dennis Cravens reported laser triggering of excess heat in P-F type D_2O LENR electrolytic cells with a Pd cathode (Au [gold] overlayer) by irradiating the cathode with a 670 nm, 30 mW red pen laser
- LENR triggering via laser irradiation was subsequently confirmed by other researchers such as McKubre (SRI) Violante (ENEA, Italy), and Storms
- As of 2006, laser triggering LENR experiments by Letts, Cravens, and Violante et al. continued

These laser triggering experiments demonstrated an important connection between nuclear reactions creating excess heat in LENR systems and absorption of energy by surface plasmon polariton electrons (SPPs) that are normally found on the surfaces of all metals

Laser photons can couple with SPPs if certain specific surface roughness conditions are met. SPPs represent a collective oscillation of electrons; only loosely bound to ion cores

Later experiments in which heat effect was altered by changing light polarization 'clinched' the causal connection to SPPs (Violante – 2004)



*Electric fields surrounding "nanorice"
Au coating on hematite core*

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2004: DOE convenes review panel to reexamine LENRs

Scientific review paper summarizing case for LENRs prepared for DOE panel by Hagelstein, McKubre, Nagel, Chubb, and Hekman. The paper and other materials provided to panel showcased Hagelstein's theoretical and McKubre's experimental work.

Excerpts from final DOE panel report dated December 1, 2004:

- ✓ *“[They] made argument that ...branching ratios are different at low energies and that in cold fusion, ^4He fusion channel is predominant ... no high energy gamma rays accompany the ^4He [production] ...”*
- ✓ *“To explain these ... [results, the] reviewers were presented with a theoretical framework that purported to describe how collective energy from the material lattice couples to a deuteron pair to induce fusion, how the only fusion reaction channel that occurs would be the production of ^4He , and how all the energy is coupled back into the material in the form of heat instead of high-energy gamma-rays.”*
- ✓ *“The reviewers raised serious concerns regarding the assumptions postulated in the proposed theoretical model for the explanation for ^4He production.”*

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2005: DOE 2004 LENR panel reviewers' comments leaked

January 2005, a copy of the DOE scientific panel reviewers' comments on the evidence provided was leaked to the public; excerpts regarding LENR theories involving D-D fusion include:

- ✓ Reviewer #7, page 17, *“From a nuclear physics perspective, such conclusions are not to be believed.”*
- ✓ Reviewer #11, page 24, *“The lack of testable theories for [LENRs] is a major impediment to acceptance of experimental claims ... What is required for the evidence [presented] to be conclusive is either a testable theoretical model or an engineering demonstration of a self powered system...”*
- ✓ Reviewer #12, page 25 - 26, *“Compared with the experimental efforts, the theoretical work is even more unconvincing ... theory has to be formulated to explain ... the enhanced nuclear reaction rate in the condensed matter environment ... Because of these deficiencies, one is having a difficult time in understanding the experimental implications ... The most puzzling part for nuclear theory is the lack of neutrons commensurate with the heat production and the complete reversal of the ratio for the reaction channels. This is still the crucial and seemingly insurmountable physics problem that needs to be resolved ... The lack of gamma rays ... from the sample forced researchers to invent a coupling between the nuclear interaction and lattice vibrations [phonons] ... A series of conjectures is formulated in Hagelstein's paper, but a lot of them appear to be too ad hoc ... In summary ... there is no theory for low-energy nuclear reactions yet.”*

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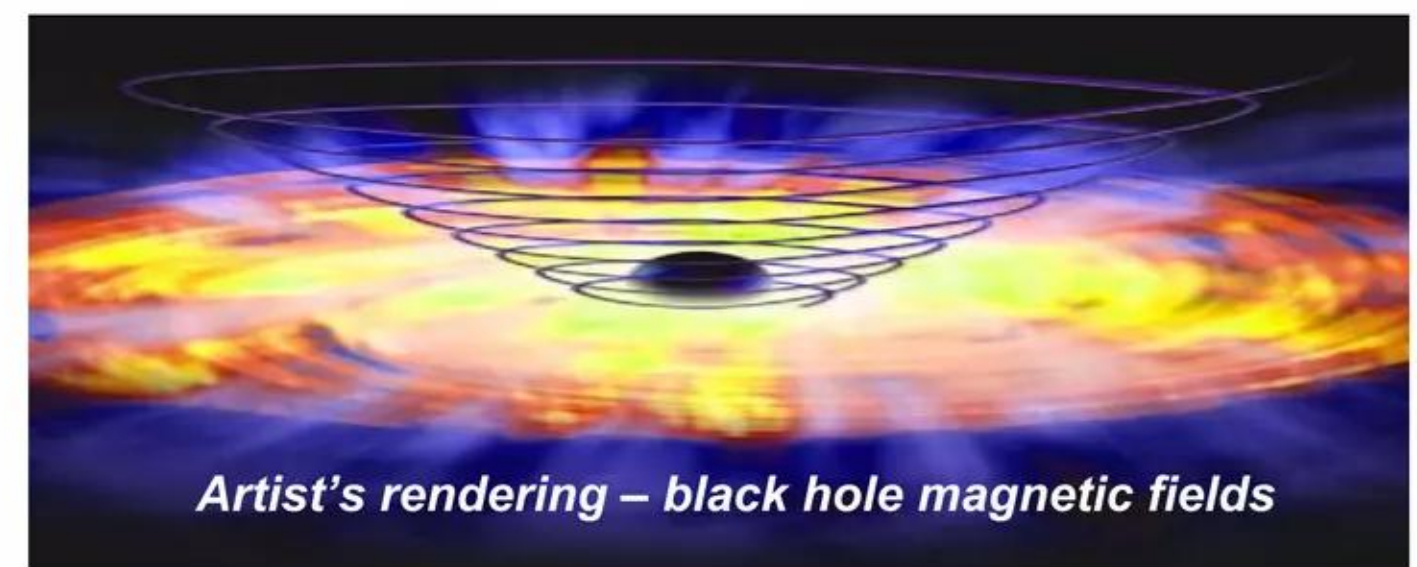
LENR facts, the problem, and the Widom-Larsen solution

- Facts: although the quality of experimental data varies greatly, a significant body of the experimental work conducted in LENRs was actually well done and, until now, inexplicable
- Problem: Standard Model nuclear theory was not applied to explain these experimental results; LENR researchers developed various ad hoc theories (e.g., Hagelstein) invoking 'new physics' to explain just some of the data. For good reason, such D-D "cold fusion" theories were rejected by mainstream physicists
- Solution: since 2005, W-L have published a theory of LENRs that successfully addresses issues raised by the 2004 DOE review panel and explains all of the good experimental data without invoking 'new physics' beyond the Standard Model

"Not unnaturally, scientists like to think that the predictions of their theories are rational expectations. But only nature is the arbiter of what is and what is not." - Richard Milton, Forbidden Science, 1995, page 216

"The whole of science consists of data that, at one time or another, were inexplicable." - B. O'Regan

"In any field, find the strangest thing and then explore it." - Prof. John A. Wheeler, Princeton theoretical physicist, first coined the term "black hole" in 1967



Artist's rendering – black hole magnetic fields

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W-L theory can answer key questions about LENRs

Widom-Larsen developed theory after careful evaluation of a large body of experimental data on LENRs; can answer key questions about LENRs that “cold fusion” researchers were unable to answer to the satisfaction of respected physicists such as Huizenga (1993):

- ✓ Overcoming the Coulomb energy barrier: weak interaction-based W-L theory posits that ultra low momentum neutrons and neutrinos are created from protons and heavy-mass surface electrons in very high electromagnetic fields found on surfaces of ‘loaded’ metallic hydrides. Unlike charged-particle D-D fusion, no Coulomb barrier to ultra low momentum (ULM) neutron absorption by nuclei; neutrons have no charge
- ✓ Absence of large emissions of dangerous high-energy neutrons: ULM neutrons of the W-L theory have extraordinarily low energies and huge absorption cross sections --- are therefore very efficiently captured by nearby nuclei. As a result, ULMNs are very difficult to detect directly
- ✓ Absence of large, dangerous emissions of gamma radiation: in condensed matter LENR systems, heavy-mass surface plasmon polariton (SPP) electrons have a unique ability to absorb gamma rays and convert them directly to lower-energy infrared photons. In LENR systems, gammas produced during neutron captures and related beta decays are thus absorbed and converted to heat internally rather than emitted to outside

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W-L theory explains other documented anomalies in LENRs

Widom-Larsen theory of LENRs can:

- ✓ Explain absence of certain “normal” nuclear products and abnormal proportions compared to what is known about D-D fusion reactions (as reported in original work of Pons & Fleischmann and thousands of other experiments since 1989) - according to Widom-Larsen, this is because LENRs do not involve appreciable amounts of D-D/D-T fusion processes
- ✓ Explain insignificant production of dangerous long-lived radioactive isotopes (as reported in the original work of Pons & Fleischmann as well as thousands of other LENR experiments since 1989)
- ✓ Explain mechanism for laser triggering of excess heat and transmutations in H/D LENR systems (as reported by Letts, Cravens, McKubre, Storms, and Violante)
- ✓ Calculate reaction rates that are in agreement with the range of rates (10^9 to 10^{16} cm²/sec) that have been observed in different types of LENR experimental systems (as reported by Miles, McKubre, Miley and others)

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W-L theory also explains many other aspects of LENRs

Widom-Larsen theory of LENRs also explains:

- ✓ Source of excess heat seen in D and H (heavy and light water) systems (e.g., Pons & Fleischmann, McKubre, Miley, Miles, Focardi et al.)
- ✓ Unusual 5-peak stable transmutation product mass spectra observed in H and D systems (e.g., Miley, Mizuno)
- ✓ Transmutation products frequently seen in H and D LENR systems (e.g., Miley, Mizuno, Iwamura, Violante, and many others) as well as in certain types of high-current exploding wire and vacuum diode experiments (US, UK, Russia - in experiments back as far as 1880s)
- ✓ ^4He and ^3He observed in D electrolytic systems (e.g., McKubre, Miles)
- ✓ Variable fluxes of soft X-rays seen in some experiments (e.g., Violante, Karabut)
- ✓ Small fluxes of high-energy alpha particles observed in certain LENR systems (e.g., Lipson, Karabut)

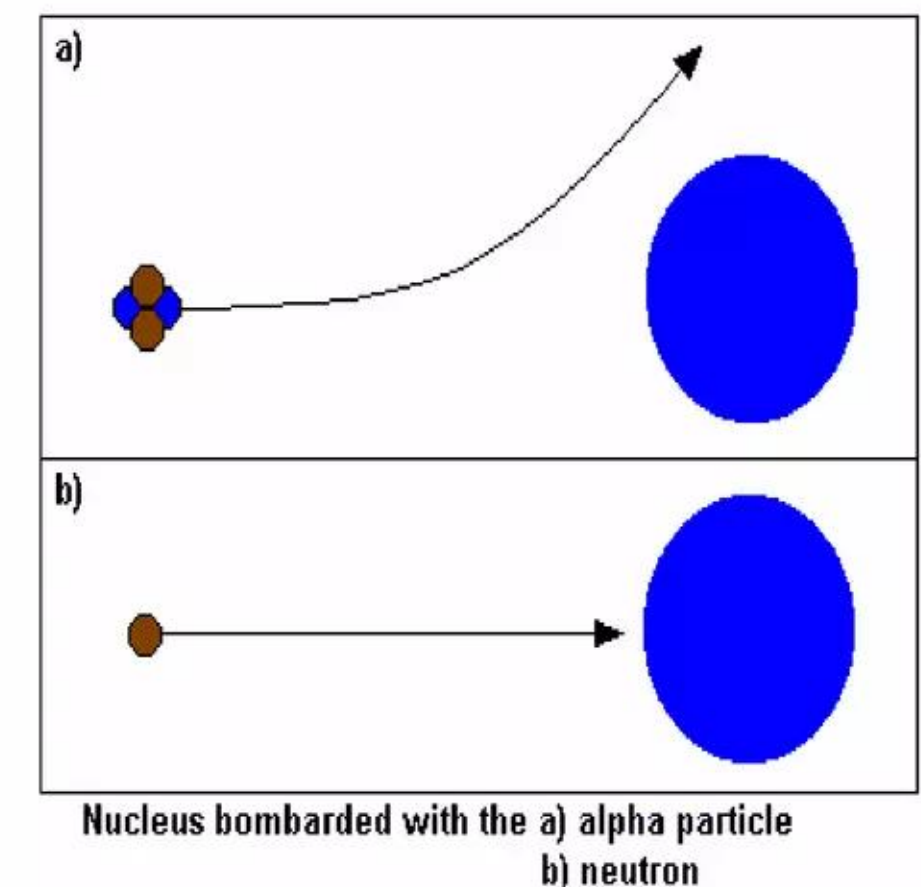
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Key features of the Widom-Larsen theory of LENRs

- Proposes that condensed matter LENRs primarily involve mass-renormalization of SPP electrons and subsequent weak interactions (creation of ultra low momentum neutrons and neutrinos; then neutron absorption by nearby nuclei followed by beta decays to stable isotopes)
- Implies that condensed matter LENRs are primarily not “cold fusion” or other forms of pure strong interactions
- Explains LENRs in terms of the well-accepted high energy Standard Model
- Includes condensed matter collective effects within the framework of the existing electroweak model
- Does not employ any microscopic ‘new physics’ or violate any conservation laws or gauge invariance
- Does not involve penetration of a Coulomb barrier --- neutrons have no charge. Furthermore, electrons and protons naturally attract each other --- there is no Coulomb barrier to surmount in $e + p$ or $e + d$ reactions

*"All great truths begin as blasphemies."
George Bernard Shaw*

*Only like charges
deflect from a
Coulomb barrier*



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Fusion and fission are not predominant in LENR systems

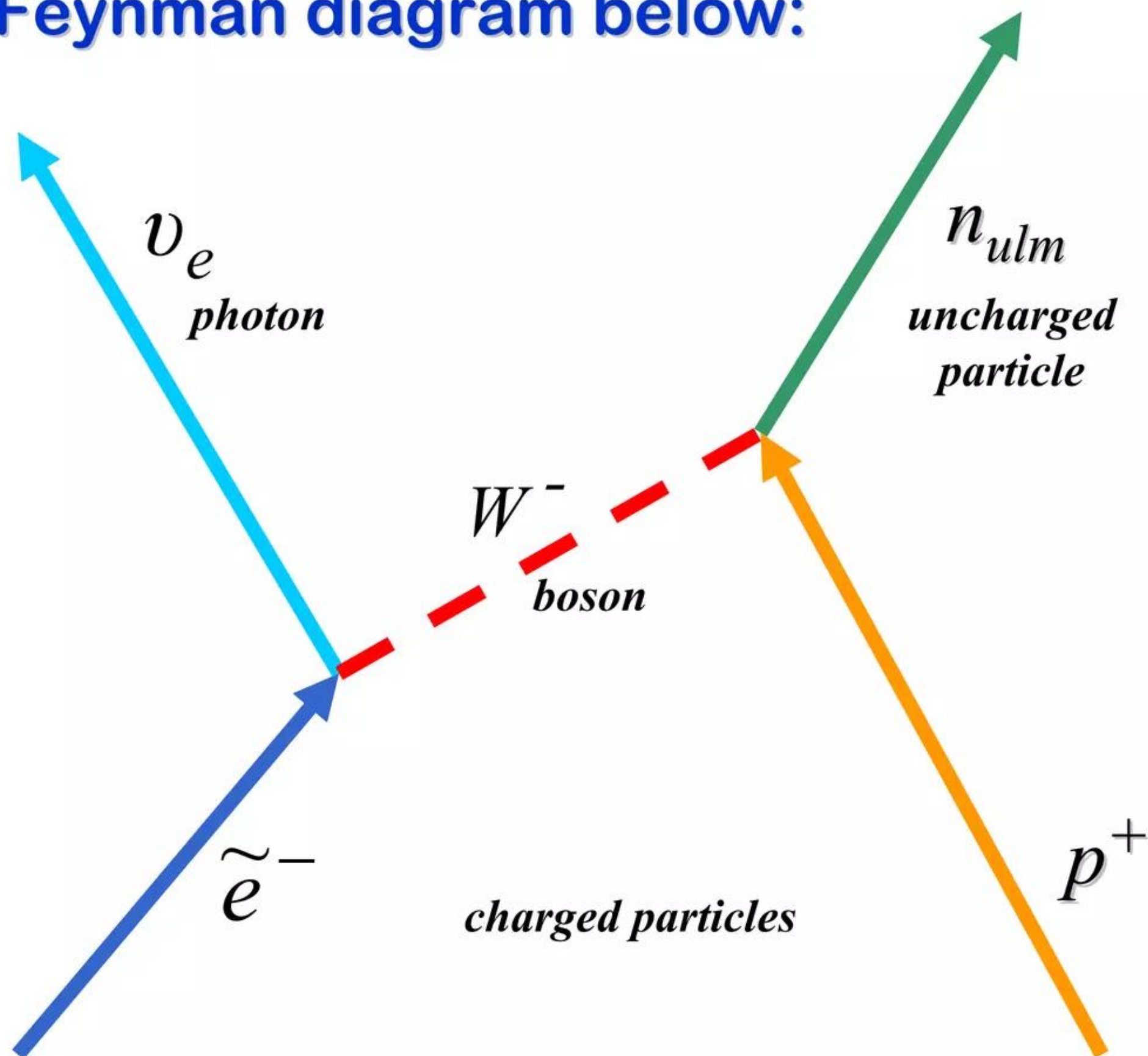
Fundamental concepts of condensed matter weak interactions in Widom-Larsen theory of LENRs are illustrated below:

1. E-M radiation on metallic hydride surface increases mass of surface plasmon electrons
 2. Heavy-mass surface plasmon polariton electrons (\tilde{e}^-) react directly with surface protons (p^+) or deuterons (d^+) to produce ultra low momentum (ULM) neutrons (n_{ulm} or $2n_{ulm}$, respectively) and an electron neutrino (ν_e)
 3. Ultra low momentum neutrons (n_{ulm}) are captured by nearby atomic nuclei (Z, A) representing some element with charge (Z) and atomic mass (A). ULM neutron absorption produces a heavier-mass isotope ($Z, A+1$) via transmutation. This new isotope ($Z, A+1$) may itself be stable or unstable
 4. Unstable isotopes beta decay, producing: transmuted new element with increased charge ($Z+1$), ~ same mass ($A+1$) as "parent" nucleus; β particle (e^-); and antineutrino ($\bar{\nu}_e$)
- No strong interaction fusion or heavy element fission taking place below*
1. $(\text{radiation}) + e^- \rightarrow \tilde{e}^-$
2. $\tilde{e}^- + p^+ \rightarrow n_{ulm} + \nu_e$
 $\tilde{e}^- + d^+ \rightarrow 2n_{ulm} + \nu_e$
3. $n_{ulm} + (Z, A) \rightarrow (Z, A+1)$
4. $(Z, A+1) \rightarrow (Z+1, A+1) + e^- + \bar{\nu}_e$
- Unstable or Stable
- Unstable Isotope
- New element – stable or unstable
- 'Green' weak interaction β^- decays (above), alpha decays (not shown), and gamma-shielded neutron captures produce most of the energy*

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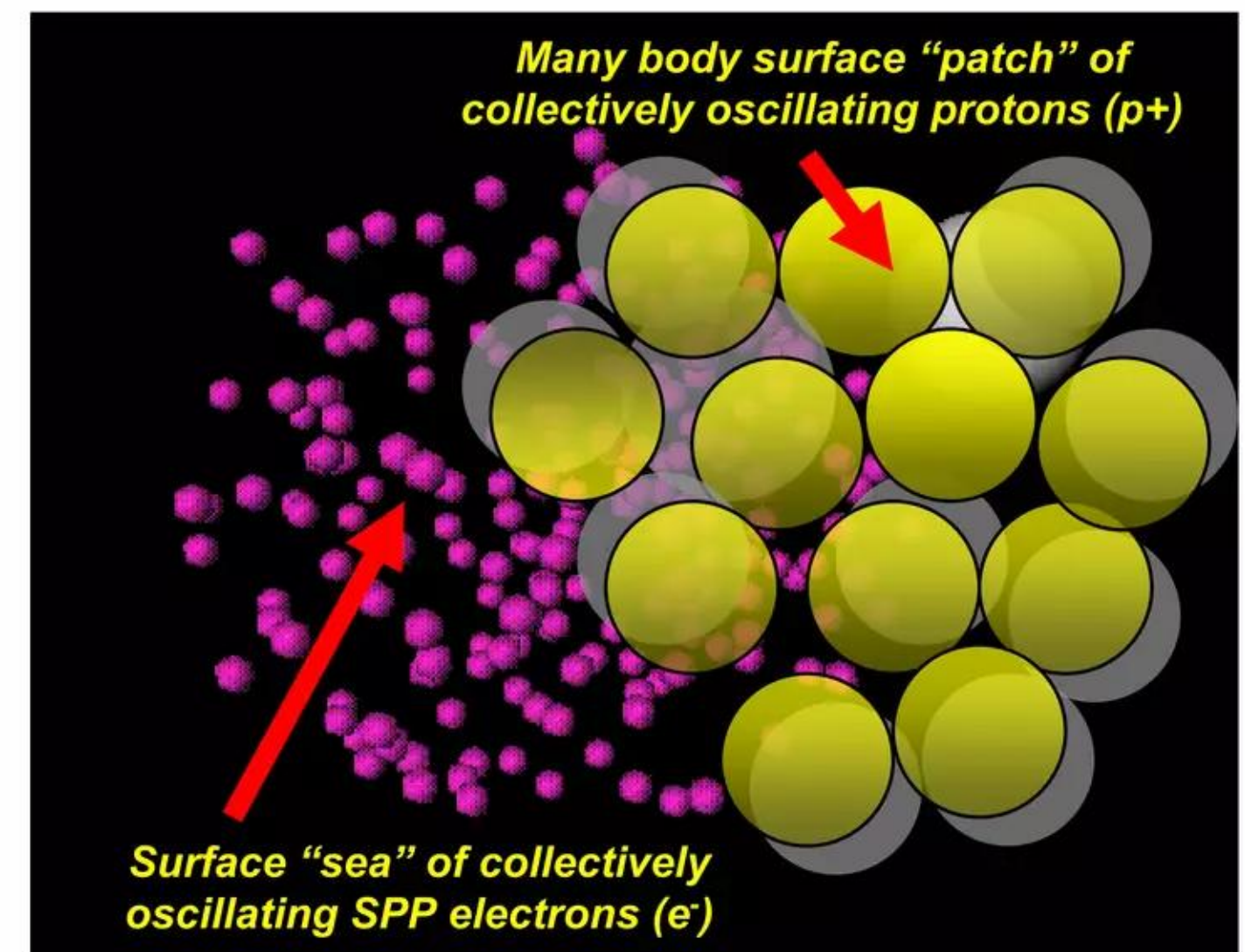
Widom-Larsen extend collective effects to Standard Model

Simple two-body collision shown in Feynman diagram below:



$$\tilde{e}^- + p^+ \longrightarrow n_{ulm} + \nu_e$$

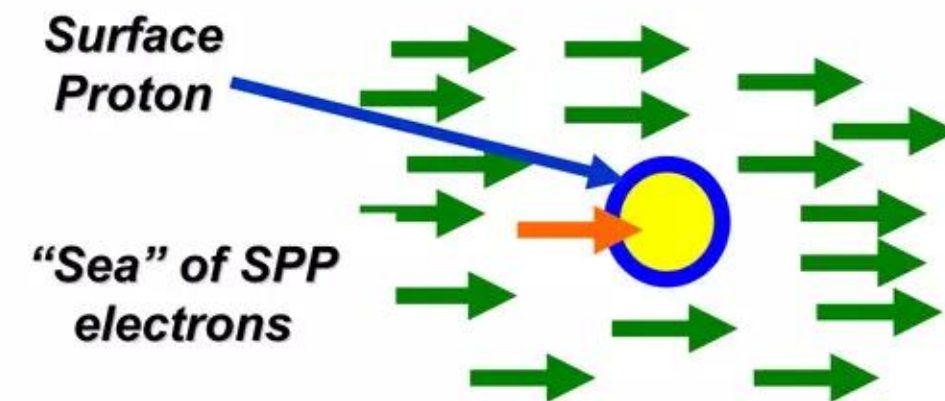
Now add collective rearrangements from condensed matter effects. It is not just a two body collision!



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Collective effects very important in Widom-Larsen theory

- Collective effects lie at the heart of the physics of condensed matter LENRs
- LENRs are able to occur at modest temperatures and pressures because of collective electromagnetic coupling (caused by a breakdown of the Born-Oppenheimer approximation) that occurs between two types of intrinsically collective oscillations found on metallic hydride surfaces:
 - ✓ Surface plasmon polariton (SPP) electrons
 - ✓ Contiguous coherent surface 'patches' of protons or deuterons that form on H or D 'loaded' hydrides
- Such coupling helps create very high local electric fields $> 10^{11}$ V/m that can renormalize masses of SPPs above threshold for ULM neutron production



When many electrons interact with a proton, only one electron may pierce into the proton's inside. That electron dies. All of the other electrons have but donated a little energy. The SPP plasma modes are collective and in synchronization

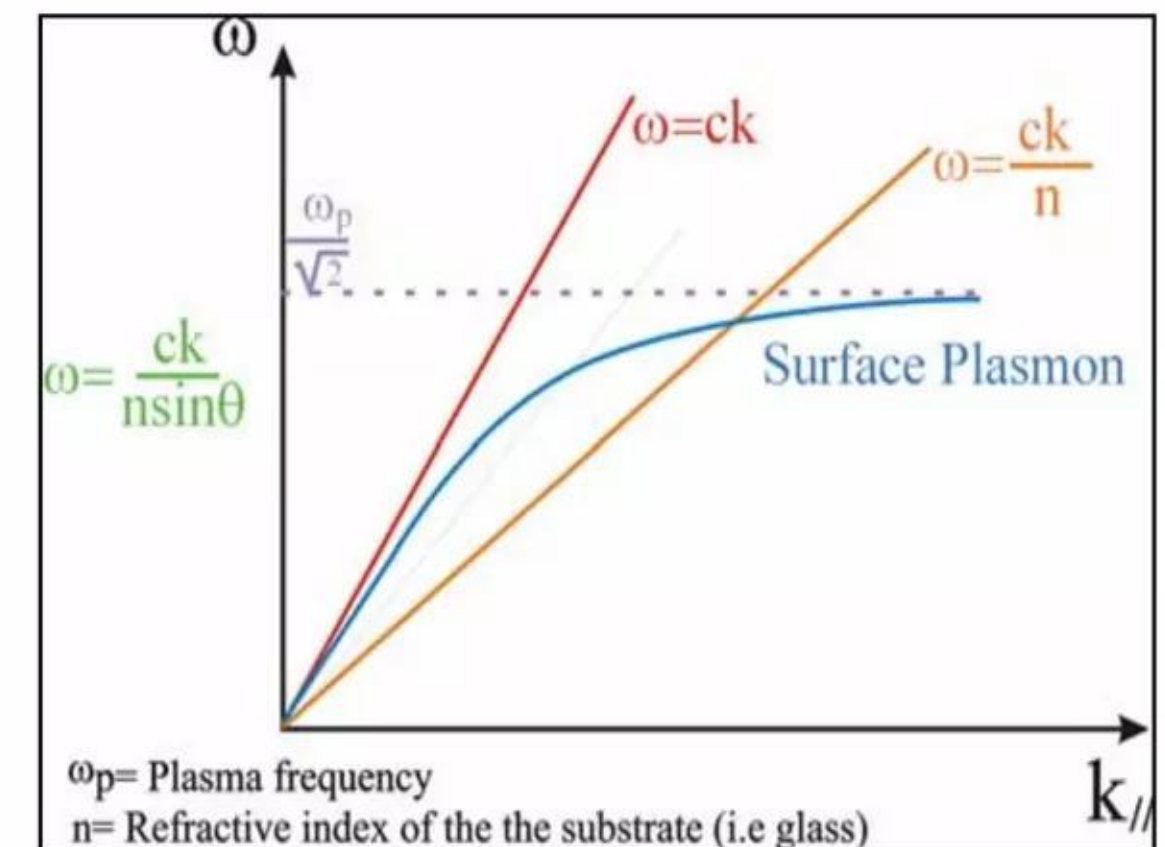
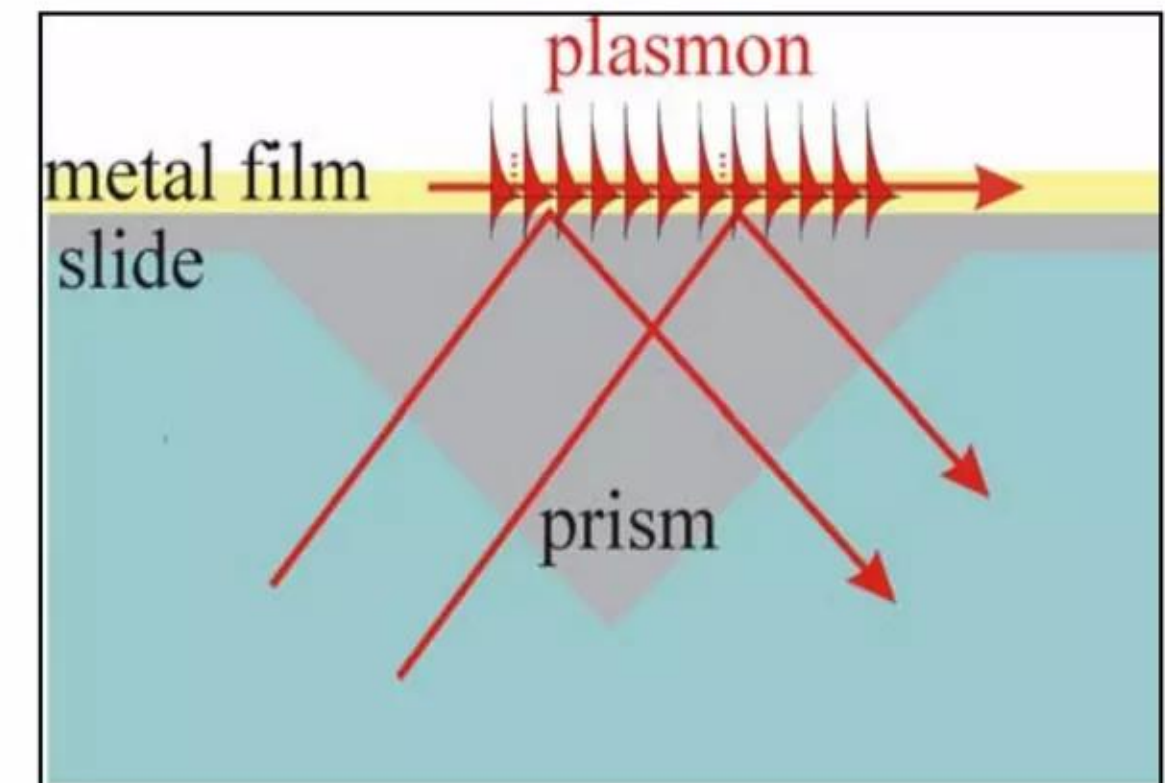


It is not difficult to throw a baseball at a target with an energy of 10^{23} electron volts, but one will not see any nuclear transmutations. The electrical currents must be collective and the electrons must transfer energy coherently and all together to trigger nuclear effects

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Collective oscillations: surface plasmon polariton electrons

- Confined to surfaces and near-surface
- Surface plasmons (SPs) are a collective oscillation of free electron gas at optical frequencies
- Surface Plasmon Polaritons (SPPs) are quasiparticles resulting from strong coupling of electromagnetic waves with an electric or magnetic dipole-carrying excitation; i.e., result from coupling of surface plasmons with light (e.g., laser)
- Play important role in Surface Enhanced Raman Spectroscopy (SERS)
- Very sensitive to the properties of the materials on which they propagate
- Interact strongly with nanoparticles located on surface; can create huge range of variation in local electric field strengths

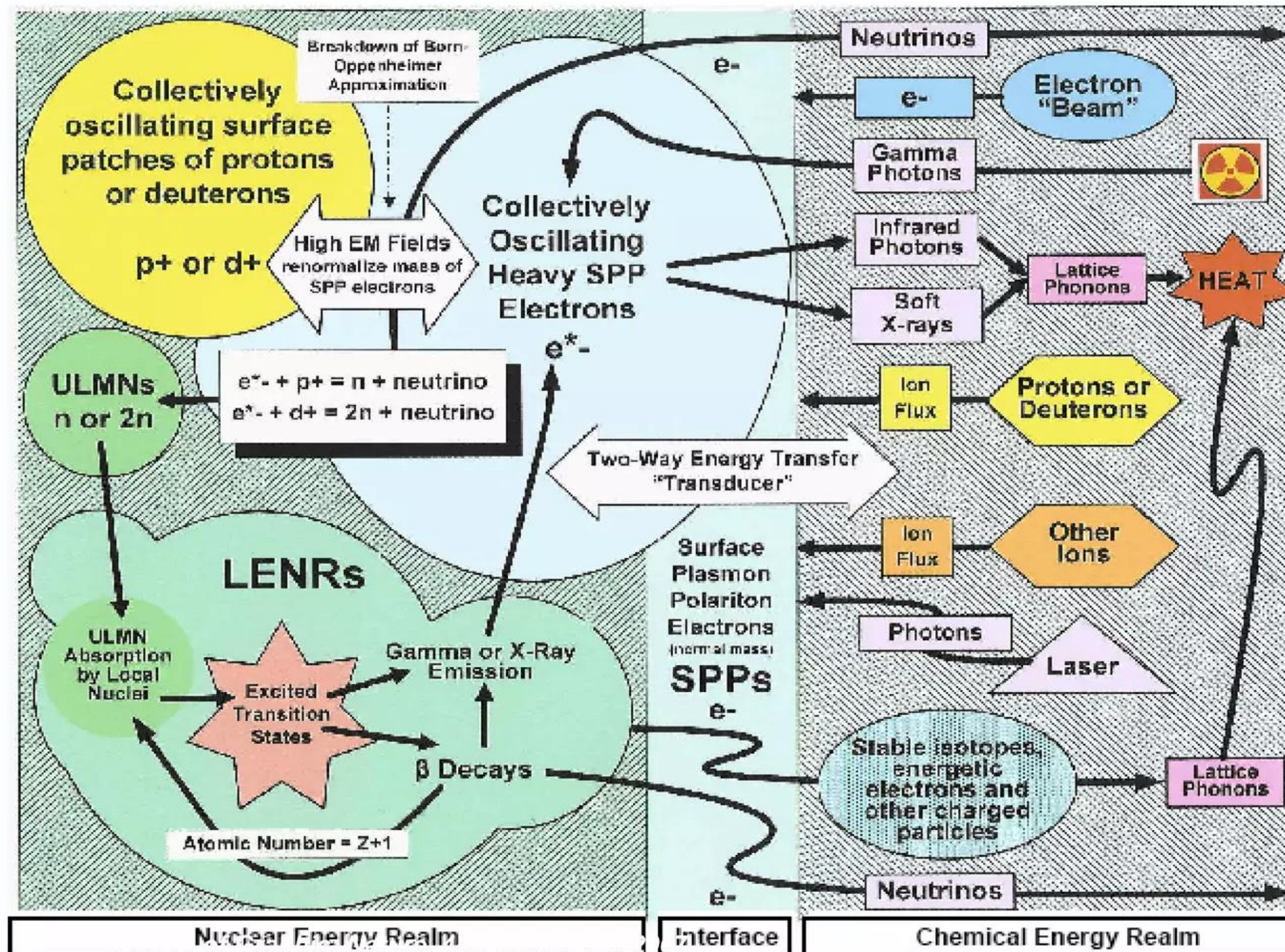


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Overview of W-L theory of LENRs in condensed matter

Conceptual Overview of the Widom-Larsen Theory of LENRs

Not fusion and not fission ---- Low Energy Nuclear Reactions (LENRs) are primarily driven by weak interactions



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While it is a 'busy' chart, this graphic summarizes everything on a single page

Please note that there are multiple ways to 'pump energy into' SPP electrons, including electric currents (electron "beam" in chart), 'bombardment' with ion fluxes, and laser photons

Collective effects and breakdown of the B-O approximation allow SPP electrons to become a 'transducer' that connects the otherwise disparate realms of chemical and nuclear energies

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W-L theory further extended beyond condensed matter

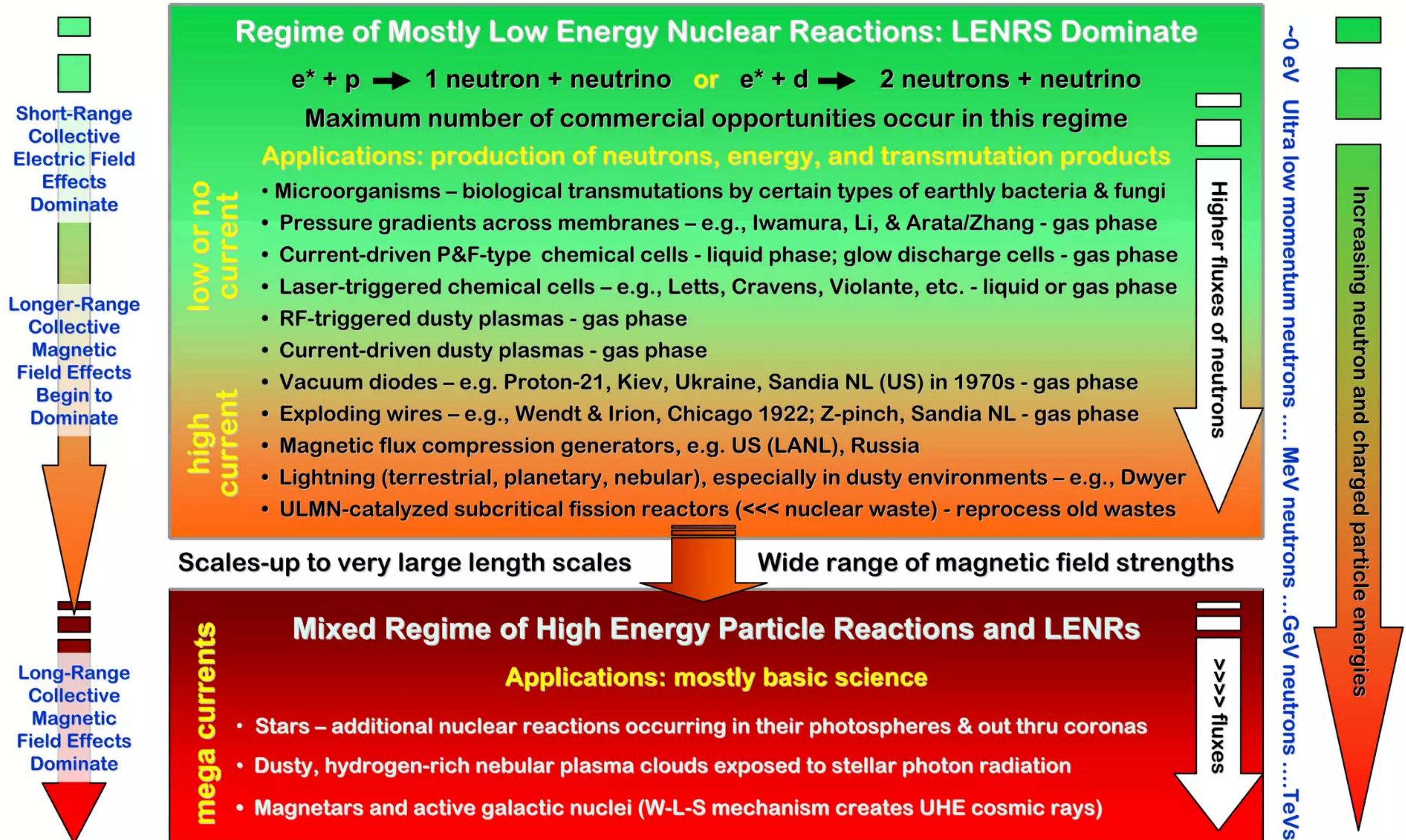
Extended W-L theory and collective effects from LENRs in condensed matter to physical environments found in high-current exploding wires: large 'wire' inductors and magnetically dominated regimes that occur in large-scale astrophysical systems.

Length Scale	Type of System	Electromagnetic Regime	Collective LENR Phenomena	Comment
Submicron	Certain earthly bacteria and fungi	Very short-range electric or magnetic fields	Transmutations, high level gamma shielding	Obtain unavailable trace elements; survive deadly gamma/X-ray radiation
Microns	Hydrogen isotopes on metallic surfaces	Very high, short-range electric fields on solid substrates	Transmutations, high level gamma shielding, heat, some energetic particles	This regime is useful for small-scale commercial power generation
Microns to Many Meters	Exploding wires, planetary lightning	Dusty plasmas: mixed high-current and high local magnetic fields	Transmutations, 'leakier' gamma shielding, heat; X-rays up to 10 keV, larger energetic particle fluxes	This regime is useful for large-scale commercial power generation
Many Meters to Kilometers	Outer layers and atmospheres of stars (flux tubes)	Dusty plasmas: high mega-currents and very large-scale, highly organized magnetic fields	Transmutations, large fluxes of energetic particles (to GeVs), limited gamma shielding, X-rays	Solves mysteries of heating of solar corona and radioactive isotopes in stellar atmospheres
Up to several AU (distance from earth to sun)	Active galactic nuclei in vicinity of compact, massive objects (black holes)		Energetic particles (GeV), gamma-ray bursts (GRBs) and ultra-high energy cosmic rays (TeV)	Solves several unexplained astronomical mysteries

Note: mass renormalization of electrons by high local E-fields not a key factor in magnetically dominated regimes at large length scales

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W-L and Srivastava – Standard Model + collective effects



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Widom-Larsen theory – seven papers publicly released

Beginning in May 2005, Lattice has publicly released seven papers on selected non-proprietary basic science aspects of our theory of LENRs:

- ✓ “*Ultra Low Momentum Neutron Catalyzed Nuclear Reactions on Metallic Hydride Surfaces*”, Eur. Phys. J. C 46, 107 (2006 – arXiv in May 2005) Widom and Larsen
- ✓ “*Absorption of Nuclear Gamma Radiation by Heavy Electrons on Metallic Hydride Surfaces*” arXiv:cond-mat/0509269 (Sept 2005) Widom and Larsen
- ✓ “*Nuclear Abundances in Metallic Hydride Electrodes of Electrolytic Chemical Cells*” arXiv:cond-mat/0602472 (Feb 2006) Widom and Larsen
- ✓ “*Theoretical Standard Model Rates of Proton to Neutron Conversions Near Metallic Hydride Surfaces*” arXiv:nucl-th/0608059v2 (Sep 2007) Widom and Larsen
- ✓ “*Energetic Electrons and Nuclear Transmutations in Exploding Wires*” arXiv:nucl-th/0709.1222 (Sept 2007) Widom, Srivastava, and Larsen
- ✓ “*High Energy Particles in the Solar Corona*” arXiv:nucl-th/0804.2647 (April 2008) Widom, Srivastava, and Larsen
- ✓ “*A Primer for Electro-Weak Induced Low Energy Nuclear Reactions*” arXiv:gen-ph/0810.0159v1 (Oct 2008) Srivastava, Widom, and Larsen

“When a new truth enters the world, the first stage of reaction to it is ridicule, the second stage is violent opposition, and in the third stage, that truth comes to be regarded as self-evident.” - Arthur Schopenhauer, 1800s

*“[New] Theories have four stages of acceptance:
i) this is worthless nonsense;
ii) this is an interesting, but perverse, point of view.
iii) this is true but quite unimportant.
iv) I always said so.”
- J.B.S. Haldane, 1963*

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Why has R&D in LENRS had limited progress in 20 years?

- Until the advent of the Widom-Larsen theory of LENRs, there were no believable theoretical explanations that could help guide experimental work; reproducibility of results was also very poor. Few mainstream scientists wished to continue work or enter the field because of its questionable reputation and notable lack of substantial government or private sector funding – worldwide numbers of researchers actively involved in work on LENRs has declined significantly since early 1990s
- Since 1989, most “cold fusion” researchers have been unaware that LENRs are actually a surface effect and that specific nanoparticle properties and certain nanoscale surface phenomena are what are actually controlling overall experimental results and reproducibility
- Bulk-effect D-D “cold fusion” paradigm, on which most LENR-related theoretical/experimental work has been based since 1989, was wrong. Experimental paths taken by many researchers were thus misguided; results of otherwise good experiments were commonly misinterpreted
- All of the above, in conjunction with a lack of multidisciplinary knowledge on the part of many researchers, hindered R&D progress