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Low Energy Neutron Reactions (LENRs) in Advanced Batteries and Other Condensed Matter Environments

Could LENRs be involved in some Li-ion battery fires?

Local E-fields >10^{11} V/m on nm - μ length-scales near fractal structures, sharp tips, and nanoparticles

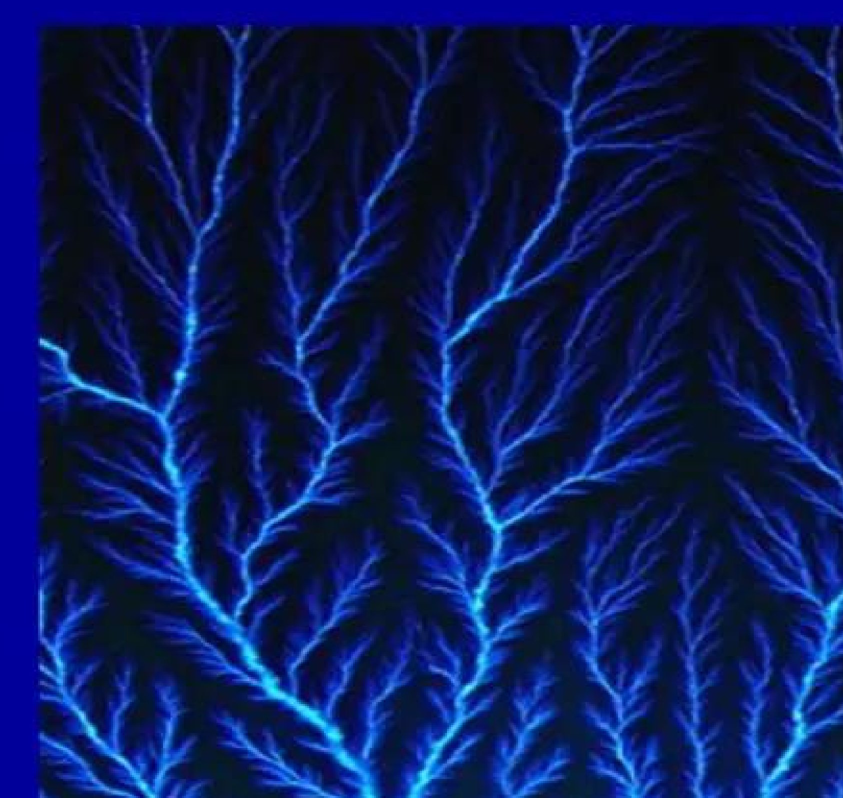
If $e \rightarrow e^*$ and ULM neutrons are produced in such spots, what are implications for advanced batteries?

Lewis Larsen, President and CEO

Lichtenberg Figures - Electric Discharge

"I have learned to use the word 'impossible' with the greatest caution."

Wernher von Braun



Lichtenberg Figures - Electric Discharge

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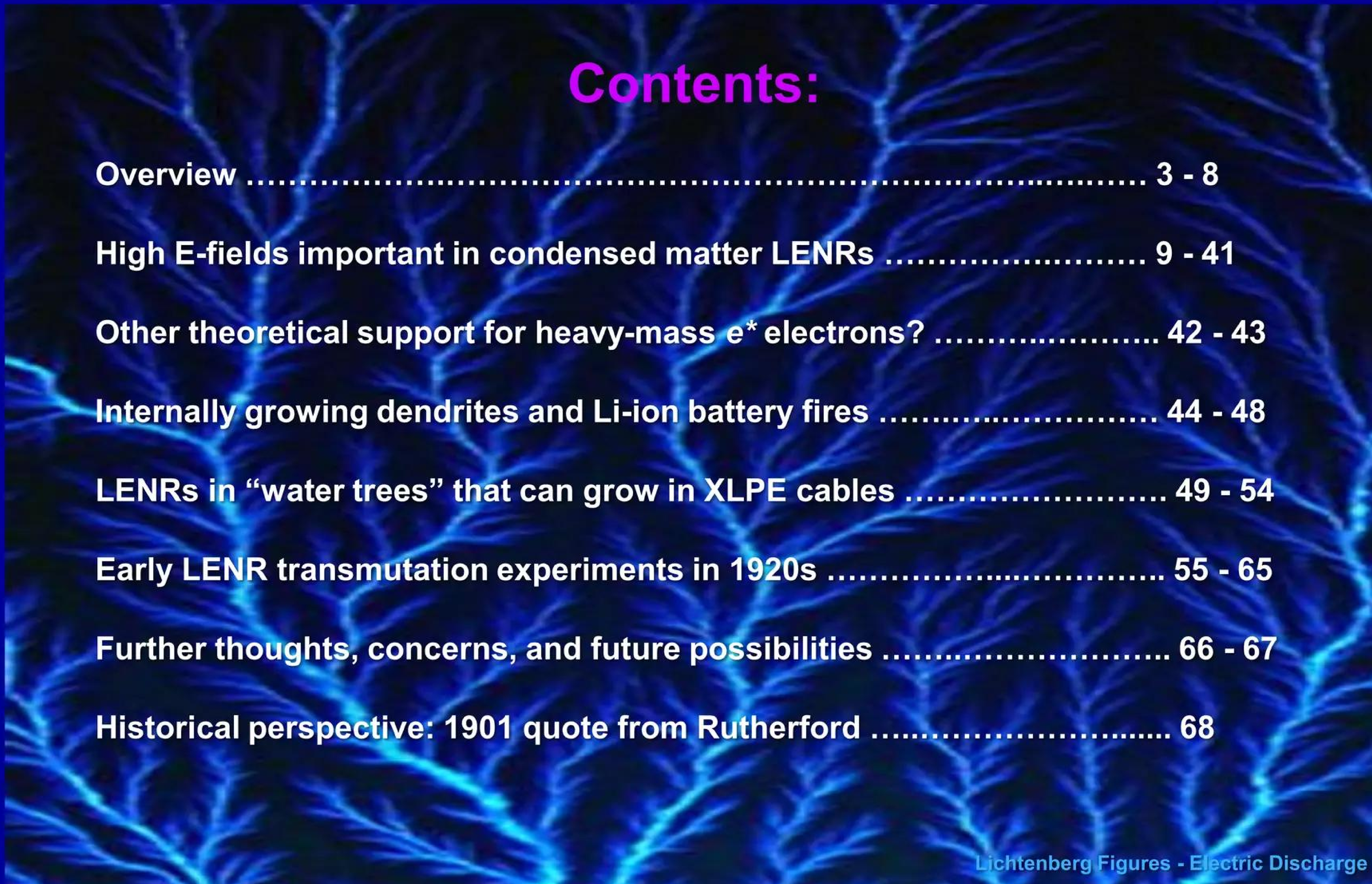

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Overview

Objectives and topics in this presentation - 1

We will discuss further applications of the Widom-Larsen theory of LENRs that we hope will interest battery scientists, as well as manufacturers of batteries and XLPE power cables:

- ✓ **About 18 months ago, based on W-L theory we conjectured that: (a) LENRs might occur in in high electric fields on nm- to micron-scale dendrites that 'grow' inside Li-ion batteries; and that (b) rapid (as little as 10 nanoseconds) multi-Watt heat-energy releases from small LENR-active 'patches' could potentially provide a triggering mechanism for an indeterminate subset of Lithium-ion battery failures and destructive fires. This hypothesis was based on simple logic:**
  - **Tiny Lithium (Li) metal dendrites, a type of fractal structure, are well known to form and 'grow' inside electrolytes of Li-ion batteries; they can grow *very* slowly in length/branching even while a battery is unused --- and then grow much faster when a battery is being charged or discharged**
  - **Under certain conditions, such dendrites are well-known to sometimes short-out electrically, rapidly discharging current arcs into nearby battery structures, creating local physical damage**
  - **High local electric fields may be created when a nanoscale metallic Li dendrite shorts-out; please recall that such Li dendrites 'grow' *within* a given battery's electrolyte, which typically contains abundant hydrogen (e.g., ethylene carbonate = $C_3H_4O_3$; diethyl carbonate = $C_5H_{10}O_3$; etc.)**
  - **In Li-ion battery, 'ingredients' for LENRs present in close proximity: a hydride-forming metal with surface plasmon electrons (Li metal dendrites); collectively oscillating protons (hydrogen atoms in carbonate electrolyte); Born-Oppenheimer breaks down on dendrite surfaces; if a violent electrical discharge from a dendrite tip suddenly produces high local electric fields, then $e \rightarrow e^*$ and voila!**

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Overview

Objectives and topics in this presentation - 2

- ✓ New data was reported in an important paper recently published in *Nature - Materials* that some believe helps further implicate dendrites as a starting point for many Li-ion battery failures and fires. Herein, after review of some background information on nanoscale E-fields, we will examine that paper and explore potential implications of very high electric fields that can potentially occur on nm - μ length-scales near fractal (dendritic) and sharp-tipped, rod-like conductive metallic structures, and surface arrays of metallic nanoparticles, that may be found in different types of present and future versions of advanced batteries

- ✓ We will then cite and discuss some papers that implicate LENRs in another type of dendritic fractal structure called a "water tree." While they occur on much larger micron- to centimeter length-scales (compared to internal structures inside batteries), 'water trees' also focus and concentrate electric fields at their dendrite tips. This would be unremarkable except for the fact that water trees form and 'grow' over time in polyethylene plastic sheathing that is used as a dielectric to insulate most types of presently available underground power transmission lines --- so-called XLPE (cross-linked polyethylene) cables. Problem is that unchecked growth of water trees in underground XLPE cables can compromise their functional and physical integrity, shorten service life, and result in potentially expensive emergency repairs

- ✓ Next, we will discuss some circa 1920s electric discharge experiments, including those of a famous Japanese physicist, Prof. Hantaro Nagaoka, "Preliminary note on the transmutation of Mercury into Gold," *Nature* 116 pp. 95 - 96, July 1925. Akin to Profs. Wendt & Irion at the University of Chicago in 1922, Nagaoka was heavily criticized by Rutherford and others; retrospectively, based on W-L theory it appears that Prof. Nagaoka was right --- he probably did in fact make Gold, but not from Mercury as he then believed

- ✓ When all is said and done, LENRs provide a potential opportunity to develop battery-like devices with energy densities, longevity, and costs that could be orders-of-magnitude better than any chemical battery

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Publications and preprints to date

- ✓ "Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces," *European Physical Journal C - Particles and Fields* 46, pp. 107 Mar 2006 Widom and Larsen (note: first released on Cornell physics preprint arXiv in May 2005)
- ✓ "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," Srivastava, Widom, and Larsen - refereed chapter in *ACS LENR Sourcebook* published in Dec 2009; expanded version with additional material accepted and will soon be published in *Pramana - Journal of Physics* (note: paper first released on arXiv in Oct 2008)

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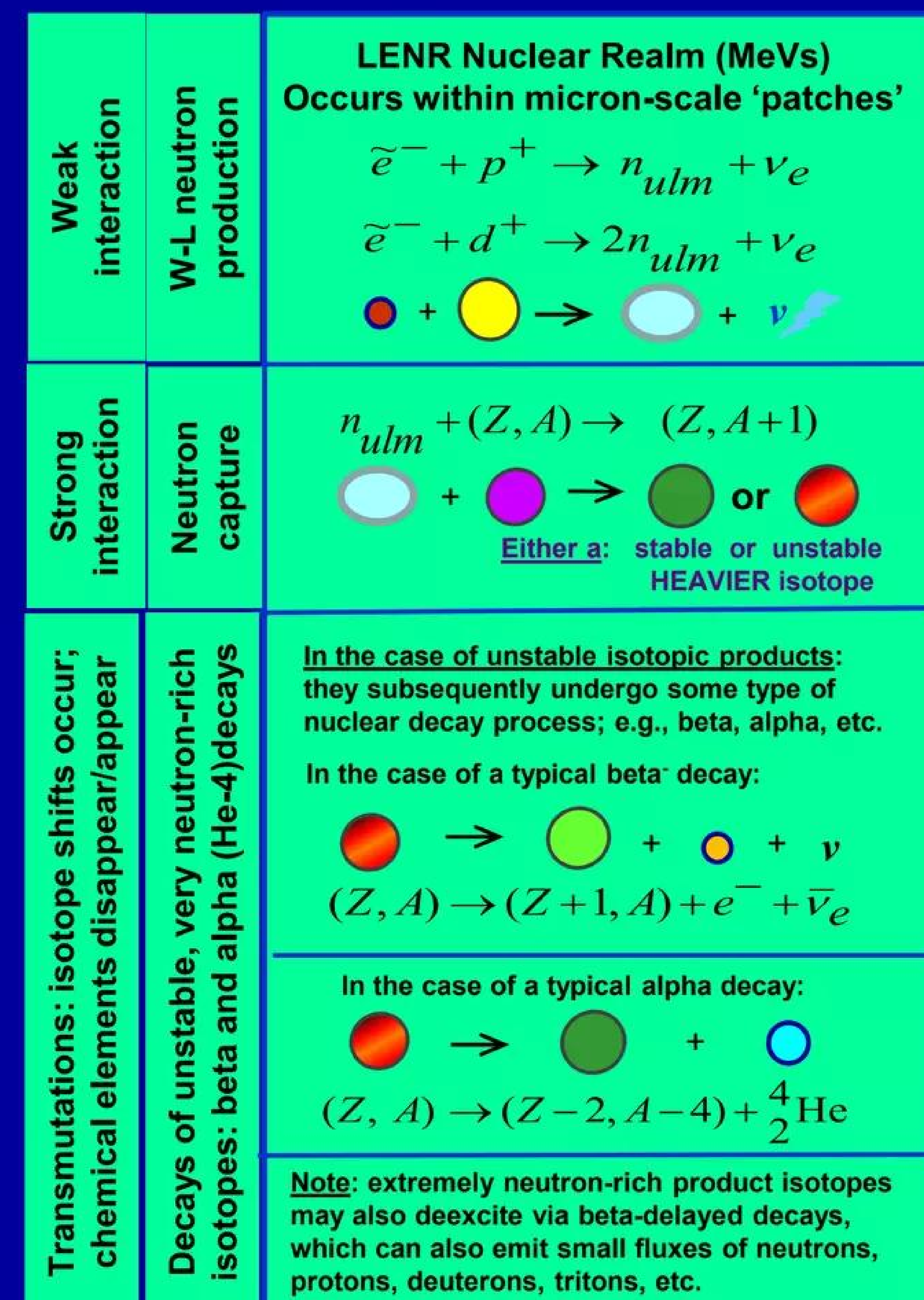
W-L theory: neutron production, captures, and β or α decays

"A Primer for Electro-weak Induced Low Energy Nuclear Reactions"

Y.N. Srivastava, A. Widom, and L. Larsen

Abstract: Under special cirumstances, electromagnetic and weak interactions can induce low energy nuclear reactions to occur with observable rates for a variety of processes. A common element in all these applications is that the electromagnetic energy stored in many relatively slow moving electrons can - under appropriate circumstances - be collectively transferred into fewer, much faster electrons with energies sufficient for the latter to combine with protons (or deuterons, if present) to produce neutrons via weak interactions. The produced neutrons can then initiate low energy nuclear reactions through further nuclear transmutations. The aim of this paper is to extend and enlarge upon various examples analyzed previously, present order of magnitude estimates for each and to illuminate a common unifying theme amongst all of them.



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What is required for LENRs to occur?

In Lattice's view, key factors for initiation and operation of LENRs are as follows:

- ✓ Substantial quantities of Hydrogen isotopes must be brought into intimate contact with 'fully-loaded' metallic hydride-forming metals; e.g., Palladium, Platinum, Rhodium, Nickel, Titanium , Tungsten, Lithium, etc.; please note that collectively oscillating, 2-D surface plasmon polariton (SPP) electrons are intrinsically present and cover the surfaces of such metals. At 'full loading' of H, many-body, collectively oscillating 'patches' of protons (p^+), deuterons (d^+), or tritons (t^+) will form spontaneously at random locations scattered across such surfaces
- ✓ Or, delocalized collectively oscillating π electrons that comprise the outer 'covering surfaces' of fullerenes, graphene, benzene, and polycyclic aromatic hydrocarbon (PAH) molecules behave very similarly to SPPs; when such molecules are hydrogenated, they can create many-body, collectively oscillating, 'entangled' quantum systems that, within context of W-L theory, are functionally equivalent to loaded metallic hydrides
- ✓ Born-Oppenheimer approximation breaks down in tiny surface 'patches' of contiguous collections of collectively oscillating p^+, d^+, and/or t^+ ions; enables E-M coupling between nearby SPP or π electrons and hydrogen ions at these locations --- creates local nuclear-strength electric fields; effective masses of coupled electrons are then increased to some multiple of an electron at rest ($e \rightarrow e^*$) determined by required simultaneous energy input(s)
- ✓ System <u>must</u> be subjected to external non-equilibrium fluxes of charged particles or E-M photons that are able to transfer input energy directly to many-body SPP or π electron 'surface films.' Examples of such external energy sources include (they may be used in combination): electric currents (electron 'beams'); E-M photons (e.g., emitted from lasers, resonant E-M cavity walls, etc.); pressure gradients of p^+, d^+, and/or t^+ ions imposed across 'surfaces'; currents of other ions crossing the 'electron surface' in either direction (ion 'beams'); etc. Such sources provide additional input energy that is required to surpass certain minimum H-isotope-specific electron-mass thresholds that allow production of ULM neutron fluxes via $e^* + p^+$, $e^* + d^+$, or $e^* + t^+$ weak interactions

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Overview

Technical side note about ULM neutron capture cross-sections

- ✓ **Unlike energetic neutrons produced in most nuclear reactions, collectively produced LENR neutrons are effectively 'standing still' at the moment of their creation in condensed matter. Since they are vastly below thermal energies (ultra low momentum), ULM neutrons have huge DeBroglie wavelengths (from *nm* to ~100 *microns*) and accordingly large capture cross-sections on nearby nuclei; most or all will be locally absorbed; few will be detectable as 'free' neutrons**

- ✓ **For the vast majority of stable and unstable isotopes, their neutron capture cross-section (relative to measurements of cross-sections at thermal energies where *v* = 2,200 *m/sec* and neutron DeBroglie wavelength is ~2 *Angstroms*) is proportional to ~1/*v*, where *v* is velocity of a neutron in *m/sec*. Since *v* is extraordinarily small for ULM neutrons, their capture cross-sections on atomic nuclei will therefore be correspondingly larger. After being collectively created, an enormous percentage of the ULMNs produced will be locally absorbed before scattering on nearby atoms can elevate them to thermal kinetic energies; per Prof. S. Lamoreaux (Yale) thermalization would require ~0.1 to 0.2 *msec*, i.e. 10^{-4} *sec*., a very long time on typical 10^{-16} - 10^{-19} *sec*. time-scale of nuclear reactions**

***Please note*: ultra low momentum (ULM) neutrons have enormous absorption cross-sections on 1/*v* isotopes. For example, Lattice has estimated the ULMN fission capture cross-section on U-235 to be ~1 million *barns* (*b*) and on Pu-239 at 49,000 *b*, vs. ~586 *b* and ~752 *b*, respectively, for 'typical' neutrons at thermal energies**

A neutron capture expert recently estimated the ULMN capture cross-section on He-4 at ~20,000 *b* vs. a value of <1 *b* for thermal neutrons; this is a huge increase

By comparison, the highest known thermal *n* capture cross section for any stable isotope is Gadolinium-157 at ~49,000 *b*

The highest measured cross-section for any unstable isotope is Xenon-135 at ~2.7 million *b*

***Crucial point*: ULMNs have many-body scattering, NOT 2-3 body**

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High E-fields important in condensed matter LENRs

In W-L theory $e \rightarrow e^*$ requires local E-fields > 10^{11} V/m - 1

- ✓ **Producing ULM neutrons via W-L weak interaction, requires a threshold minimum local electric field of at least 2 x 10^{11} Volts/meter, i.e., so $e \rightarrow e^*$ --- please note that this is a typical nuclear-strength E-field 'seen' by inner electrons in un-ionized atomic nuclei**
- ✓ **For example, the electric field strength at a Bohr radius, ~0.5 Angstrom, away from an isolated proton is roughly 5 x 10^{11} V/m (please see our 2009 - 2010 *Primer* papers for details on this issue)**
- ✓ **When Born-Oppenheimer approximation breaks down on metal hydride surfaces, local E-M coupling between 'films' of collectively oscillating surface plasmon polariton electrons (on metals) or π electrons (on aromatic rings) and nearby collectively oscillating surface 'patches' of protons or deuterons, can theoretically create an estimated electric field in the immediate vicinity of the 'patch' on the order of 28.8 x 10^{11} V/m (Eqs. 26 and 27 in *Primer*). This value is well-above bare minimum threshold for ULM neutron production via direct $e^* + p^+$, $e^* + d^+$, or $e^* + t^+$ weak interactions**
- ✓ **Some have expressed concerns that our theoretical electric field strength estimate may be 'unphysical' in it being hard to exceed 2 x 10^{11} V/m in the 'real world'. Such fears are groundless: local E-fields >10^{11} V/m are readily created on sub-nm - μ length-scales**

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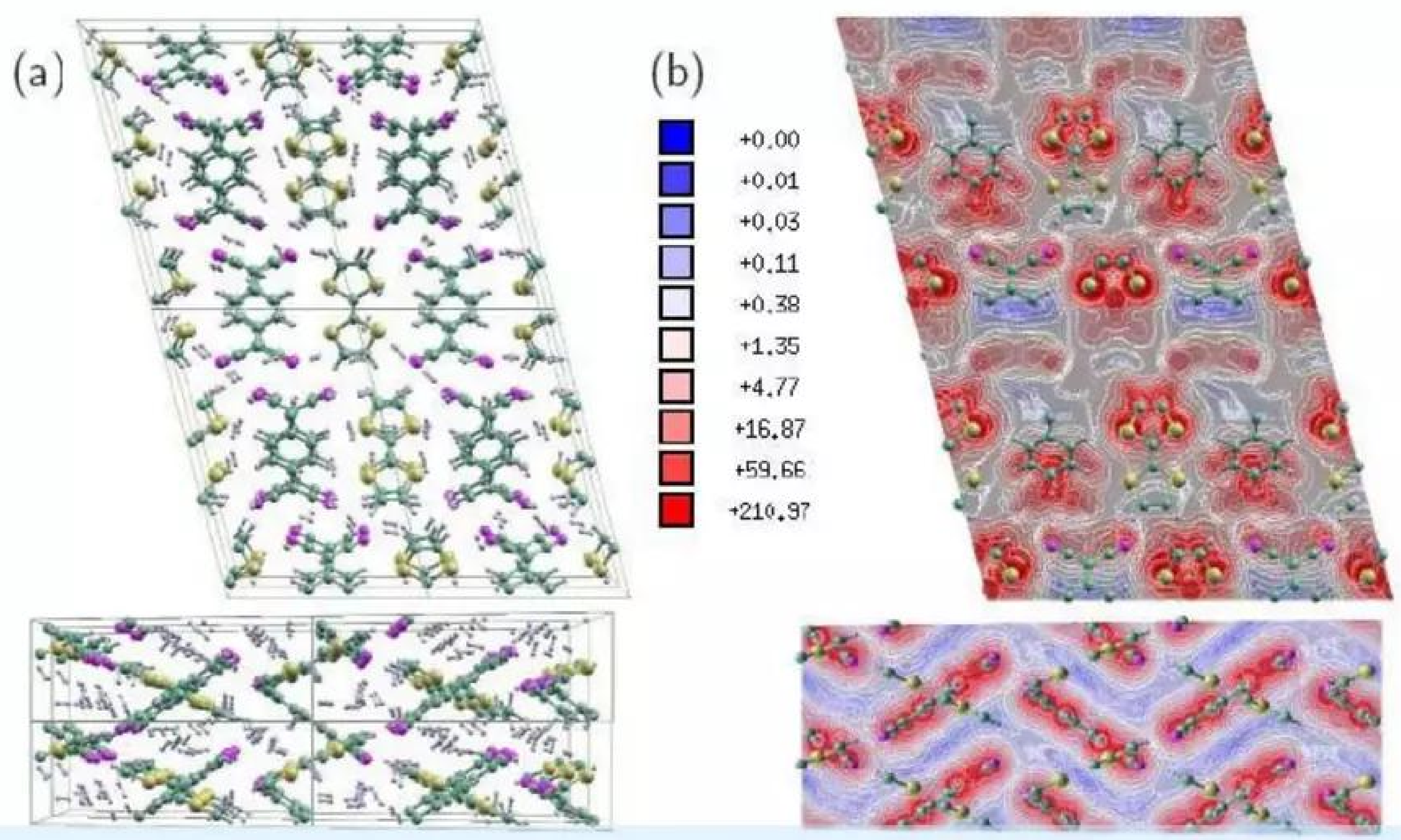
High E-fields important in condensed matter LENRs

In W-L theory $e \rightarrow e^*$ requires local E-fields > 10^{11} V/m - 2

"Single-Walled Carbon Nanohorns for Hydrogen Storage and Catalyst Supports"

"Electric fields within the crystal are in units of 10^{10}V/m --- scale shown in (b.) --- and illustrate the high-field areas where H_2 molecules are strongly bound"

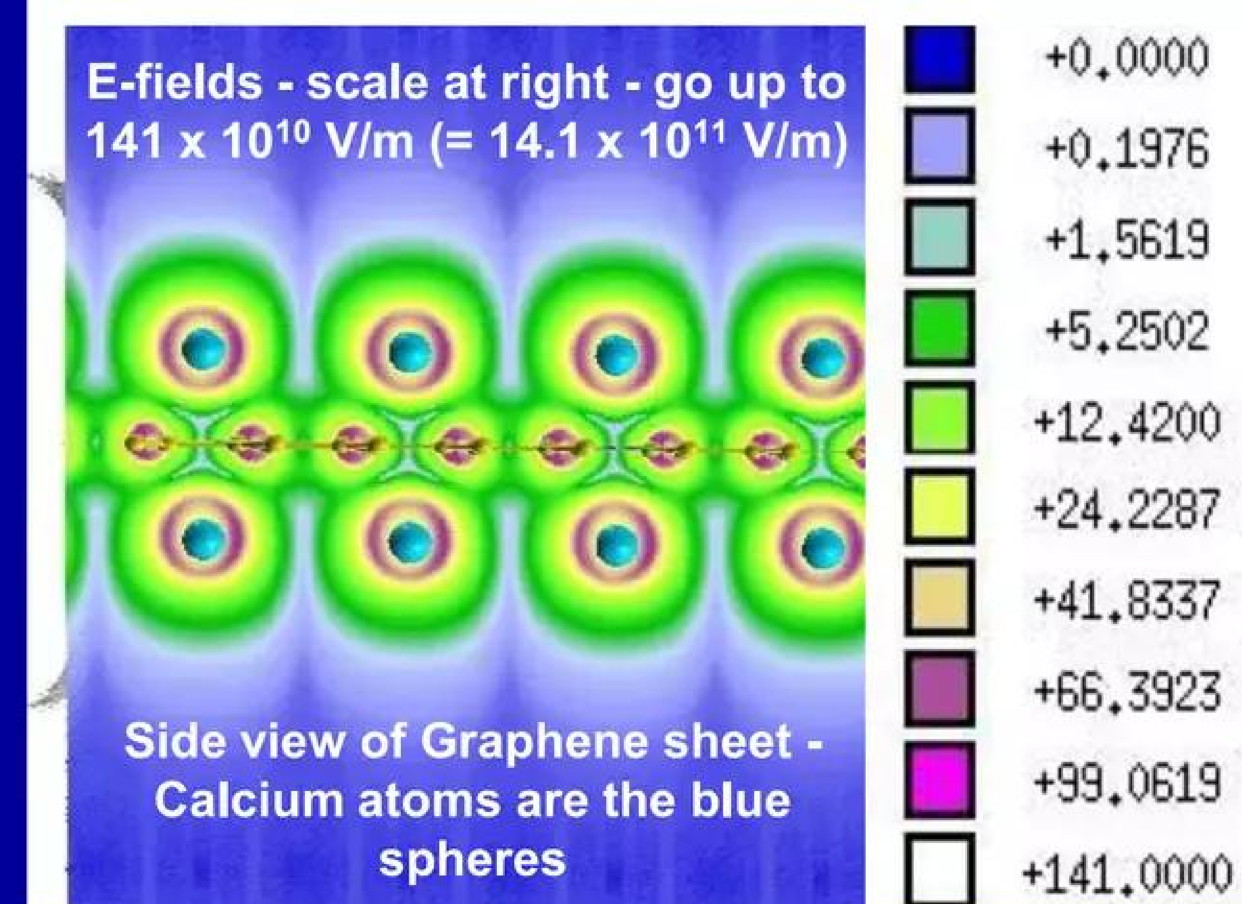


Note: electrostatic E-fields in TTF-TCNQ go up to 210.97 x 10^{10} V/m (= 21.097 x 10^{11} V/m)

FIG. 4: (a) Crystal structure of segreggated TTF-TCNQ containing 34 H_2 in an unit cell, which corresponds to gravimetric densities 7.7 wt% and 8.2 g/l volumetric density with average H_2 binding energy 0.17 eV. Two perspective of solid structures are displayed. (b) Electric field (in the unit of 10^{10} V/m) generated in the TTF-TCNQ crystal.

Slide #18: "Proposed Future Work: Charge Transfer Organic Crystals"

π electrons on Graphene surface oscillate collectively



Slide #8: electrostatic electric fields around Calcium atoms decorating both sides of graphene sheet

"Ca atoms on both sides of graphene polarize and bind hydrogen molecules by electric field-induced polarization just as effectively as Ca atoms on just one side."

Source URL:

http://www.hydrogen.energy.gov/pdfs/review10/st017_geohegan_2010_p_web.pdf

Source: D. Geohegan et al., Oak Ridge National Laboratory (ORNL), Project ID ST017 June 9, 2010

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High E-fields important in condensed matter LENRs

In W-L theory $e \rightarrow e^*$ requires local E-fields > 10^{11} V/m - 3

- ✓ **Size matters: on *macroscopic* length scales, electric field strengths >10^{11} V/m occur mainly in extreme environments, e.g., surfaces of neutron stars ('typically' 10^{10} - 10^{13} V/m). However, on tiny *sub-nm to μ length-scales,* extremely high E-fields are much easier to achieve. Previous slide adapted from Geohegan et al. (ORNL) supports the notion that our estimate of surface 'patch' E-fields potentially reaching 28.8 x 10^{11} V/m is quite reasonable**
- ✓ **Please note that for many years it has been well-known: electric fields that can exceed 10^9 V/m commonly occur in 1-3 nm regions of charge separation comprising the so-called "electrical double layer" found on surfaces of electrodes, e.g., in aqueous chemical cells (please see Wikipedia: http://en.wikipedia.org/wiki/Double_layer_(interfacial)#Electrical_double_layers)**
- ✓ **In order to exceed W-L's key ULM neutron production threshold of ~2 x 10^{11} V/m in condensed matter systems, Nature needs to be able to provide us with a variety of sub-nm to μ local 'nanoenvironments' in which incident E-M fields can be locally 'channeled,' 'amplified,' or otherwise enhanced by a factor of at least ~100x, i.e., ~10^2 or more: $e \rightarrow e^*$**
- ✓ **Electro-geometric, including "lightning rod effect," and local nanoscale E-M coupling mechanisms that can provide necessary levels of E-M field strength and/or enhancement are varied and well known. They include: electric breakdown and spark discharges; metallic nanoparticles; nanoantennas; resonant E-M (RF) cavities; plasmonics; lasers; etc., etc.**

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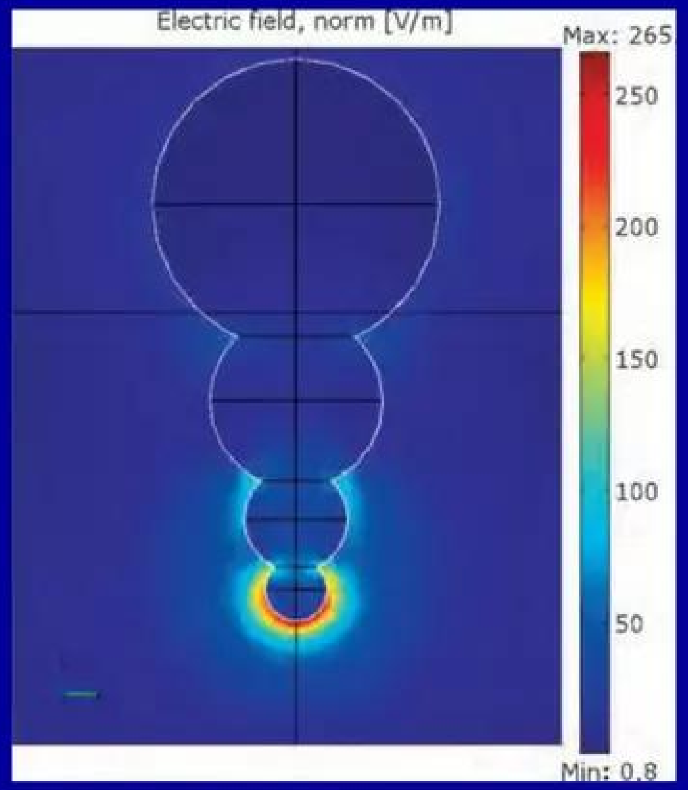
High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 1

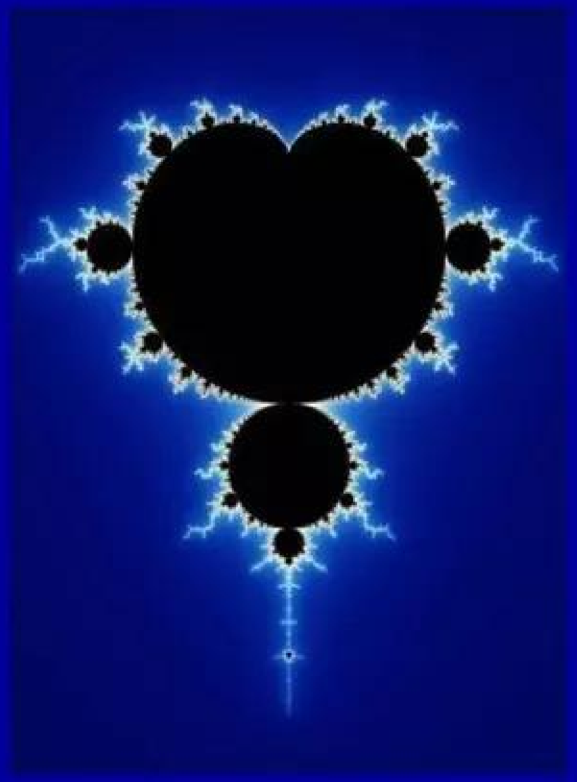
Lightning rod effect:

"Refers to the well-known fact that sharp metallic objects tend to generate very large localized [E-M] fields … This effect tends to concentrate the field lines at any sharp points of highly conductive materials. This is a shape effect, not a resonance effect, and therefore does not have any particular wavelength dependence. It may or may nor be associated with a [collective] longitudinal surface plasmon resonance …The lightning rod effect can generate extremely large field enhancements … the triangle antenna also provides an excellent illustration of [this] effect. A third technique for field enhancement is the dual-dipole effect. In this case, two resonant particles are brought close enough together to interact with each other. In the gap region between the two particles, the field can become much more intense than that from either particle separately."

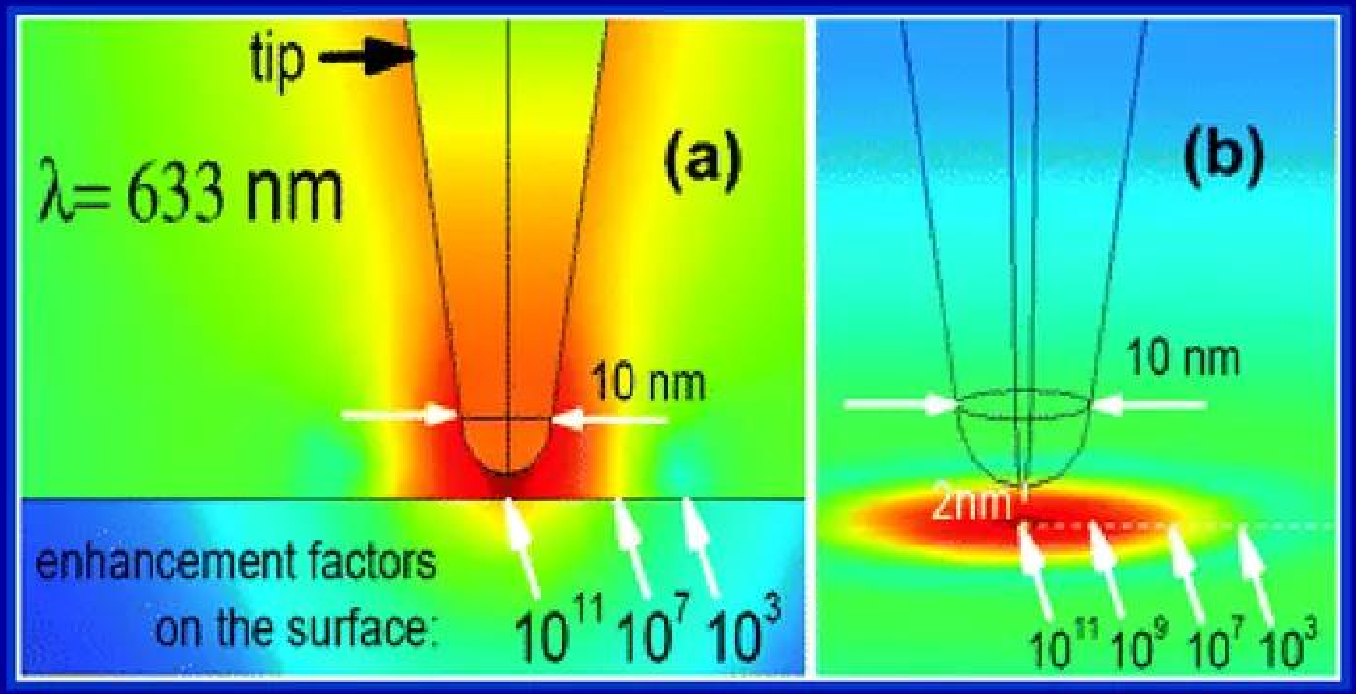
Source: "Modern Aspects of Electrochemistry 44, Modeling and Simulations II", Vol. 2, pp. 70-73, M. Schlesinger, ed. Springer 2009



Electric field enhancement at nano-antenna tip: R. Kappeler et al., 2007



Mandelbrot Set Classic fractal



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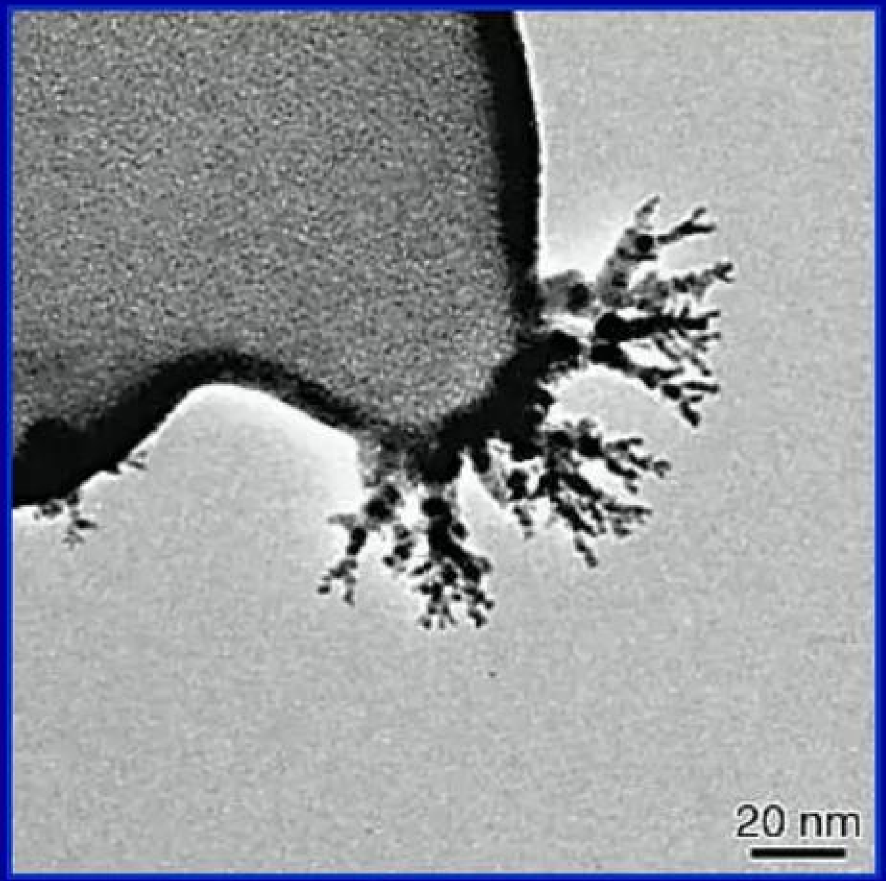
High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 2

Many fractal structures have sharp, tapered tips:

Fractals are intrinsically self-similar on all length-scales, from meters down to nanometers. As illustrated in these Figures, many types of natural fractal forms narrow-down to very sharp tips on smaller length-scales. Structures with such geometries can be prone to exhibit the lightning rod effect if they happen to be comprised of materials such as metallic conductors



***TEM image*: nanodendritic Tungsten growth Credit: Furuya and Hasegawa, CNMT - Korea**

***Image*: macroscopic cm length-scale Copper dendrite growing in aqueous Copper Sulfate solution**

***Image*: terrestrial lightning very large length scale**

***Image*: mm length-scale Lichtenberg Figures from electrical discharge through plastic**

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High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 3

Examples of fractal dendritic structures in Li-ion batteries:

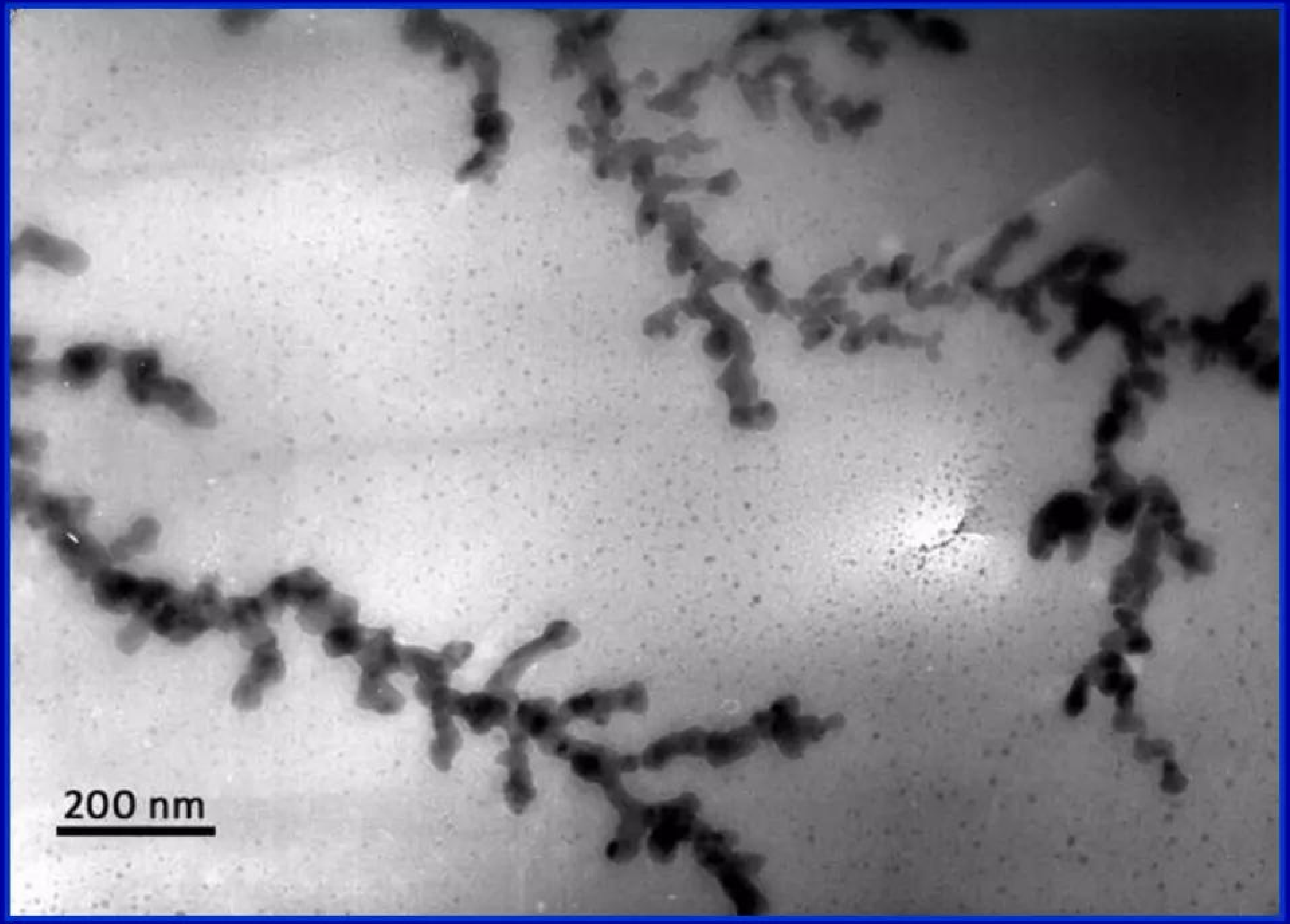
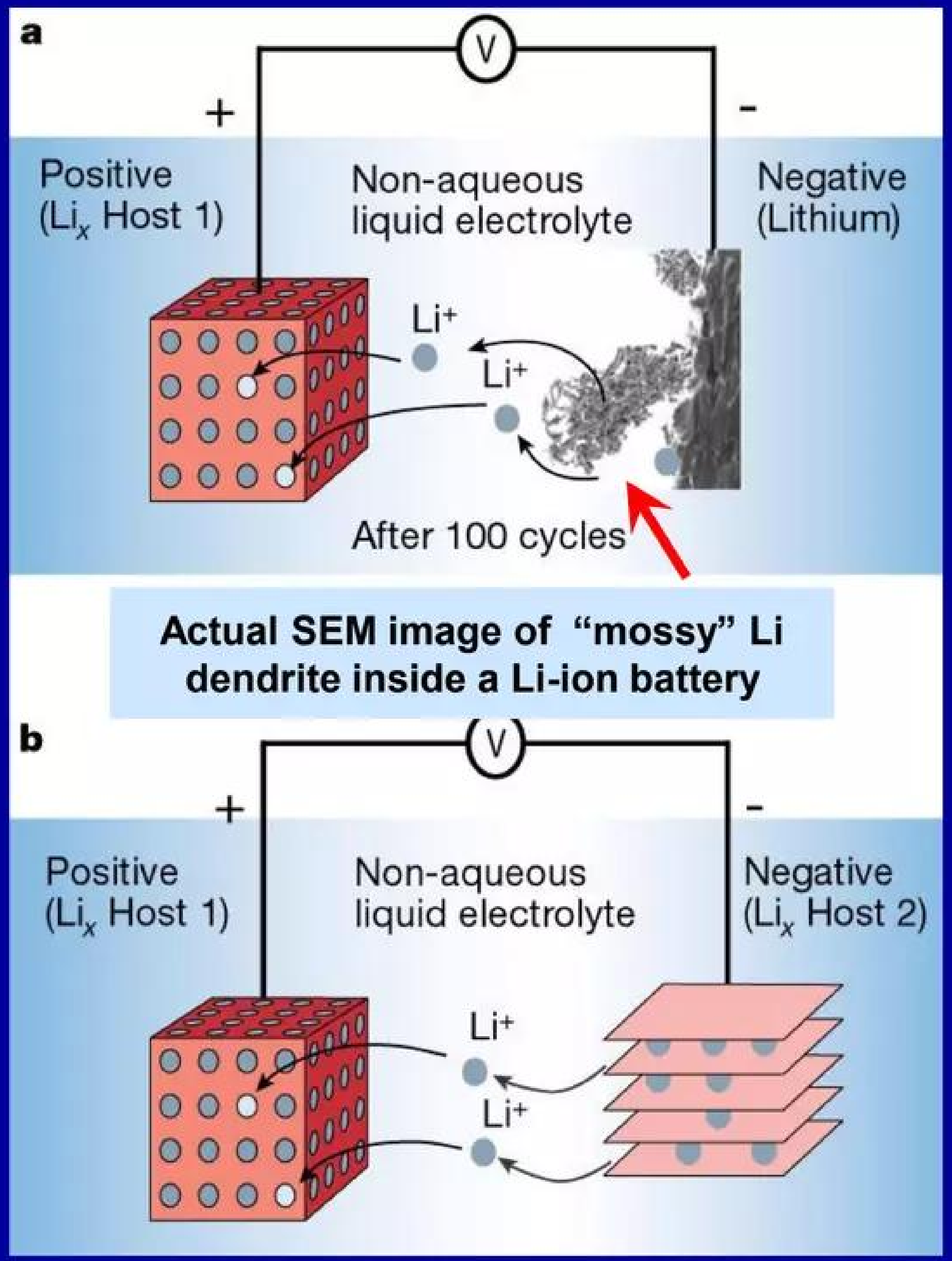


Image: Lithium metal dendrites growing within solid polymer electrolyte - G. Stone et al., Lawrence Berkeley National Laboratory, APS March 17, 2010

Abstract: Q16.00005: "Retarding Dendrite Formation in Rechargeable Lithium Metal Batteries with Block Copolymer Electrolytes"



Source: Fig. 2 in J.M. Tarascon and M. Armand, "Issues and challenges facing rechargeable lithium batteries" *Nature* 414, pp. 359-367 (2001)

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High E-fields important in condensed matter LENRs

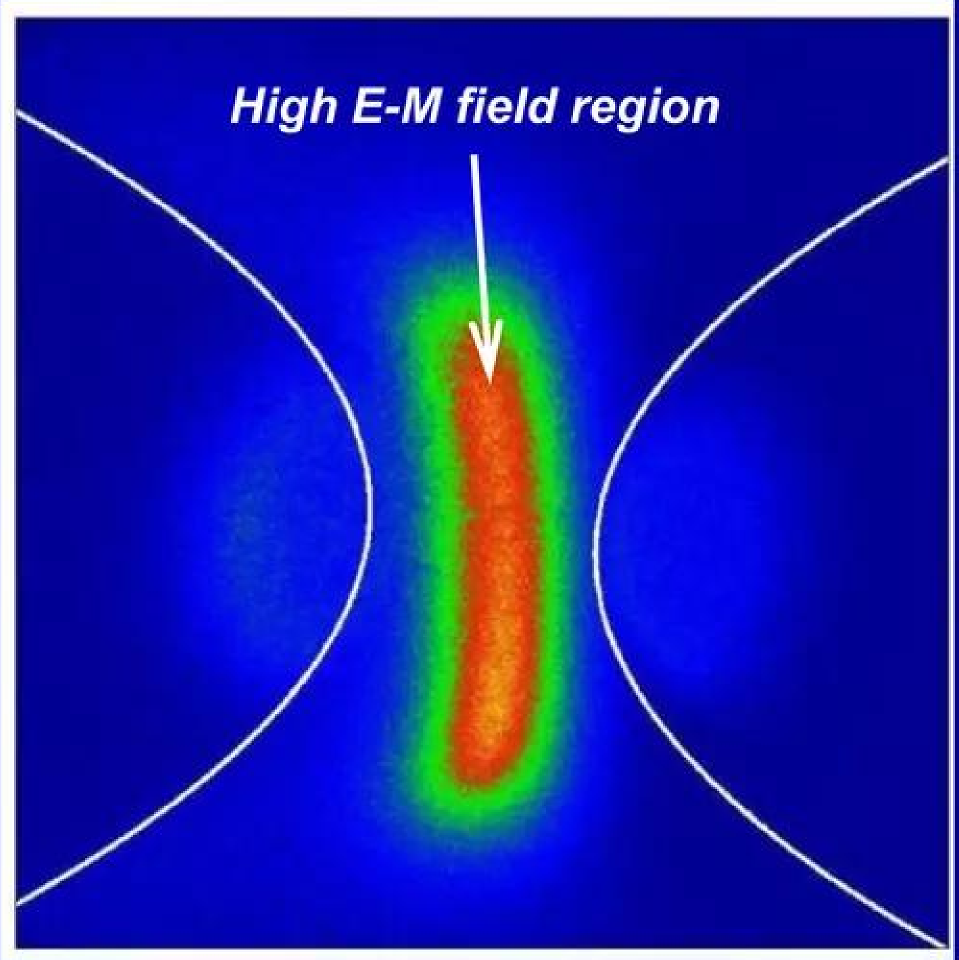
Lightning rod effect, electrical arc discharges, and field emission - 4

Electrical breakdown and arc discharges (i.e., sparks):

Although they have been studied for 200 years, in many ways electric discharges are still not all that well understood. Recent measurements (2007) of spark discharge in low-pressure Xenon gas using rapidly pulsed lasers has helped better understand the still enigmatic process:

"A spark flying between a metal doorknob and your hand is an intricate chain of electrical events … researchers report the first direct measurements of the sharply changing electric fields that pave the way for a visible flash in a precisely controlled laboratory arc. Their results provided concrete detail in an area where theoretical modeling remains scanty, and may offer a way to study electrical discharges in settings ranging from plasma televisions to lightning strikes ... Whether it's a lightning bolt or the spark inside a bad switch, the process is the same: The voltage across a region of air becomes large enough to drive an electric current by creating a plasma. The process starts when a few stray electrons--accelerated by the electric field--knock into atoms and liberate more electrons, which continue the process. In carefully designed lab experiments the region between a pair of electrodes fills with plasma smoothly, starting at the positive end, with a wave front that sweeps quickly across to the negative end. At the leading edge of this so-called ionization front is a narrow band of enhanced electric field, according to theory and indirect experiments, but theorists only vaguely understand what determines the field's profile. Nor have experimenters been able to map the field profile directly, because inserting metal probes distorts the discharge. Researchers have tried to infer field strengths from the glow following the breakdown, but that light is feeble and only appears once the ionization is well under way.

Source: D. Monroe, *Physical Review Focus*, "Xenon on the verge of an electric breakdown," Feb. 9, 2007 URL = http://focus.aps.org/story/v19/st4



E. Wagenaars/Eindhoven Univ. of Tech

PRL paper: E. Wagenaars, M. Bowden, and G. Kroesen, "Measurements of electric field strengths in ionization fronts during breakdown," Physical Review Letters 98, pp. 075002 (2007)

High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 5

Field electron emission (in high E-M fields; usually occurs prior to breakdown and discharge):

"Field emission (FE) (also known as electron field emission) is an emission of electrons induced by external electromagnetic fields. Field emission can happen from solid and liquid surfaces, or individual atoms into vacuum or open air, or result in promotion of electrons from the valence to conduction band of semiconductors. The terminology is historical because related phenomena of surface photoeffect, thermionic emission or Richardson-Dushman effect and 'cold electronic emission', i.e. the emission of electrons in strong static (or quasi-static) electric fields, were discovered and studied independently from 1880s to 1930s. When field emission is used without qualifiers it typically means the 'cold emission'."

"Field emission in pure metals occurs in high electric fields: the gradients are typically higher than 1000 volts per micron and strongly dependent upon the work function. Electron sources based on field emission have a number of applications, but it is most commonly an undesirable primary source of vacuum breakdown and electrical discharge phenomena, which engineers work to prevent."

"Field emission was explained by quantum tunneling of electrons in the late 1920s. This was one of the triumphs of the nascent quantum mechanics. The theory of field emission from bulk metals was proposed by Fowler and Nordheim. A family of approximate equations, 'Fowler- Nordheim equations', is named after them."

"In some respects, field electron emission is a paradigm example of what physicists mean by tunneling. Unfortunately, it is also a paradigm example of the intense mathematical difficulties that can arise. Simple solvable models of the tunneling barrier lead to equations (including the original 1928 Fowler-Nordheim-type equation) that get predictions of emission current density too low by a factor of 100 or more. If one inserts a more realistic barrier model into the simplest form of the Schrödinger equation, then an awkward mathematical problem arises over the resulting differential equation: it is known to be mathematically impossible in principle to solve this equation exactly in terms of the usual functions of mathematical physics, or in any simple way. To get even an approximate solution, it is necessary to use special approximate methods known in physics as "semi-classical" or "quasi-classical" methods. Worse, a mathematical error was made in the original application of these methods to field emission, and even the corrected theory that was put in place in the 1950s has been formally incomplete until very recently."

Source: Wikipedia article titled "Field electron emission" as of July 10, 2010 http://en.wikipedia.org/wiki/Field_electron_emission

High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 6

D. Seidman's candid comments on field emission and breakdown in a grant proposal written back in 2005:

Seidman is the Walter P. Murphy Professor of Materials Science and Engineering at Northwestern University in Evanston, IL, and leads the Seidman Research Group at NWU's Center for Atom-Probe Tomography (NUCAPT) - http://arc.nucapt.northwestern.edu/Seidman_Group

Prof. Seidman has a unique knowledge of high surface electric fields, field emission, and arc discharges as a result of his many years of work with atom-probe tomography (APT) which uses nanoscale local electric fields of 10^{10} V/m *and higher* to image the structure and analyze the chemical composition of surfaces on near atomic-scales (see image to right courtesy of Imago, Inc., a manufacturer of APTs)

Quoting (ca. 2005), "NUCAPT is among the world leaders in the field of three-dimensional atom-probe microscopy, particularly as result of the recent installation of a LEAP microscope, manufactured by Imago Scientific Instruments. Currently only three other LEAP microscopes, with a comparable performance, exist throughout the world."

Readers will find a boldness and blunt candor in Seidman's insightful remarks to follow that tend to be absent in published refereed papers

Seidman's quoted remarks were made in the context of a publicly posted 2005 grant proposal: Seidman, D., and Norem, J., "Experimental study of high field limits of RF cavities"

Please see source URL:

http://www.hep.uiuc.edu/LCRD/LCRD_UCLC_proposal_FY05/2_49_Seidman_Norem.pdf

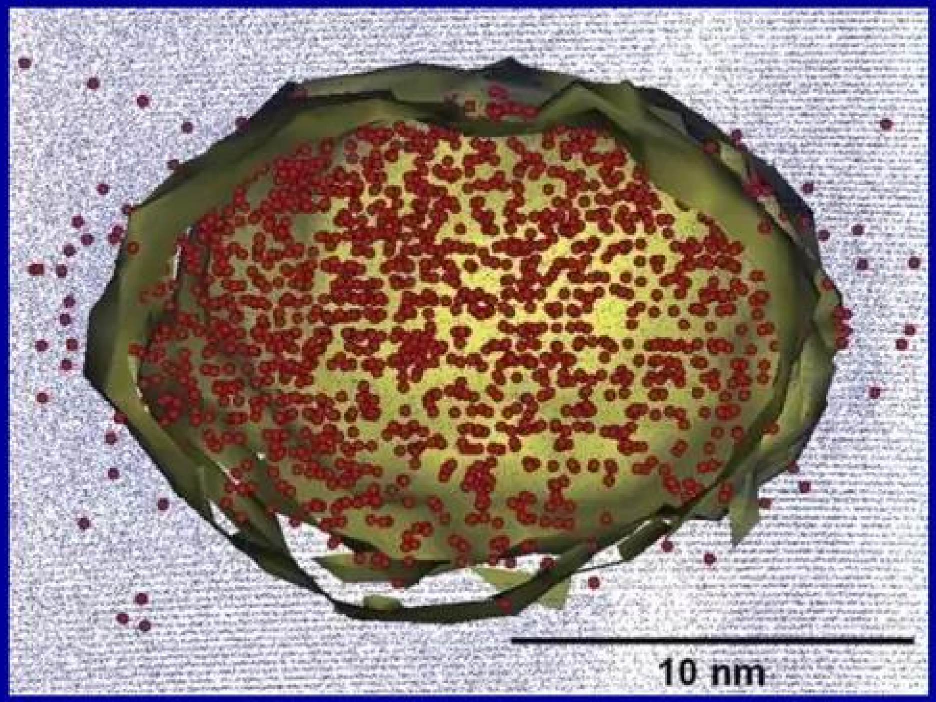


Image: Larson & Kelly, Imago, Inc., local-electrode atom probe image of ordered $L1_2$ Al_3Sc precipitate in aluminum matrix (Al – blue, Sc – red). The <200> planar spacing of the crystalline Al lattice (spacing ~0.2nm) is evident and contrasts with the <100> planar spacing (~0.4 nm) of the Al_3Sc precipitate. Alloy provided by van Dalen, Dun, and Seidman

High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 7

Seidman's comments circa 2005:

"[Electric arc] breakdown at surfaces was discovered by Earhart and Michelson, at [the University of] Chicago, in 1900 … While checking the new 'electron' theory of gas breakdown at small distances, they discovered that there were two mechanisms present, at large distances gas breakdown dominated, and at small distances [i.e., on small length-scales] breakdown of the surface was correctly identified as the mechanism. The break point where the two mechanisms met, at atmospheric pressure, occurs at about 300 V … This was confirmed 5 years later by Hobbs and Millikan, and is consistent with modern data on vacuum breakdown."

"Although high electric fields have been used in DC and RF applications for many years, up to now there has been no fundamental agreement on the cause of breakdown in these systems … Until our work, no theoretical understanding of this process developed over the last 100 years, although many papers have been written."

"Another interesting feature of this [electrical breakdown] mechanism is that the power densities involved are enormous. The numbers can be obtained from the values we measured for field emitted currents, electric field, the emitter dimensions, and volume for transferring electromagnetic field energy into electron kinetic energy. Combining these gives, (10 GV/m)(10^{-7} m)(1 mA)/(10^{-7}m)^3 = 10^{21} W/m^3, a value that seems to be greater than all other natural effects, except perhaps Gamma Ray Bursters (GRB's). The power density is comparable to nuclear weapons. Michelson and Millikan noticed the 'hot sparks' in 1905, bought a vacuum pump, (which they didn't have), and invented vacuum ultraviolet spectroscopy. Both moved on, and did not look in detail at the mechanisms involved."

Seidman, D., and Norem, J., "Experimental study of high field limits of RF cavities"

Again, please refer to source URL:

http://www.hep.uiuc.edu/LCRD/LCRD_UCLC_proposal_FY05/2_49_Seidman_Norem.pdf

In the following Slide, we modify a chart shown in Seidman & Norem's above-noted proposal to illustrate the very approximate regions of physical parameter space in which LENRs may occur if ALL the necessary preconditions that we have previously outlined are obtained. ***Please note carefully that just the presence of very high local E-M fields by itself does not guarantee that LENRs will take place at a given location in time and space***

Also please note that once the nuclear processes begin, power densities in LENR-active 'patches' can go even higher for brief periods of time until nearby nanostructures are destroyed by violent 'flash' heating and LENRs temporarily cease in a given 'patch' (all of this occurs on the order of <1 to 200 nanoseconds)

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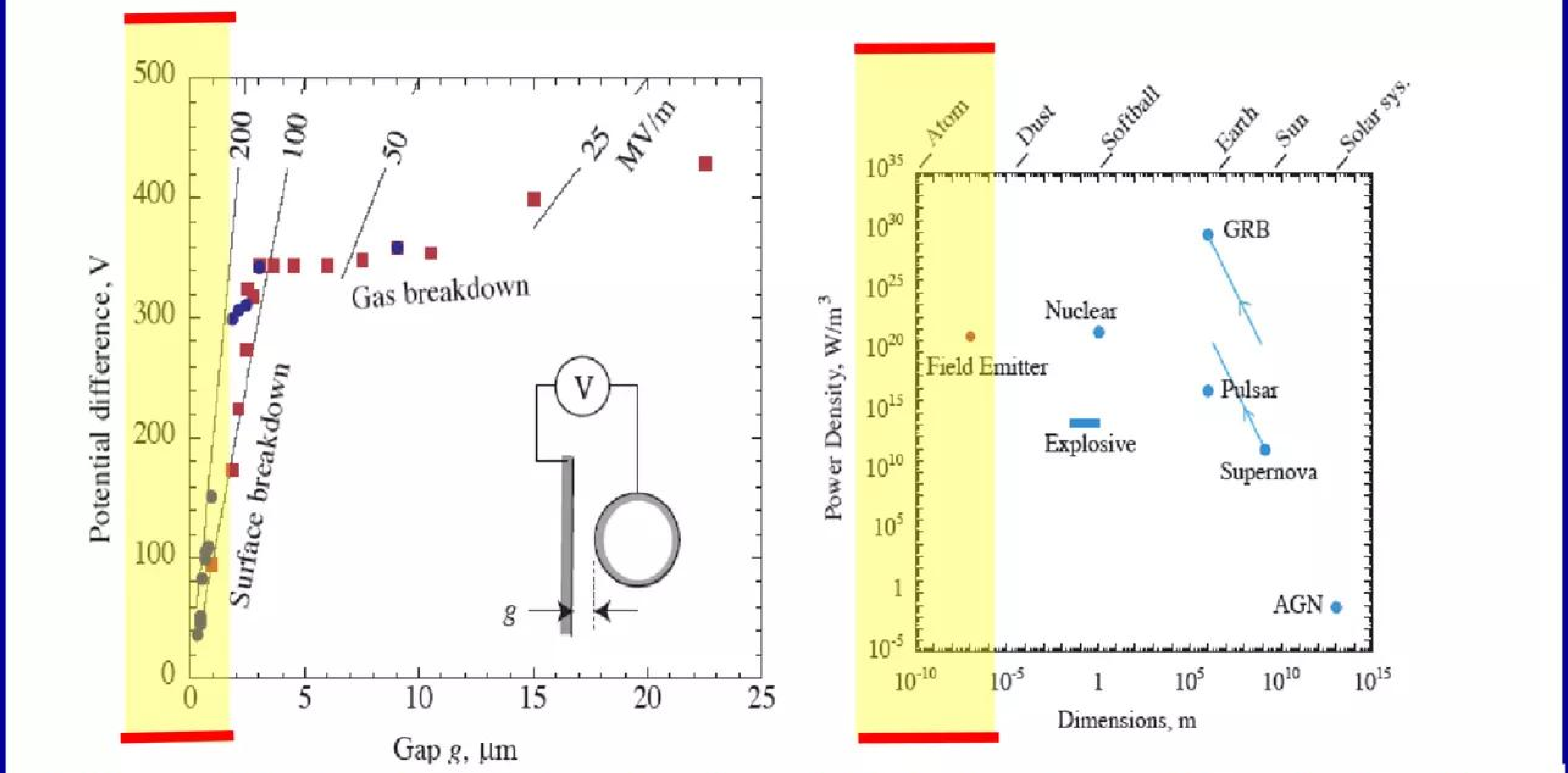
High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 8

Adapted by L. Larsen after Seidman and Norem (2005)



<u>Lattice modification of original chart</u>: yellow-shaded regions 'capped' by red-colored bars are approx. regions of parameter space where LENRs may occur in condensed matter systems IF all of the necessary conditions met (please refer back to an earlier Slide)

<u>Source</u>: :Fig. 2, pp. #3, Seidman & Norem proposal, "Experimental study of high field limits of RF cavities" (2005)

High E-fields important in condensed matter LENRs

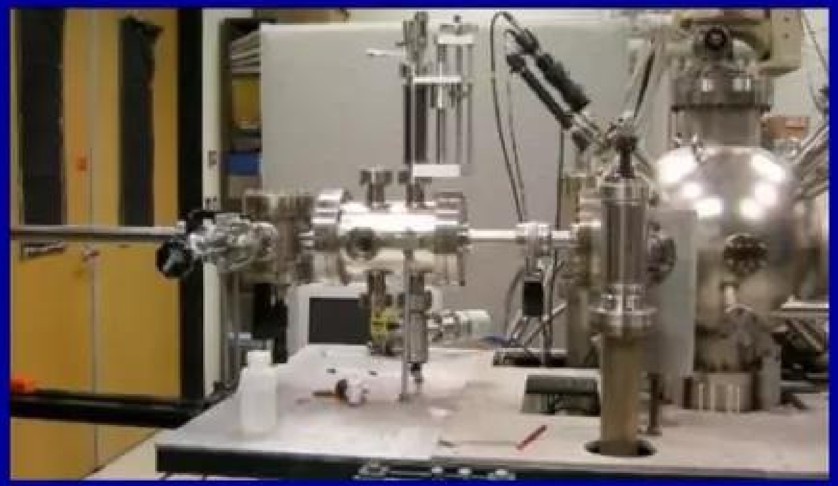
Lightning rod effect, electrical arc discharges, and field emission - 9

D. Seidman's comments circa 2005 (continued):

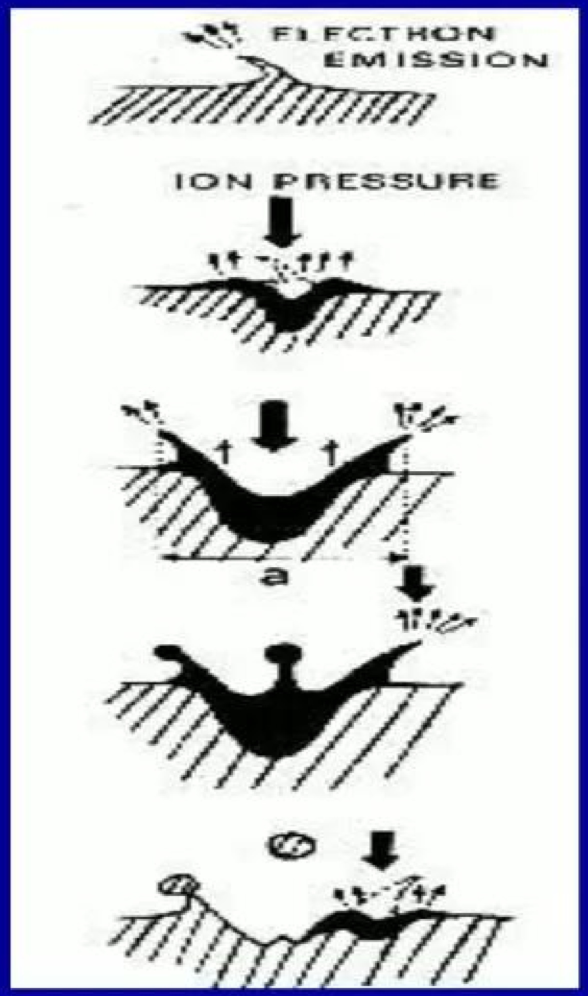
"We think we have developed a model of breakdown that explains the phenomenon in almost all environments ….The model strongly argues that breakdown events are the result of fragments or clusters breaking off of the surface and rapidly being ionized in the electron beams from the field emitter. Within the active volume, the power involved in these beams is comparable to nuclear weapons. This model is also generally in agreement with the experience with APFIM samples at the high fields used. Tiny APFIM samples operate at fields about 5 times higher than the local E field limit we postulate, but they also frequently fail, however there has been no systematic study of these failure modes."

"Combining these two ideas, however, one can conclude that: 1) this mechanism produces perhaps the highest power density commonly found in nature, and, 2) it is accessible to anyone with a wall switch or an electric light, and is used many times a day by everyone."

"While there has been extensive study of the time development of breakdown events from the first small local ionization to complete breakdown of a cavity, the trigger for breakdown, and how it was related to the metallurgy of surfaces has received very little attention until now. Our model predicts that the production of clusters and fragments is an essential component of breakdown. This is consistent with experience in Atom Probe Tomography, however there is almost no systematic data on sample failures under the high field environment used in data taking. Our previous work has been published in three refereed papers and many conference papers."



Pulsed Laser Atom Probe Microscope at NWU, Source: :Fig. 7, pp. #9, Seidman & Norem proposal (2005)



Breakdown of surface
Figure courtesy of B. Jüttner, Berlin

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High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 10

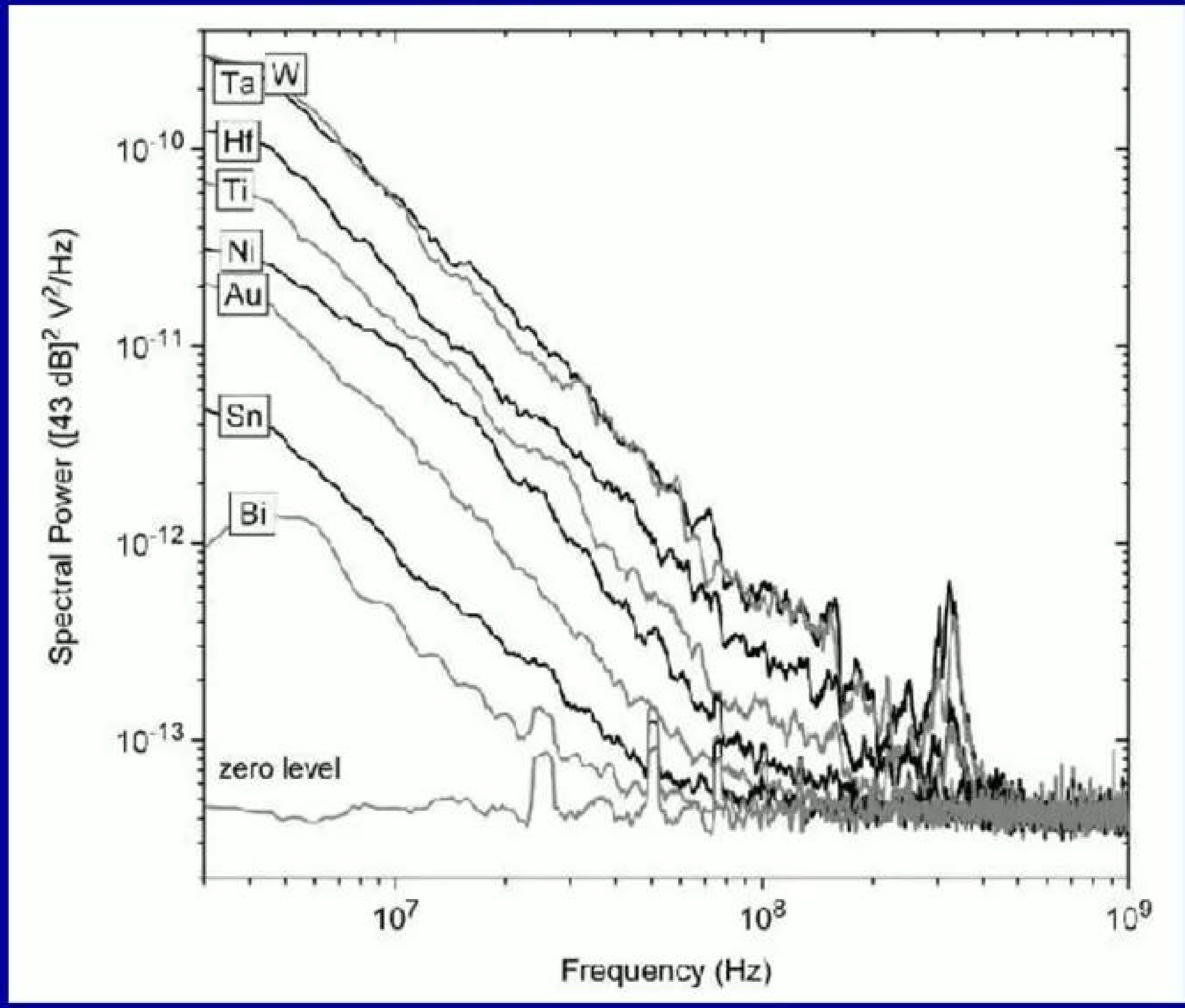
In 2010, Dr. Andre Anders of Lawrence Berkeley National Laboratory (LBNL) publicly posted a very interesting 32-slide PowerPoint presentation titled, "Cathodic Arcs, and related phenomena":

Among other things, he believes that 'hot cathode spots' are fractal, as shown in the Figure to the right, and that the electron current is higher than the arc current (his Slide #6)

On Slide #7, he makes an important distinction between *collective* electron emissions that occur in arc discharge regimes (namely, thermionic, field, thermo-field, and explosive emissions) versus "*individual*" electron emission mechanisms (such as secondary electron emission by primary ion, electron, or excited atom impact, and photo-emission) that tend to occur in glow discharge regimes

On Slide #11, he describes an "arc spot ignition" involving a, "Local thermal run-away process [that] leads to micro-explosion and formation of extremely dense plasma."

Evidence that "cathode spots" are fractal:



Original source: A. Anders, "Cathodic Arcs," Springer, NY (2008)

In 2010, this Figure appears in a workshop presentation:

A. Anders (Lawrence Berkeley National Laboratory - LBNL), "Cathodic Arcs, and related phenomena," work supported by the U.S. Department of Energy under Contract DE-AC02-05CH11231

URL =

https://twindico.hep.anl.gov/indico/getFile.py/access?sessionId=3&resId=0&materialId=1&confId=69

High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 11

Dr. Andre Anders - LBNL (continued):

On Slide #11, he then elaborates a model as follows:

High [local] electric field, enhanced by:

- **Protrusion (e.g. roughness, previous arcing)**
- **Charged dielectrics (e.g. dust particles, flakes)**

Feedback Loop

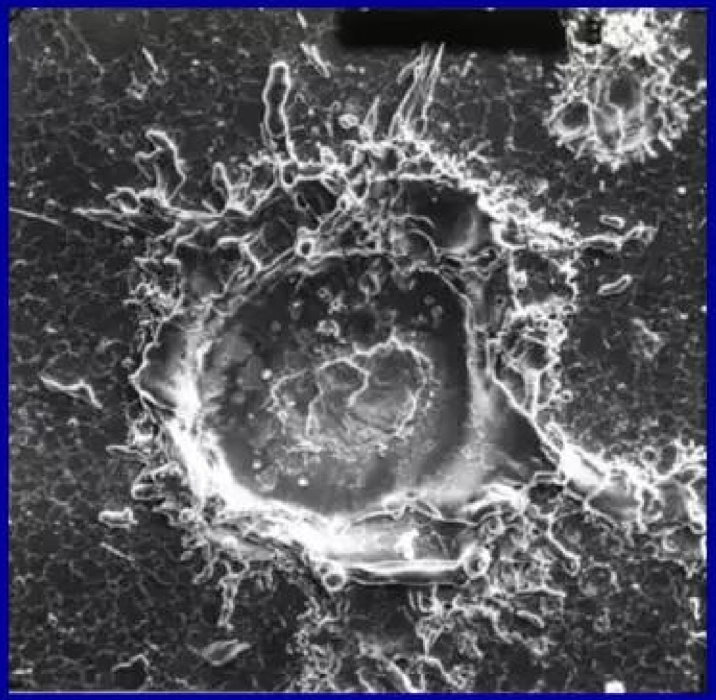
1. **Higher field leads to locally greater e-emission**
2. **Joule heat enhances temperature of emission site**
3. **Higher temperature amplifies e-emission non-linearly**
4. **Runaway!**

To which we would like to add, based on W-L theory:

5. **LENRs --- if other necessary preconditions are also fulfilled, as we have outlined previously**

Anders then goes on to show an array of fascinating SEM images of surfaces on which 'explosive' cathode arcs have occurred that bear a certain resemblance to post-experiment SEM images of LENR cathodes (with one difference that we will explain)

"Crater" in cathodic arc expt.:



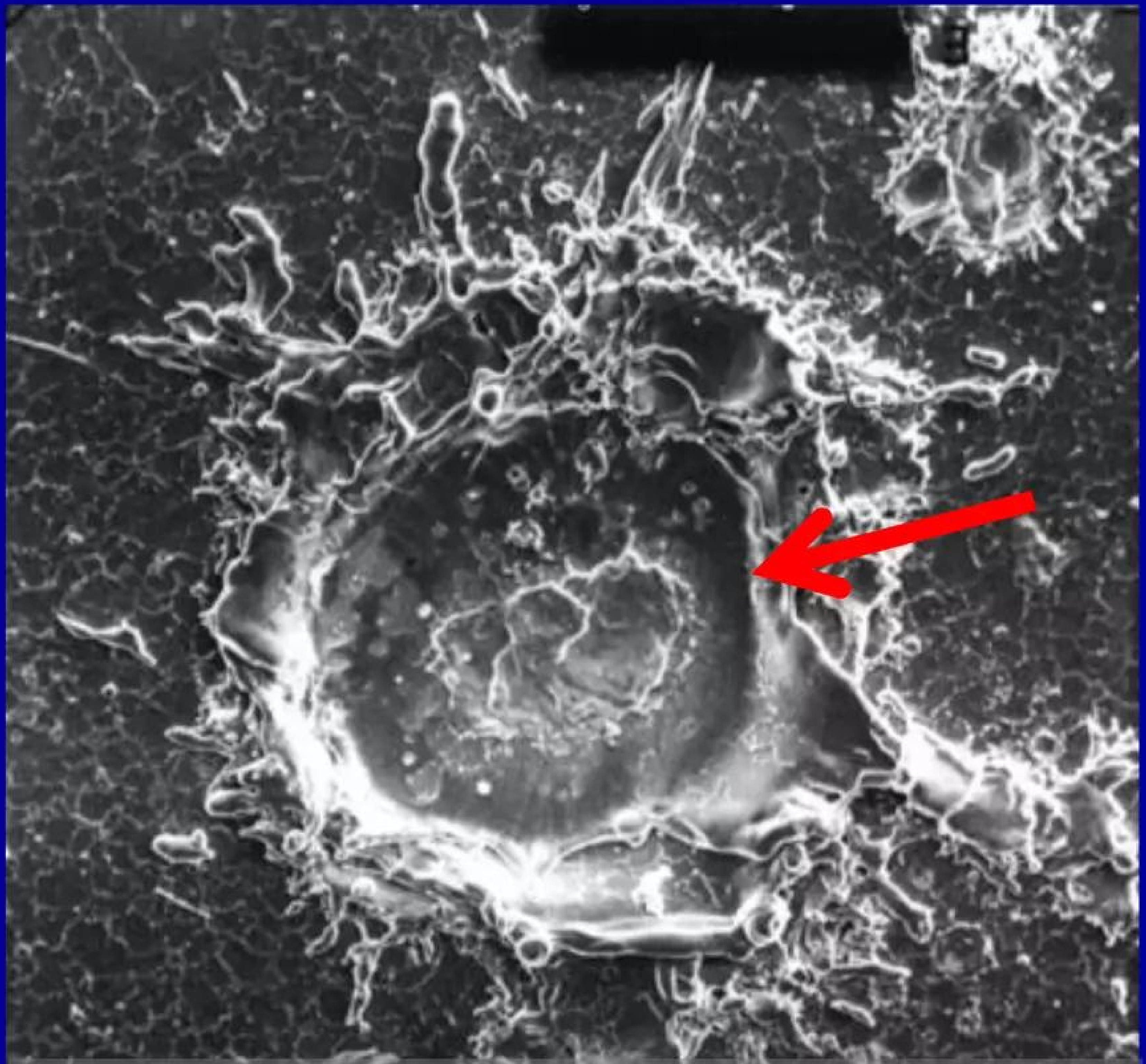
Anders: "Cathodic Arcs, and related phenomena," Slide #12 of 32 (2010)

High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 12

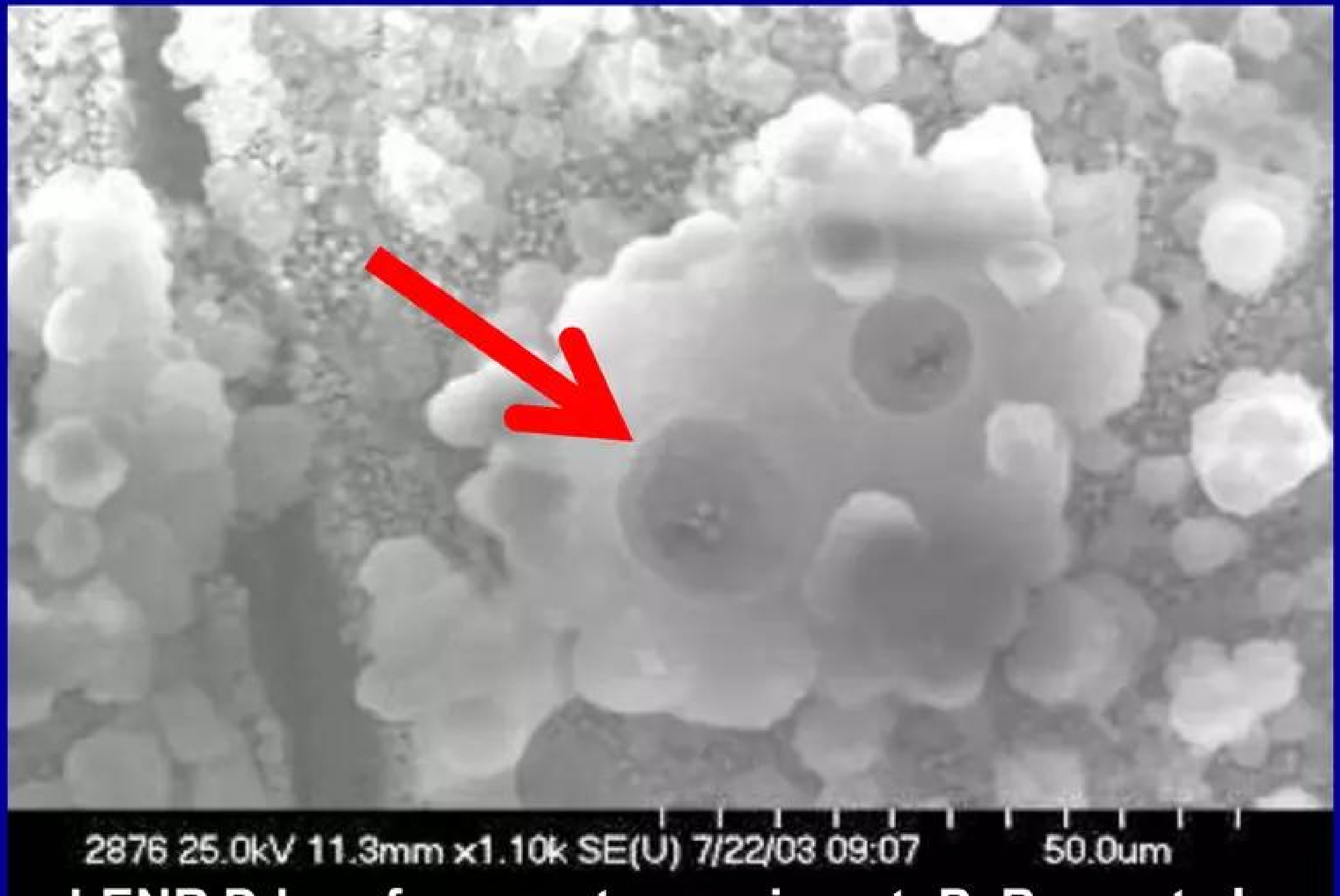
Anders' SEM photos vs. selected images of post-experiment surfaces in LENR experiments:

Cathodic Arcs



Anders cathodic arc: post- experiment surface feature

LENRs



LENR Pd surface post-experiment: P. Boss et al.

Please note what appears to be a somewhat common morphological difference between LENR 'craters' and those produced by prosaic cathodic arcs as discussed by Anders. Many central 'craters' in LENR SEM images often appear to have more sharply defined, 'crisper' interior walls and greater depths (relative to the surface area) compared to arc discharges without LENRs; this might be indicative of even more rapid, higher levels of heating than those contemplated by Anders

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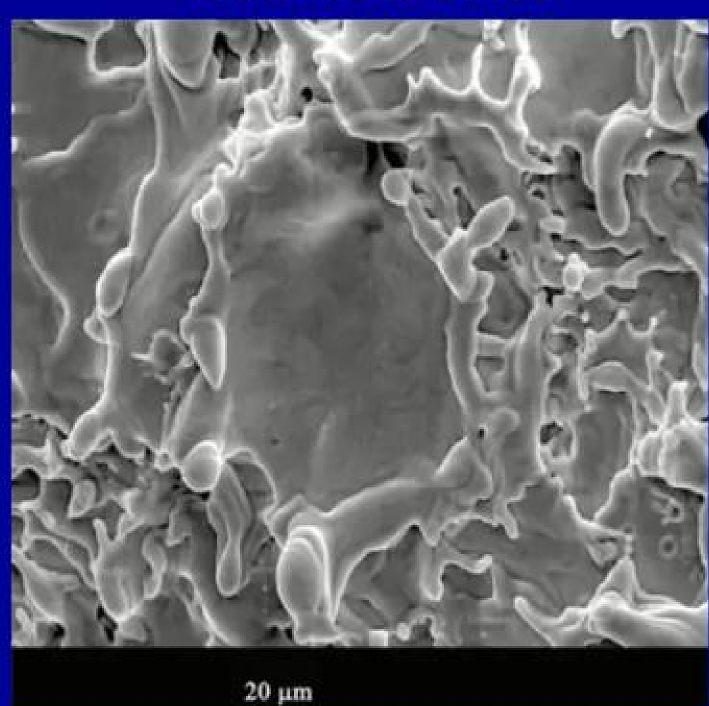
High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 13

Anders' SEM photos vs. selected images of post-experiment surfaces in LENR experiments:

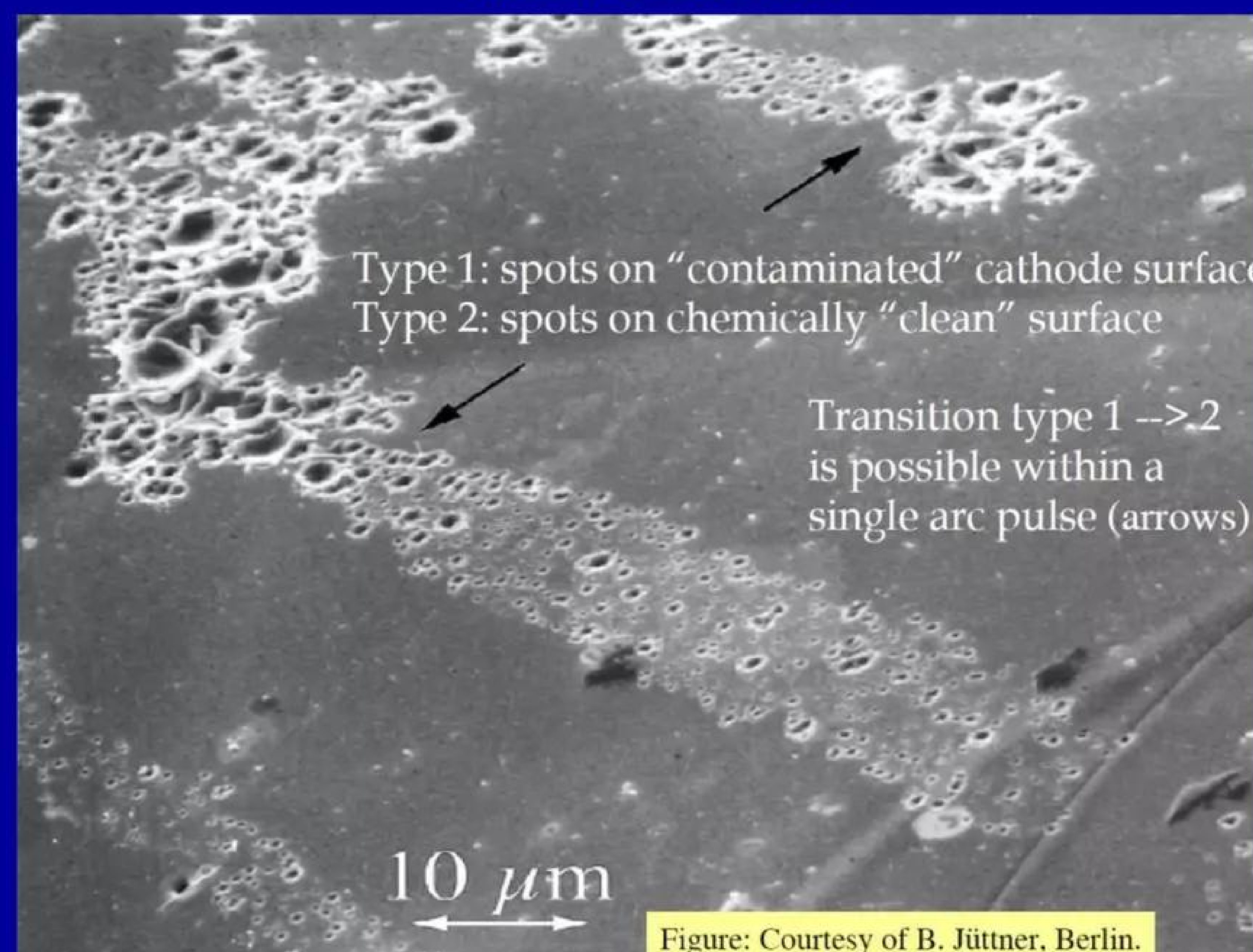
Cathodic Arcs



A. Anders "Cathodic Arcs, and related phenomena" (2010)

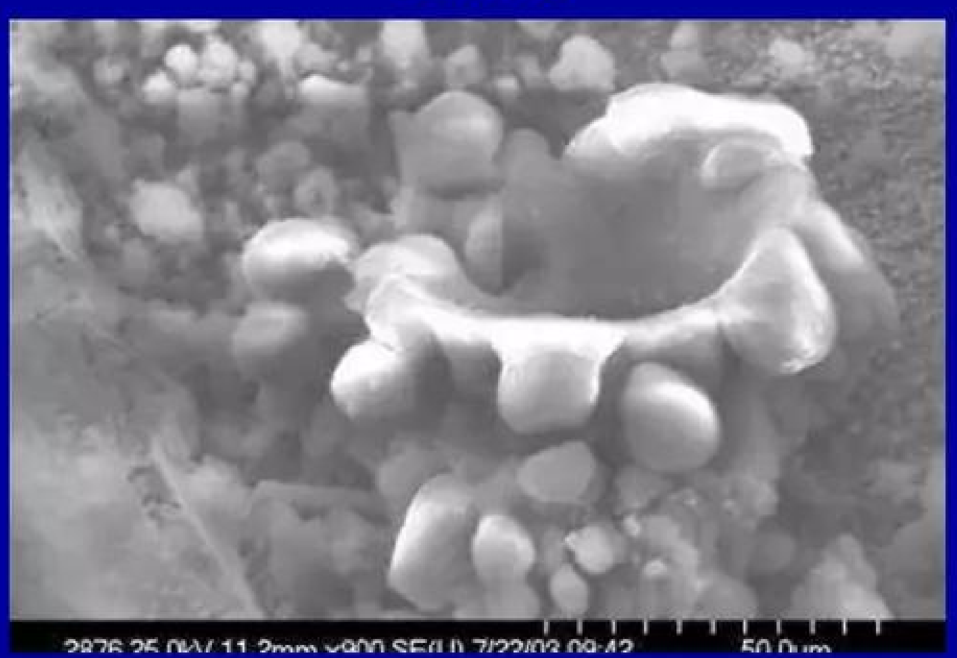
Cathodic Arcs

Anders: Slide #27

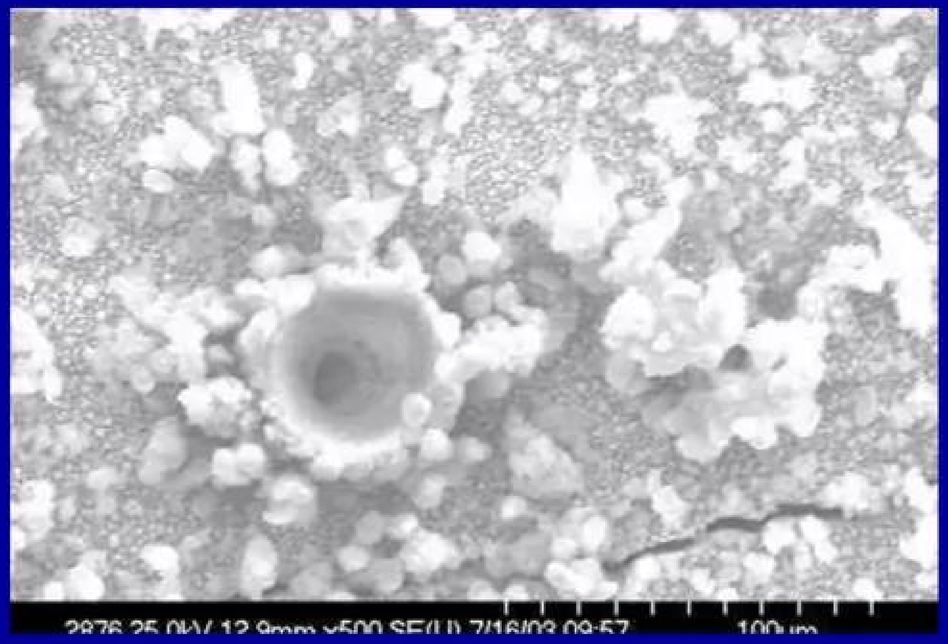


A. Anders "Cathodic Arcs, and related phenomena" (2010)

LENRs



P. Boss et al. , US Navy - SPAWAR



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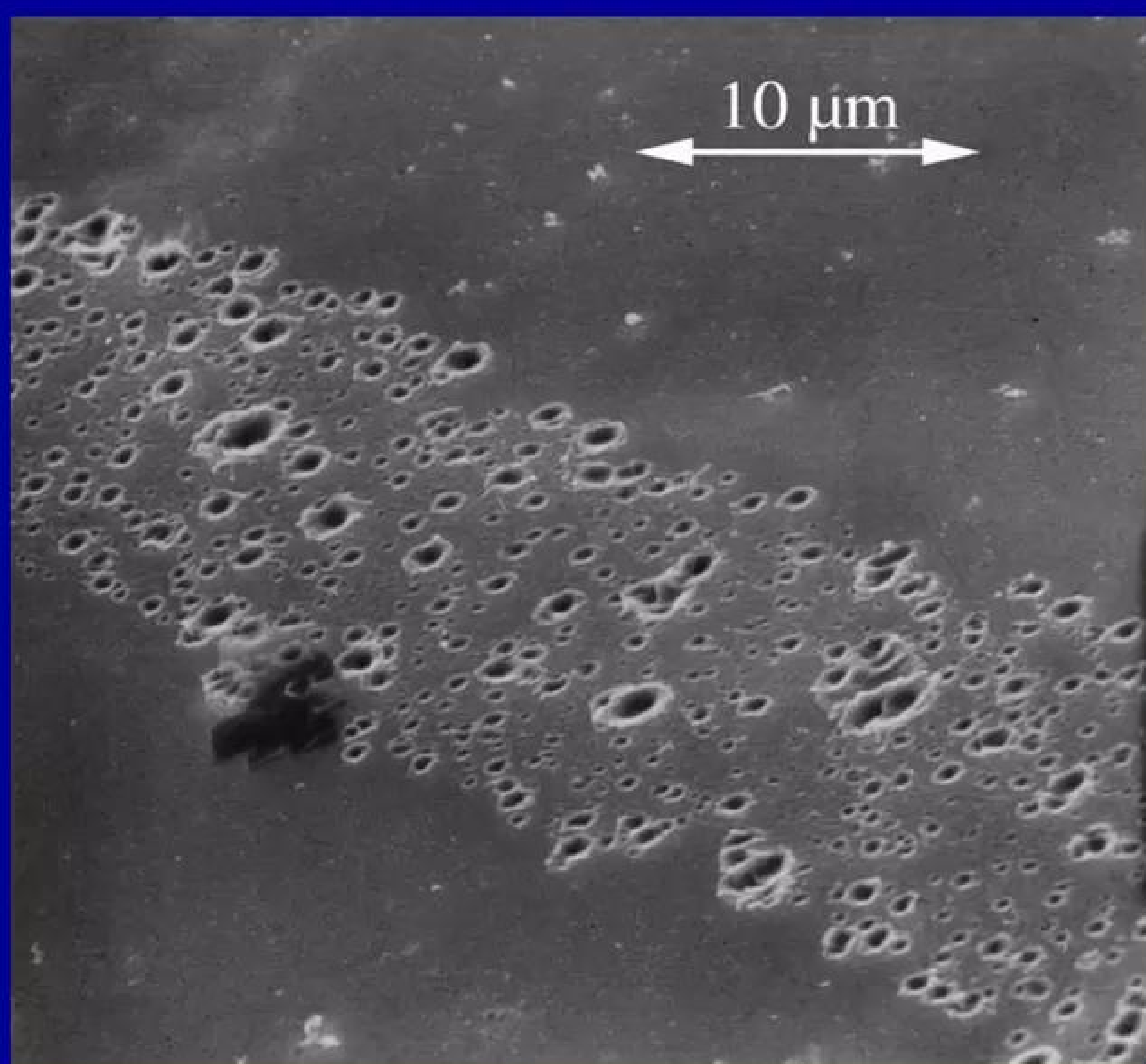
High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 14

Anders' SEM photos vs. selected images of post-experiment surfaces in LENR experiments:

Cathodic Arcs

A. Anders "Cathodic Arcs, and related phenomena" (2010)



Anders: Spot Type 1 - "contaminated" surface

LENR surface, which started-out smooth at the beginning of the experiment, appears to be much rougher in texture than cathodic arc

Free copy of Zhang and Dash paper at:

http://www.lenr-canr.org/acrobat/ZhangWSexcessheat.pdf

Quoting from discussion of Fig. 10: "Ni was listed as "not detected" in the chemical analysis provided by the vendor of the Pd foil. It is very unlikely to have resulted from the cold rolling process or from electrodeposition because it is highly localized near one corner of the cathode. If it is the result of either contamination from the rolling mill or from electroplating it should not be highly localized on only one corner of the cathode. It could not have resulted from SEM systems because the stainless steel components of the SEM chamber also contain Fe and Cr. Fe and/or Cr are not present in any of the spectra. The SEM does not have components made of pure Ni. Therefore, the origin of the Ni is not known."

LENRs

Zhang and Dash (2007) --- Fig. 10. SEM picture of region #2 in Fig. 4(b). SEM No.WS060424Pd-H-CC-i2-150X

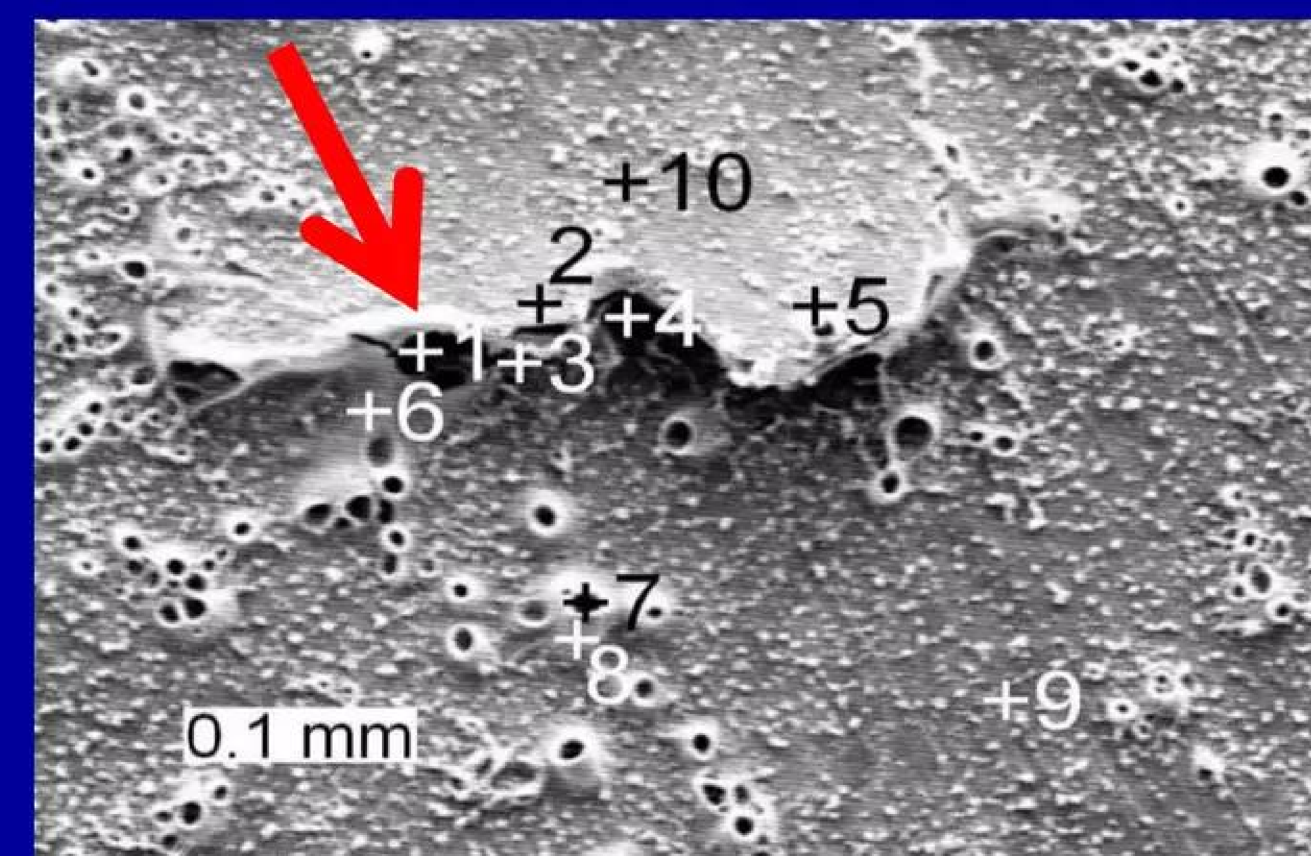
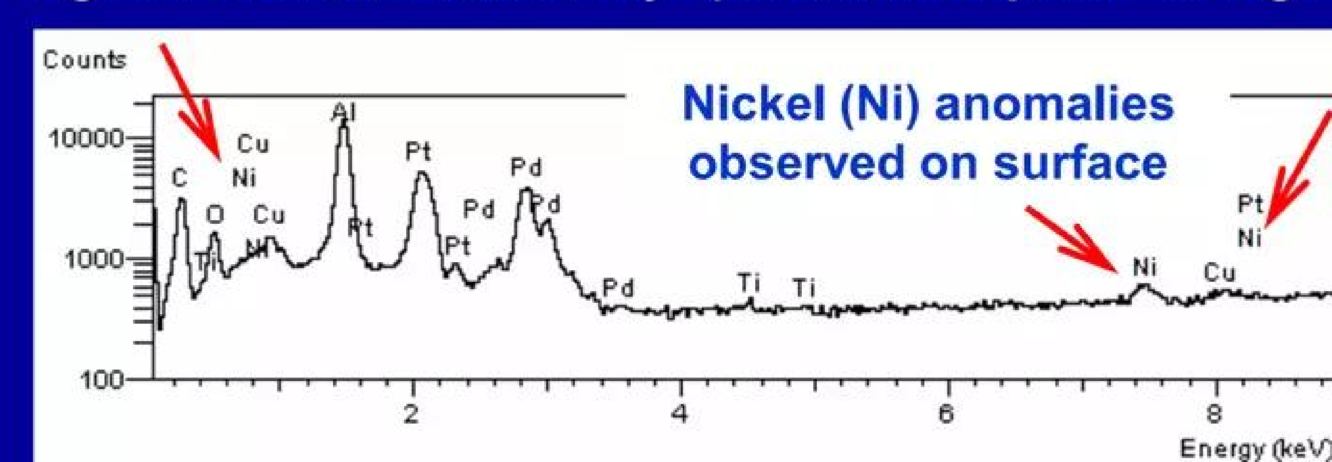


Fig. 11. Characteristic X-ray spectrum of spot #1 in Fig. 10.



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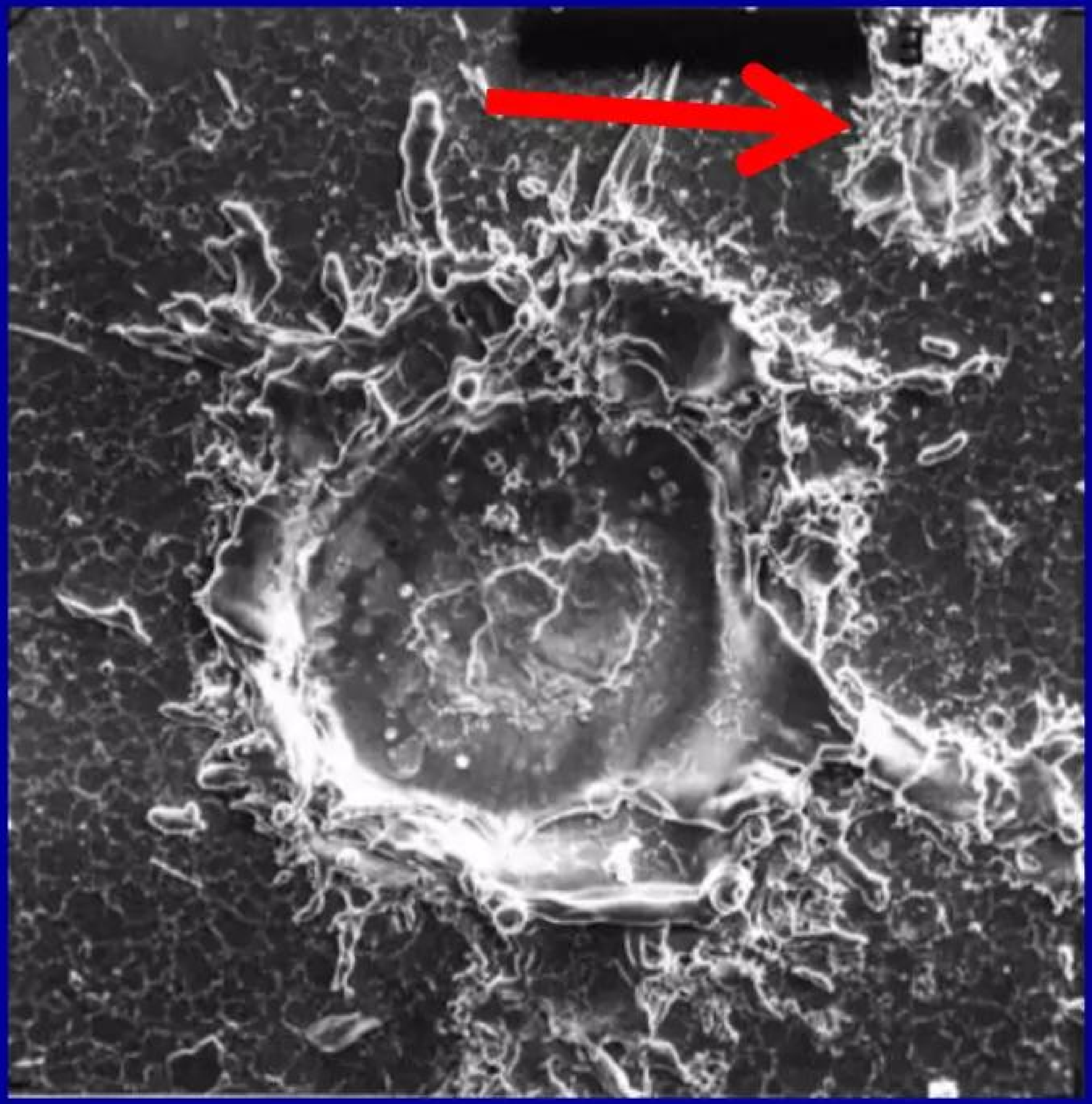
High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 15

Anders' SEM photos vs. selected images of post-experiment surfaces in LENR experiments:

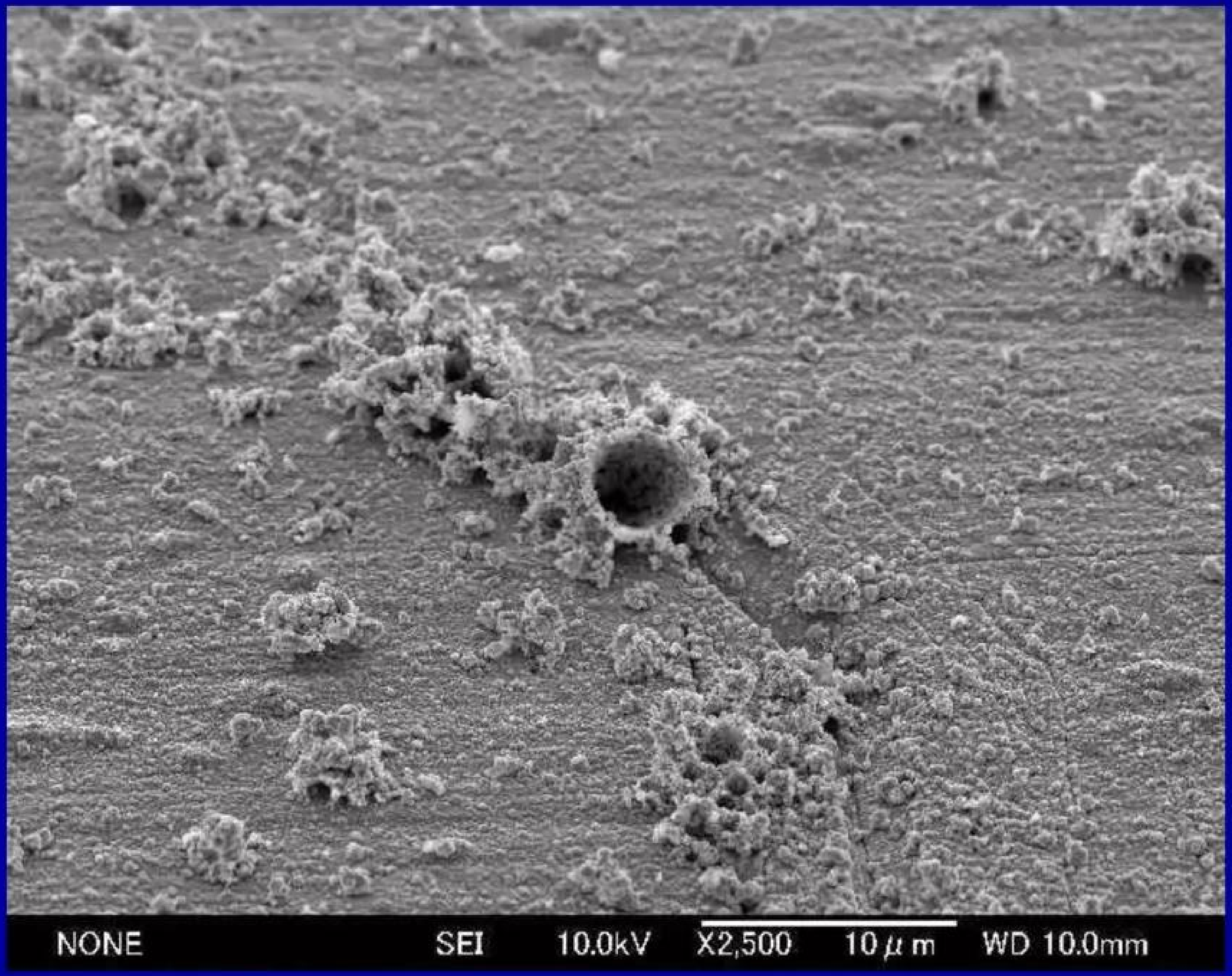
Cathodic Arcs



Anders: "Cathodic Arcs, and related phenomena," Slide #12 of 32 (2010)

LENRs

Free copy of paper: http://www.lenr-canr.org/acrobat/ToriyabeYelementala.pdf



"Elemental analysis of palladium electrodes after Pd/Pd light water critical electrolysis" Y. Toriabe et al., Fig. 9

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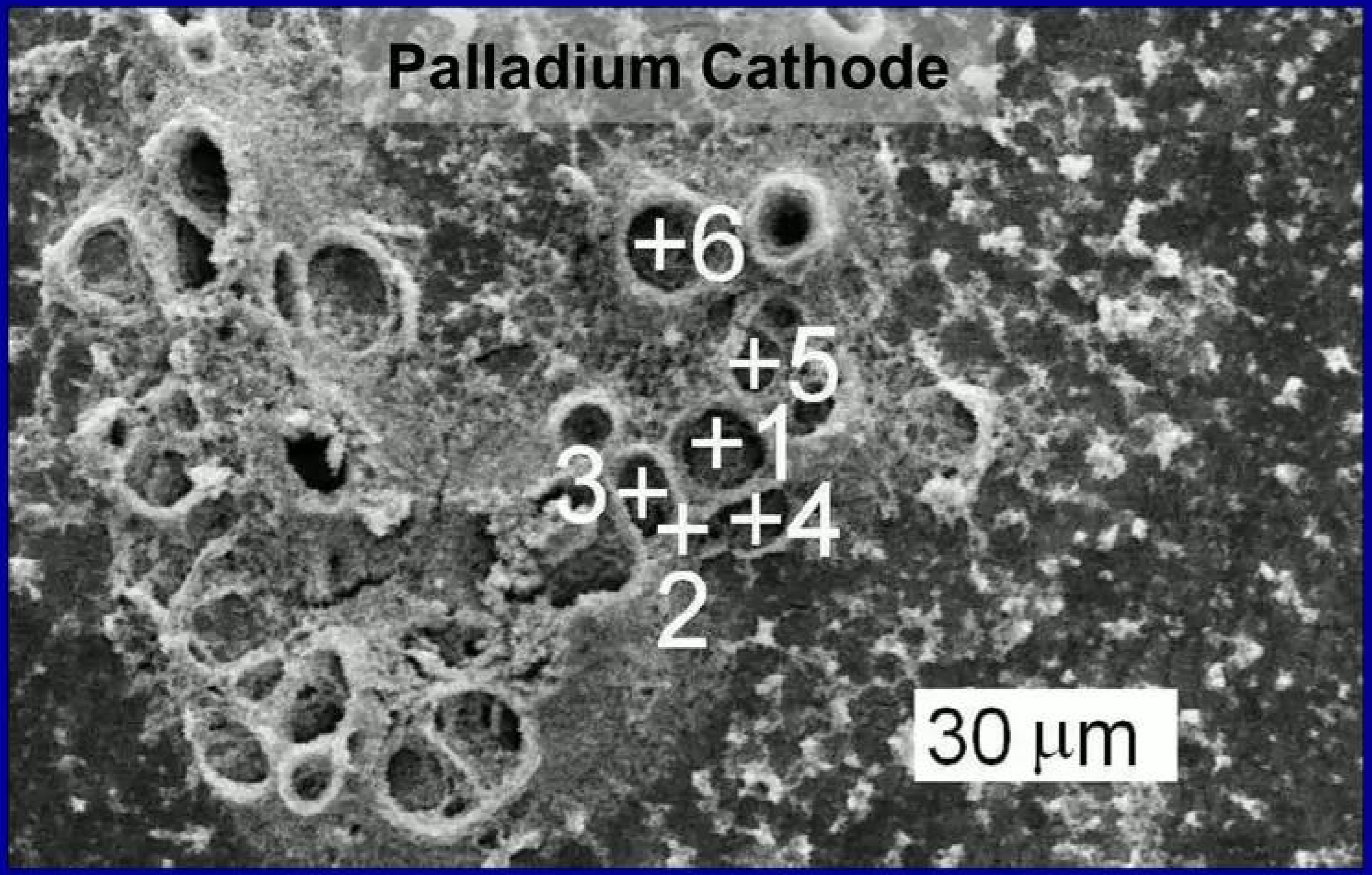
High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 16

Selected images of post-experiment surfaces in LENR experiments by Zhang and Dash:

LENRs: Zhang and Dash (2007) - Fig. 8



Note: Pd surface b.p. = 2,970^{O}C

Free copy of Zhang and Dash paper at:

http://www.lenr-canr.org/acrobat/ZhangWSexcessheat.pdf

LENRs: Zhang and Dash (2007) - Fig. 9

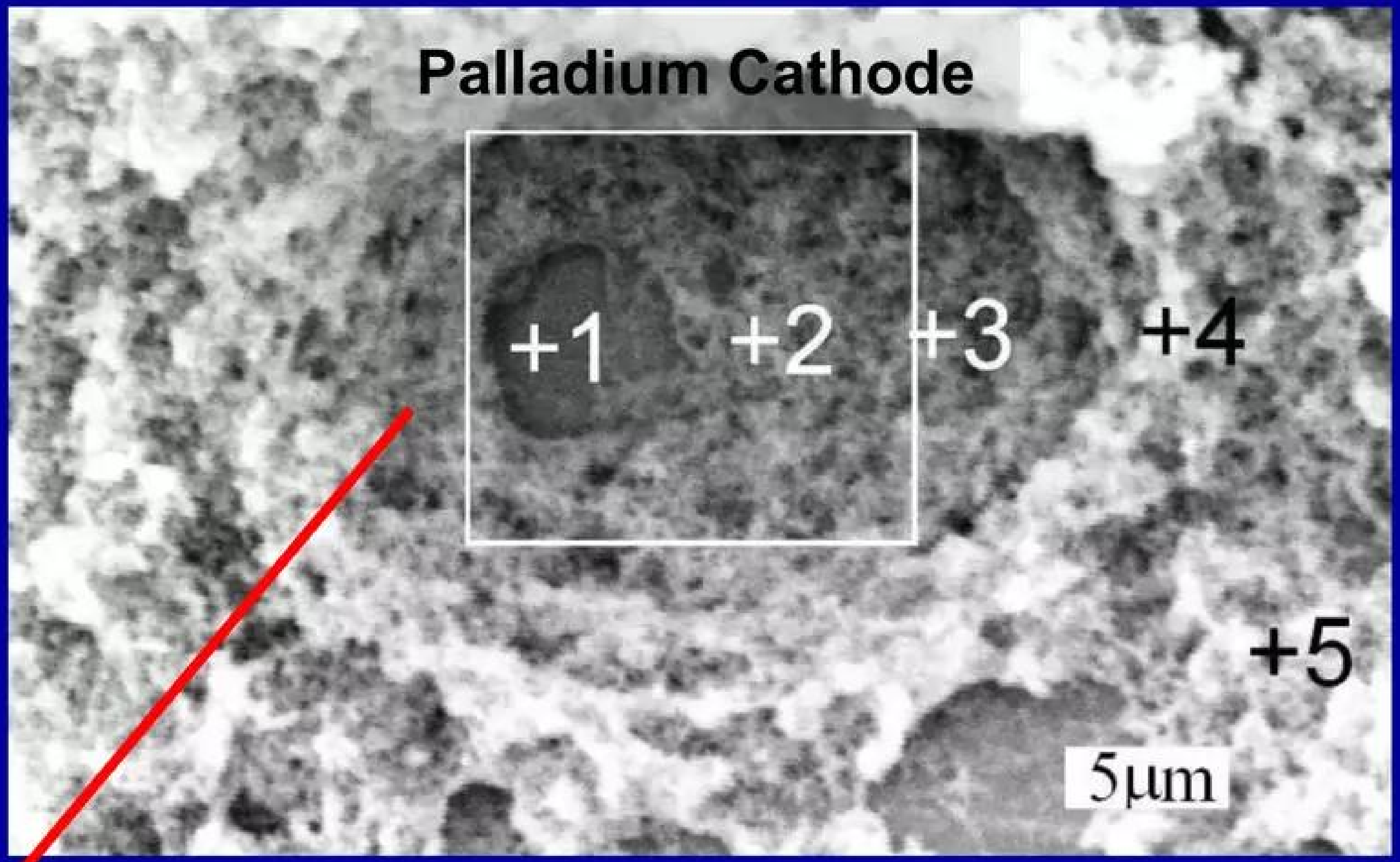


Fig. 9. SEM picture of crater at another time. SEM No.WS060607Pd-H-CC-i2-2kX

Quoting: "The most common finding is that silver occurs in craters, such as those shown in Fig. 8. These craters with rims almost certainly formed during electrolysis. Pt deposition was concentrated on these protruding rims."

Zhang and Dash: Table IX. Relative atomic percent concentrations of silver (Ag) in area and spots shown in Fig. 9

Spot #	wa*	area**	+1	+2	+3	+4	+5
Ag/(Pd+Ag)	1.2 +/- 0.5	5.6 +/- 0.4	6.8 +/- 0.4	5.6 +/- 0.3	6.3 +/- 0.4	3.6 +/- 0.6	1.2 +/- 0.5

*wa = whole entire area comprising image in Fig. 9

** area = delimited by the white square outlined in Fig. 9

Following likely took place in these experiments:

neutron capture — beta decay

Pd + n ⟶ unstable n-rich Pd isotope ⟶ Ag isotopes

High E-fields important in condensed matter LENRs

Lightning rod effect, electrical arc discharges, and field emission - 17

Anders' SEM photos vs. selected images of post-experiment surfaces in LENR experiments:

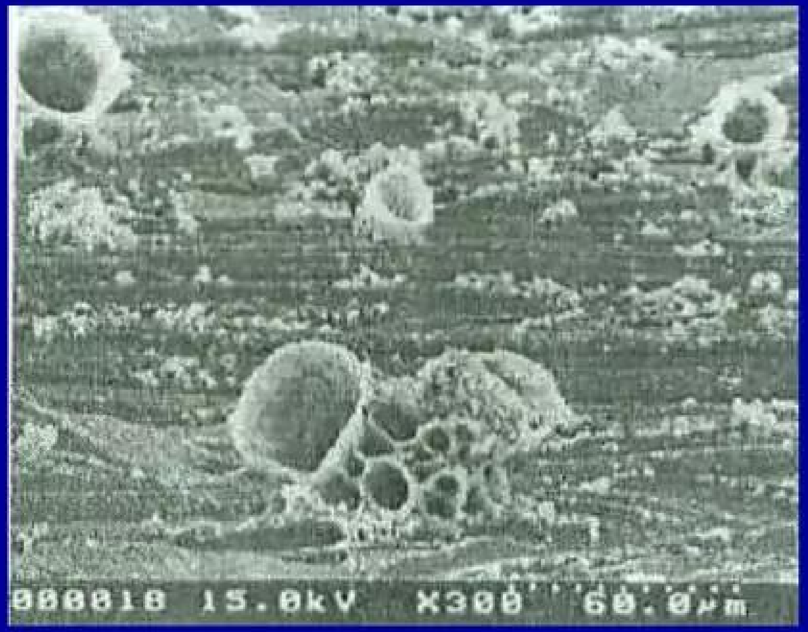
<u>Comments</u>:

- ✓ **Although there are differences, there is a degree of morphological similarity in SEM images of post-experiment cathodic arc surfaces (e.g., crater-like structures) versus those observed in LENR experiments**
- ✓ **To the extent that such morphologies are truly indicative of very rapid heating and quenching in small areas of cathode surfaces, it implies that temperatures reached in such 'spots' or 'patches' were briefly high enough to melt, if not boil, substrate metals, e.g., Pd b.p. = $2,970^{o}C$**
- ✓ **While local E-M field strengths were not measured or estimated in the LENR experiments, they may have been at least as high as those reached in the cathodic arcs discussed by Anders, i.e., 10^{10} V/m or even higher**
- ✓ **W-L theory would suggest that, if the necessary preconditions are met, LENRs can be triggered in high-local-current arcs and related high-field electrical phenomena including field emission and surface breakdown**
- ✓ **Variety of different nuclear transmutation products observed by a large number of LENR researchers in and around surface structures such as 'craters' suggests that LENRs are probably occurring in such locations**

LENRs

Y. Toriabe et al

Y. Toriabe et al

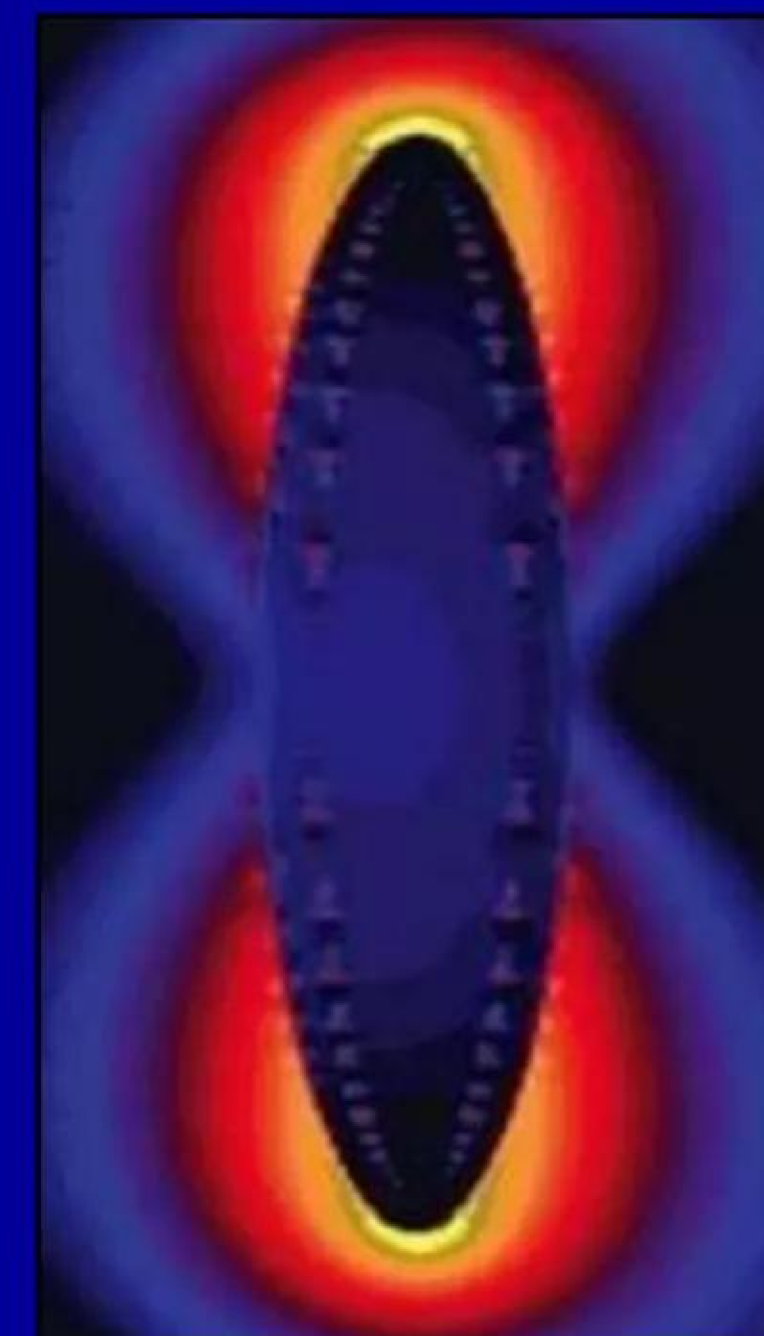


High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 1

Surface plasmons are one key element of LENRs in condensed matter:

- ✓ **Surface plasmon (SP) electrons and B-O breakdown on surfaces are central elements in W-L theory of LENRs in condensed matter**
- ✓ **Surface plasmons have many-body collective oscillation modes, e.g., longitudinal, that are crucial to operation of coherent, many-body interactions (effectively 'entangled' Q-M wave functions) in W-L theory**
- ✓ **Mass-renormalized (i.e., $e_{sp} \rightarrow e_{sp}*$) SPs are the 'type' of electrons that react directly with many-body 'patches' of protons (p^+), deuterons (d^+), or tritons (t^+) to collectively produce ultra-long wavelength, ultra low momentum neutrons (n_{ulm}) via weak interaction in the W-L theory**
- ✓ **High local E-M fields provide input energy necessary to drive ULMN production at substantial rates; produced neutrons capture on nearby atoms (very few thermalized prior to capture - no neutron radiation)**
- ✓ **Please note that this is NOT the same thing as inner-electron (e.g., K-shell) capture reactions; LENRs mainly take place on or near 'surfaces'**
- ✓ **Heavy-mass ($e_{sp}*$) electrons can directly convert 'hard' gamma photons into infrared photons at high efficiencies (little or no γ - ray radiation)**



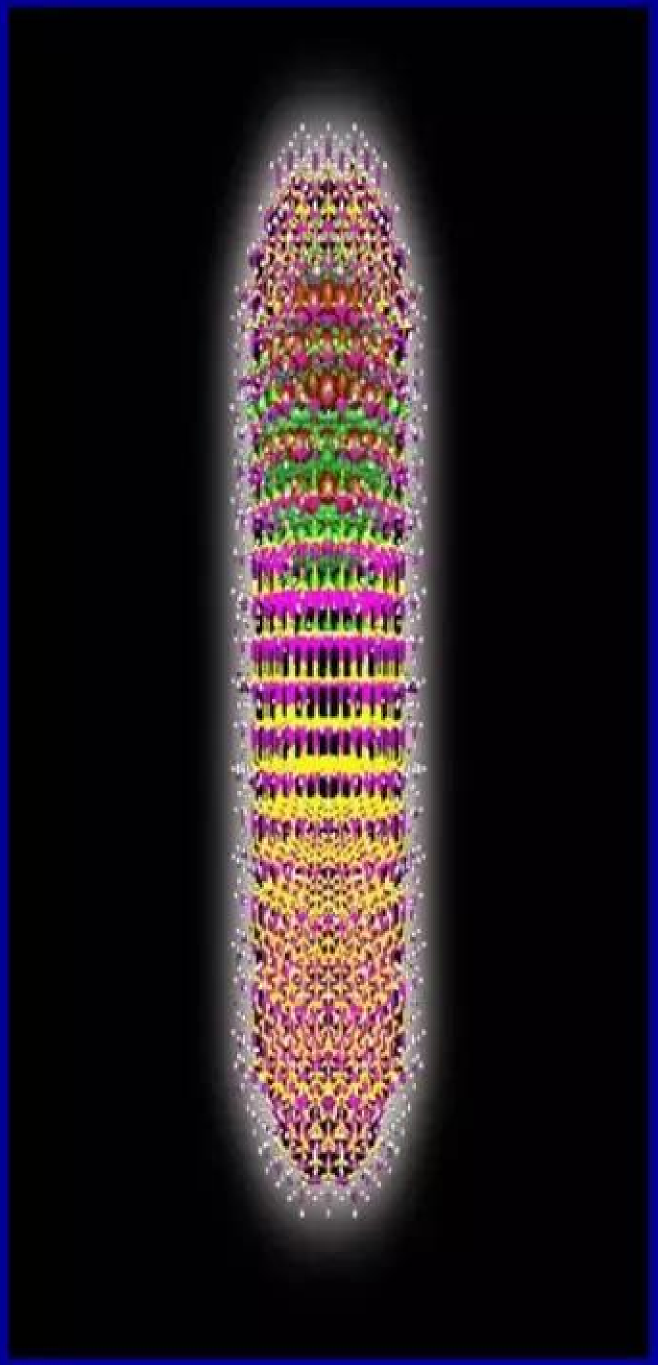
High local SPP electric fields surrounding "nanorice" - Au coating on hematite core

High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 2

Surface plasmons are one key element of LENRs in condensed matter:

- ✓ In this presentation, we have previously discussed topics of electrical arc discharge phenomena (e.g., short-outs at sharp tips of dendrites) and high-E-M-field processes like field emission and surface breakdown which can create local heating and a variety of distinctive structural features such as 'craters'
- ✓ On the very same substrate surfaces, there are a myriad of other complex, micron to nanoscale electromagnetic processes *operating in parallel* that involve interactions between surface plasmons, E-M fields, and a truly enormous array of different types of nanostructures with varied geometries, surface locations relative to each other, and chemical composition; the published literature covering such topics is vast and growing exponentially
- ✓ To greater or lesser degrees, many of these complex, time-varying surface interactions are electromagnetically coupled on a variety of length-scales
- ✓ Surface plasmons and their interactions with nanostructures enable physics that allows LENRs to occur in condensed matter systems under relatively mild *macroscopic* conditions (stars or supernovas not required). In concert with many-body collective effects, SPs also function as two-way 'transducers' that interconnect otherwise distant realms of chemical and nuclear energies



Credit: Argonne National Laboratory, CdSe/CdS core/shell nanorod calculated by the LS3DF code

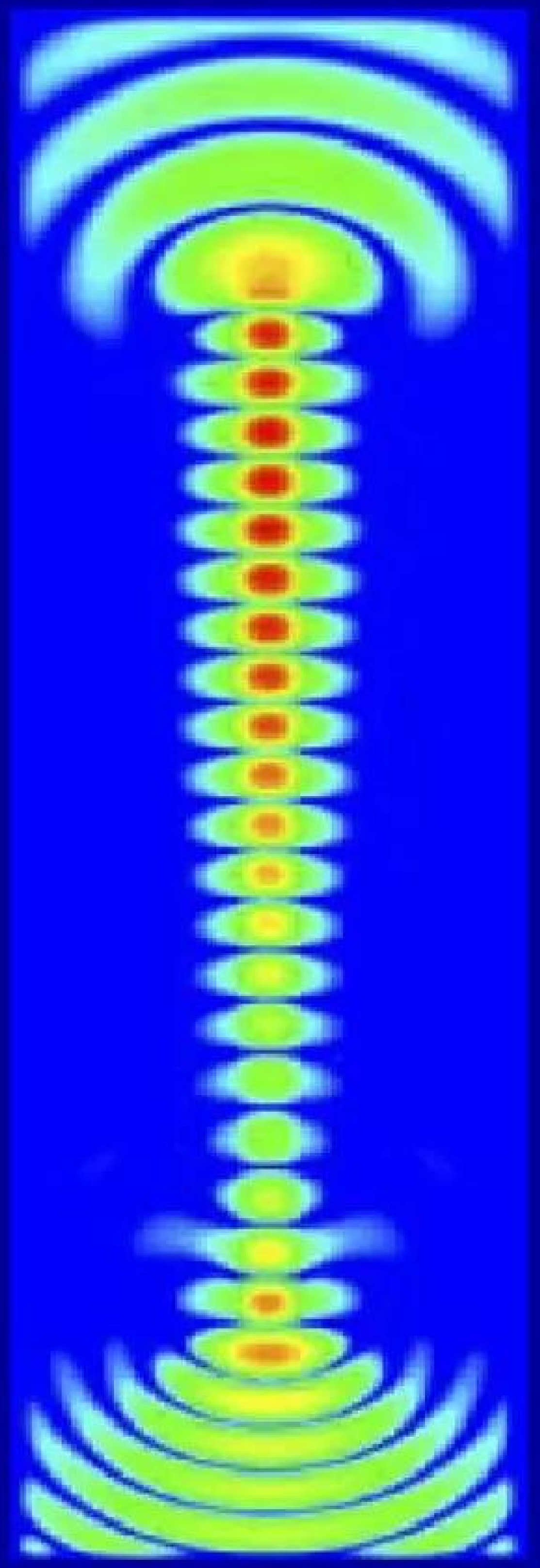
High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 3

Surface plasmons are one key element of LENRs in condensed matter:

- ✓ **We will now provide quotes from selected papers that illustrate E-M processes involving different types of nanostructures in which incident energy in various forms is collected, 'channeled', and 'concentrated' such that local E-M fields are substantially enhanced (so-called β factor). The published literature on this subject matter is so utterly vast and ever-expanding that one cannot even begin to scratch the surface of this relatively new body of knowledge in a full-length book, let alone a short document**

- ✓ **Again, please be aware that a wide variety of complex, interrelated E-M phenomena may be occurring simultaneously in parallel in different *nm* to μ-scale local regions of a given surface. For example, some regions may be absorbing E-M energy locally, while others can be emitting energy (e.g., as energetic electrons, photons, other charged particles, etc.). At the same time, energy can be transferred from regions of absorption or 'capture' to other regions in which emission or 'consumption' is taking place: e.g., photon or electron emission, and/or LENRs in which:** $\textit{E-M field energy} + e \rightarrow e^* + p^+ \rightarrow n_{ulm}$
  --- note that in LENRs, electrons and protons are truly destroyed!



C. Ning, "Nanolasers based on nanowires and surface plasmons," SPIE (2009)

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High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 4

Overview - 1:

[Quoting from Ref. 1] "If metal structures are exposed to electromagnetic radiation, modes of collective charge carrier motion, called plasmons, can be excited ... Surface plasmons can propagate along a distance of several tens of micrometers on the surface of a film ... In the case of one nanoparticle, the surface plasmon is confined to the three dimensions of the nanostructure and it is then called localized surface plasmon (LSP). In this situation, the LSP resonance depends on the metallic nature (effect of the metal permittivity) and on the geometry (effect of the confinement of the electron cloud) of the nanostructure."

"It is a frequently used approximation to consider a metal nanowire as an ideal antenna. This approach has been proposed also for the modeling of nanowires in the visible spectral range ... Field is enhanced at the tip of the nanowire when the excitation wavelength corresponds to an antenna mode ... End of the nanowires in a relatively sharp and abrupt surface is a perfect candidate to host a lightning rod effect."

" ... for metallic wires larger than several hundred nanometers ... The increasing size of the nanoantennas makes the resonances to appear at wavelengths that present larger negative values of the dielectric function, i.e. for wavelengths well in the mid infrared portion of the spectrum in the case of micron-sized wires. It is actually this extension of the resonant behavior to micron-sized antennas what makes these structures optimal candidates for surface enhanced Raman spectroscopy (SERS) and surface-enhanced infrared absorption spectroscopy (SEIRA)."

"Use of cavities or other effective configurations that produce this large field enhancement has allowed for pushing the limits of this spectroscopy, even though certain limits (10^{11}) are inherent to the electromagnetic contribution of the SERS enhancement. Several situations creating large field enhancement and singular optical response have been studied in dimers, bowtie antennas, and sets of metal nanoparticles. Coupled nanorods have also been treated recently as convenient field-enhancers at the [E-M] cavity between rods."

***References for this section** (URLs to free copies included):*

[1] A. Pucci et al., "Electromagnetic Nanowire Resonances for Field-Enhanced Spectroscopy," Chapter 8 in "One-Dimensional Nanostructures, Lecture Notes in Nanoscale Science and Technology", Volume 3. ISBN 978-0-387-74131-4. Springer New York, pp. 175-215 (2008) http://dipc.ehu.es/aizpurua/publications/chapter8_full_text_springer_book.pdf

*[2] W. Zhang et al., "Local field enhancement of an infinite conical metal tip illuminated by a focused beam," Jour. of Raman Spectroscopy **40** pp. 1338-1342 (2009) http://nam.epfl.ch/pdfs/121.pdf*

*[3] R. Sardar et al., "Gold nanoparticles: past, present, and future," Langmuir **25** pp. 13840-13851(2009) http://bg.bilkent.edu.tr/jc/topics/Langmuir%20overview/papers/Gold%20Nanoparticles%20Past,%20Present,%20and%20Future.pdf*

*[4] R. Kappeler et al., "Field computations of optical antennas," Jour. of Computational and Theoretical Nanoscience **4** pp. 686-691 (2007) http://www.optics.rochester.edu/workgroups/novotny/papers/kappeler07a.pdf*

[5] J. Lu and Y. Chang, "The lightning-rode mode in a core shell nanocylinder dimer," Optics Communications, in press (2010) http://ntur.lib.ntu.edu.tw/bitstream/246246/177727/1/opt_comm(2010).pdf

[6] M. Dionne et al., "Electrostatic screening effects between vertically aligned Carbon nanotubes and fast transient Joule heating during field emission, " Excerpt from the Proceedings of the COMSOL conference in Boston, MA (2007) http://cds.comsol.com/access/dl/papers/3189/Dionne.pdf

High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 5

Overview - 2:

[Quoting from Ref. 1] **"Optical properties of such metal nanoobjects are dominated by electromagnetic resonances that are related to considerable electromagnetic field enhancement in the proximity of a nanoparticle. If such resonances are due to free-charge carrier (plasmon-like) excitations, this field enhancement can be particularly strong, which is related to the large negative real part of the dielectric function in a metal (for energies below the plasma edge), much larger than characteristic values of other excitations, like for example optical phonons in a halide or oxide. The fields are strongly enhanced in the range of few nanometers from sharpened metal points, if the radius of curvature is much smaller than the incident illumination wavelength. Therefore rod-like metallic particles may give higher nearfield strength than spherical ones ... dimensions of the particle are of multifold importance for resonance positions and the related field enhancement."**

"Resonant nearfield enhancement can be increased by the interaction with another resonant particle in proximity … extremely high optical nearfield enhancement localized in nanoslits between gold nanorods is possible to obtain. This example indicates that the surface plasmon resonances of metal nanoparticles can be exploited to confine electromagnetic radiation to a volume of subwavelength dimensions. This volume can also be a nanohole in a continuous metal film ."

"A metal-island film can be considered as a more or less random array of metal nanoparticles with distribution of sizes, shapes, and orientations. On a local scale, strong field enhancement is predicted for such films, especially at certain 'hot spots' for random (fractal-structured) metal island film; an effect that is used to explain extraordinary strong surface enhanced Raman scattering (SERS), different to ordered metal structures. The basic idea is that the local field enhancement obtained by metal nanostructures at resonance produces increased local response of an excitation at the resonance frequency. This excitation can be of vibrational nature (SEIRA = surface enhanced infrared absorption), of electronic nature (second harmonic generation), and a combination of both (SERS, fluorescence)."

"But SERS and SEIRA have indicated the pathway towards the extreme amplification of the electromagnetic field on the local scale ... Sufficiently high and predictable nearfield enhancement can be achieved with antenna-like plasmon resonances of rod-like metal particles (here they are called "wires"). It is a great challenge to produce well-defined antenna structures according to … theoretical predictions for maximum field enhancement over t… frequency range of ... interest."

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High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 6

Overview - 3:

[Quoting from Ref. 3] "Plasmonics. A direct consequence of the localized surface plasmon resonances of metal nanoparticles is an enhancement of the field close to the nanoparticle surface, known as the near field. The close approach (i.e., within 2.5 times the particle diameter) of two nanoparticles leads to the interaction of their localized surface plasmon resonances. The coupling of the plasmon resonances of metallic nanoparticles has recently emerged as a strategic area widely applicable across physics, chemistry, and biology. The driving force behind these potential applications is the formation of highly enhanced, localized electromagnetic fields in the coupled structures."

"The “hot spots” created by localized electromagnetic fields from the nanoparticles allow the detection of single molecules via surface-enhanced Raman spectroscopy (SERS). Surface plasmons propagate along the surface of metals, providing a means to confine, guide, and focus energy using subwavelength structures such as EBL-fabricated nanometer thin metal strips or nanostructured surfaces. It has recently been found that chemically synthesized gold and silver nanowires are also able to act as waveguides for visible light. This phenomenon is echoed by interacting single particles where the coupling of nanoparticles spaced less than two diameters apart results in the transmission of light energy down a nanoparticle chain."

"Near-field interaction between nanoparticles is highly distance-dependent ... When the initial nanoparticles are themselves nanorods rather than spherical, a large number of coupling geometries become possible between both longitudinal (along the length of the nanorod) and transverse (along the width of the rod) plasmon resonance modes. The coupling between each of these modes mirrors the features observed for coupling between spheres ... electric field between an electrode and a particle during closest approach exceeds 10^9 V/m, orders of magnitude above the dielectric strength of water."

"NP [nanoparticle] properties depend on size (including quantization effects). NPs with fewer than 300 Au atoms can display distinct optical and electronic properties compared to the bulk metal ... most active catalysts … small gold nanoparticles approximately 2-4 nm in diameter."

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Interactions between plasmons, E-M fields, and nanostructures - 7

Overview - 4:

[Quoting from Ref. 3] "Bulk-Continuum Voltammetry. Just as ionic space charges; the electrical double layer; exist at all electrified metal/electrolyte solution interfaces, nanoparticles in solutions (colloids, metal sols, regardless of the metal, and semiconductor nanoparticles) have double layers with ionic surface excesses on the solution side that reflect any net electronic charge residing on the metal nanoparticle surface (or its capping ligand shell). In this light, one can say that all metal-like nanoparticles are intrinsically electroactive and act as electron donor/ acceptors to the quantitative extent of their double-layer capacitances …electron charge storage capacity, per nanoparticle, depends on the nanoparticle size (surface area), nanoparticle double-layer capacitance C_{DL}, and potential (relative to nanoparticle zero charge). This capacity can be quite substantial … a 10-nm-diameter nanoparticle with C_{DL}=120 aF (equivalent to 40 μF/cm^2) can store ~750 e/V. This capacity is capable, as a 'colloidal microelectrode', of driving electrochemical reactions such as proton reduction to H_2. The quantitative demonstrations of this property by Henglein et al. and Gratzel et al., starting in 1979, represented the beginning of the modern understanding of the electrochemistry of metal nanoparticles ... even though a metal nanoparticle yields no voltammetric wave and exhibits no discrete 'formal potential', its electrochemical charging is observable and demonstrable by the application of mass transport criteria."

" Quantized Double-Layer Charging (QDL). The metal-like nanoparticle's double layer can become quantized if its size and consequently capacitance CDL are much smaller, for the same reasons that coulomb staircase charging is observed in solvent free experiments on solid-state nanostructures ... These nanoparticles are 'quantum capacitors', with their stored-charge potentials changing by palpable values upon single electron transfers."

"Molecule-Like Voltammetry. The progression of properties from large to smaller nanoparticles; continuum voltammetry to QDL voltammetry; culminates in the emergence of molecularity in the smallest nanoparticles, as signaled by the presence of HOMO-LUMO gaps and by structure in nanoparticle electronic spectra. This metal-to-molecule transition is seen in changes in optical band edge energies and by the interruption of the regular spacing of QDL voltammetric patterns by a central larger spacing."

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High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 8

Overview - 5:

[Quoting from Ref. 2] "Introduction. Tip-enhanced Raman spectroscopy (TERS) is a near-field spectroscopic technique measuring both the topographic information and Raman spectrum with nanometer spatial resolution using a sharp metal tip. The tip apex functions as a single 'hot' spot, which enhances the Raman scattering from the scanned sample area. At optimized conditions, single-molecule sensitivity can be achieved and the spatial resolution can reach ~10 nm ... TERS has also been used to study some of the most fundamental aspects of its cousin technique, surface-enhanced Raman spectroscopy (SERS), especially the properties of the 'hot' spot in SERS, since TERS is playing with a single 'hot' spot and can collect both the topographic information and the Raman spectrum simultaneously. Thanks to these merits, TERS has provided a direct proof for single-molecule Raman detection, an issue debated for almost 10 years in the SERS community. Furthermore, TERS also allows us to investigate the detailed physical properties of the 'hot' spots, such as the influence of nanometer-scale corrugation on the field enhancement[and thermal effects at the 'hot' spot. Despite [this], our understanding of the enhancement mechanisms of TERS is still superficial."

"As a nanowire, a TERS tip can guide, 'focus' surface plasmon polaritons (SPPs) propagating on its flank, and consequently enhance the local electric field at the tip apex. It is important to investigate the impact of such delocalized effects at the tip apex. Besides the infinite length, the illumination is also an important issue in TERS."

"Optical behavior of an infinitely long tip is different from that of a common SERS substrate, which is mainly dictated by the LPR of nanoparticles or particle aggregates ... For tips of 1000 nm and longer, the resonance peaks become weaker and periodic in the red-infrared (IR) regime ... When the tip is short (smaller than the focus spot), the light drives the conducting electrons in the metal tip in phase and generates collective oscillations (i.e. LPRs). As a result, the contributions from individual electrons build up and generate a strong local electric field at the tip apex. For a long tip, the focus spot is smaller than the tip length and there are no such collective electron oscillations in the whole tip. Instead, the illumination at the tip apex causes two different types of excitations: LPRs, which are mainly concentrated at the tip apex, and SPPs, the delocalized modes. The LPRs store the electric field energy in the vicinity of the tip apex and appear as resonance peaks in the near ultraviolet and blue range. On the contrary, SPPs as delocalized modes can propagate along the tip. When the SPPs meet the ends of the tip, they are reflected and form cavity modes."

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High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 9

Overview - 6:

[Quoting from Ref. 2] "**Tip sharpness influences the field enhancement.** It is well known that for an ideally sharp metal cone, the apex represents a field singularity and generates an infinitely strong electric field, the so-called lightning rod effect. As a result, a sharper tip apex is closer to such a singularity and produces a stronger field enhancement. In fact, this has been clearly seen during the evolution of TERS over the last 5 years. Small molecules have only become visible once the fabrication methods for producing extremely sharp Au and Ag tips became available. Besides sharpening the tip, another way to increase the enhancement is to increase the wavelength of the illumination, since the sharpness refers to the relative dimension between the radius of curvature of the tip apex and the wavelength. However, to the best of our knowledge, nothing has yet been reported in this direction because the sensitivity of the detectors is generally much lower in the IR regime than in the optical regime."

"One interesting phenomenon ... that ... enhancement increases dramatically when r decreases from 20 to 10 nm. In other words, a slight improvement of tip sharpness will lead to a significant increase of the field enhancement. This could explain the different results reported by two independent groups, in which the Raman spectra from similar molecules were very different. The tips used by Neascu *et al.* have an apex diameter $r \sim 10$ nm, while in the case of Domke *et al.*, r was >20 nm. This variety could cause a twofold difference in the field enhancement and consequently a fourfold difference in the heat generated by ohmic loss. Considering that a thinner tip is less capable of dissipating heat, the local temperature at the apex of the $r = 10$ nm tip can be much higher than in the case of the $r = 20$ nm tip. This may have a significant influence on the Raman spectra."

"**Substrate effect** ... in practice, close to the tip apex there is always a substrate that can influence the local optical response in a dramatic way ... It has been experimentally demonstrated that varying the substrate can dramatically change the field enhancement at the tip apex. With a Au substrate, the electric field intensity can be enhanced by two orders of magnitude ... If the substrate is changed to Pt, still a metal, the enhancement drops. For a semiconductor or dielectric substrate, e.g. Si or glass, the field enhancement decreases further and is even one order of magnitude lower than in the case of a Au substrate."

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High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 10

Overview - 7:

[Quoting from Ref. 4] Nanoantennas."Antennas are components to receive and transmit electromagnetic waves. Whereas antennas are primary devices in radio frequency applications for many years, the concept of optical antennas is relatively new. Analogously, optical antennas are components designed to transceive optical signals. The application range where optical antennas will be used is likely to become as wide as the one for the radio wave counterpart. Already an established application area for optical antennas is near-field optical microscopy and spectroscopy. There the antenna efficiently converts the energy of an incident electromagnetic wave to highly localized energy."

"The optical antenna often consists of a sharp noble metal tip, which is illuminated by a laser beam. The tip localizes the energy of the incoming laser beam such that light is concentrated to a highly localized area whose dimensions are essentially defined by the sharpness of the tip (currently down to 10 nm).The underlying physical effects are manifold and often hard to determine: static effects such as the lightning rod effect as well as dynamic effects such as surface plasmon polariton (SPP) resonances contribute to the antenna behavior. For example, according to the lightning rod effect, any sharp geometry should yield high electrical fields, but in practice only about half of the tips show a good electrical field enhancement even if they are equally sharp. Additionally, the field enhancement depends on the local environment, on the tip shape and also on the experiment itself (illumination conditions)."

"A good optical antenna has to provide a strong local field enhancement and low energy dissipation ... To improve the field enhancement, spheroids or nanorods can be used. As shown later, a nanorod behaves like a downscaled dipole antenna known from classical antenna theory. However, at optical frequencies the properties of metals are significantly different from their behavior at radiowave or microwave frequencies. Rather than being characterized by an instantaneous response to the driving external field the electrons in the metal behave like a plasma confined by the particular geometry of the metal's boundaries. Consequently, the resonances of an optical antenna made of real metals are red-shifted with respect to the resonances of a perfect metal ... fusing different sized silver particles together allows the resonance to be shifted from the UV into the visible ... Interestingly, although the silver core is now surrounded by a gold layer the resonances are still defined by the silver–air interface. However, the thicker the gold coating the weaker is the silver resonance. As the gold layer thickness increases a new resonance emerges."

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Interactions between plasmons, E-M fields, and nanostructures - 11

Overview - 8:

[Quoting from Ref. 5] "Plasmon modes of a solid nanostructure are characterized by the surface charge distributions on the surface of the solid nanostructure. For the core–shell structures, the interaction between the surface charge distributions at the inner and outer surfaces of the core–shell structure splits the plasmon resonance modes into two different alignment plasmon modes and result in the large variation of the plasmon resonance wavelength for the core-shell nanocylinder. The plasmon resonance wavelength of the core–shell structure can be tuned by the permittivity of the dielectric core and the ratio of the outer radius to inner radius. By the same token, when two plasmon-resonant core–shell nanoparticles are brought together, the plasmon modes in the individual nanocylinders can interact with each other, leading to new resonance modes for the coupled system. These plasmon modes have been investigated in detail ... In this work, a new plasmon mode associated with the core–shell nanocylinder pair is reported. We found that a resonance mode resulted solely from the coupling of the electrons at the outer surfaces of the two core–shell nanocylinders can be observed when the size of the nanocylinder is large enough … Size-dependence and permittivity-dependence of this special plasmon mode indicate that this plasmon mode shows up as a result of the screening effect of the metallic shell and reflection at the metal/dielectric boundary. Such a phenomenon is essentially caused by the lightning-rod effect, which occurs when metals approach to the perfect conductors in low frequency and the electric field concentrates in the gap of the nanocylinder dimer ... We can thus infer that this special plasmon mode is resulted from the coupling of the electrons at outer surfaces between the two core–shell nanocylinders, similar to the coupling of surface plasmon modes between a pair of solid gold nanocylinders."

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Interactions between plasmons, E-M fields, and nanostructures - 12

Overview - 9:

[Quoting from Ref. 6] Vertically aligned carbon nanotubes. "Arc electrodes face important erosion problems that hinder the commercial use of many plasma-based processes ... A design having theoretical surface averaged field-emitted current density as high as 10^{10} A/m^2 was selected and a candidate process for its fabrication is identified. A time dependent model was used to study the temperature profile along the CNT structure with typical lifetime of arc discharge cathodes spots for the applied electric field time scale."

"At low temperatures, electron emission from metal surfaces is governed by the Fowler-Nordheim (F-N) equation. When a strong DC field is applied between two electrodes at room temperature, field emission is the first phenomenon supplying the electron current. Joule heating and ion bombardment can cause the surface temperature to rise until thermionic emission takes over. In arc discharges, this transition is characterized by the formation of a dense plasma ball near the cathode surface known as the cathode spot (CS). CS inner structure and the energy distribution of the electrons and ion species within them is complex. Anders showed that a CS subdivides itself into substructures known as microspots and nanospots. The erosion rate for the electrode increases if the cathode melts underneath a burning CS … surface melting should be prevented. Surface averaged current densities within vacuum arcs CS reach 10^9 A/m^2. To minimize erosion, this current density must be achievable from field emission alone. Above 1000 K …F-N equation does not apply and surface melting becomes possible depending of the cathode composition. CS lifetimes lie around 10-200 nanoseconds. Below 1000 K, radiation losses may remove some of the local heat load but most of the remaining part is conducted into the bulk."

"To favor field emission, the surface electric field characterized by the field enhancement factor β (equation 2-1) is critical. β compares the local field to the reference value $\Delta V/d$. (d = anode-cathode gap, ΔV = potential difference). β depends on the shape of the structure of interest. Its value on a surface has been related to the surface curvature radius ... F-N equation relating the field emitted current density, the surface electric field $E = \beta E_0$, and the surface work function φ_0 is highly nonlinear … Lifetime of a CS is so short that the whole theoretical range of accessible I_{eq} could have to be visited within 200 nanoseconds or less. The new results reported here are related to this particular issue. Different time scales are involved and heat conduction is the slowest. The electrostatic field can be assumed to prevail instantaneously. Very dense arrays (Δx =100 nm) of very short (h_{CNT} = 100 nm) structures with relatively low aspect ratio close to 5 could deliver surface averaged current densities of the order of 10^{10} A/m^2 through field emission without exceeding a temperature of 600 K on the emitter's tip."

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***[3]** R. Sardar et al., "Gold nanoparticles: past, present, and future," Langmuir **25** pp. 13840-13851(2009)*
http://bg.bilkent.edu.tr/jc/topics/Langmuir%20overview/papers/Gold%20Nanoparticles%20Past,%20Present,%20and%20Future.pdf

***[4]** R. Kappeler et al., "Field computations of optical antennas," Jour. of Computational and Theoretical Nanoscience **4** pp. 686-691 (2007)*
http://www.optics.rochester.edu/workgroups/novotny/papers/kappeler07a.pdf

***[5]** J. Lu and Y. Chang, "The lightning-rode mode in a core shell nanocylinder dimer," Optics Communications, in press (2010)*
http://ntur.lib.ntu.edu.tw/bitstream/246246/177727/1/opt_comm(2010).pdf

***[6]** M. Dionne et al., "Electrostatic screening effects between vertically aligned Carbon nanotubes and fast transient Joule heating during field emission, " Excerpt from the Proceedings of the COMSOL conference in Boston, MA (2007)*
http://cds.comsol.com/access/dl/papers/3189/Dionne.pdf

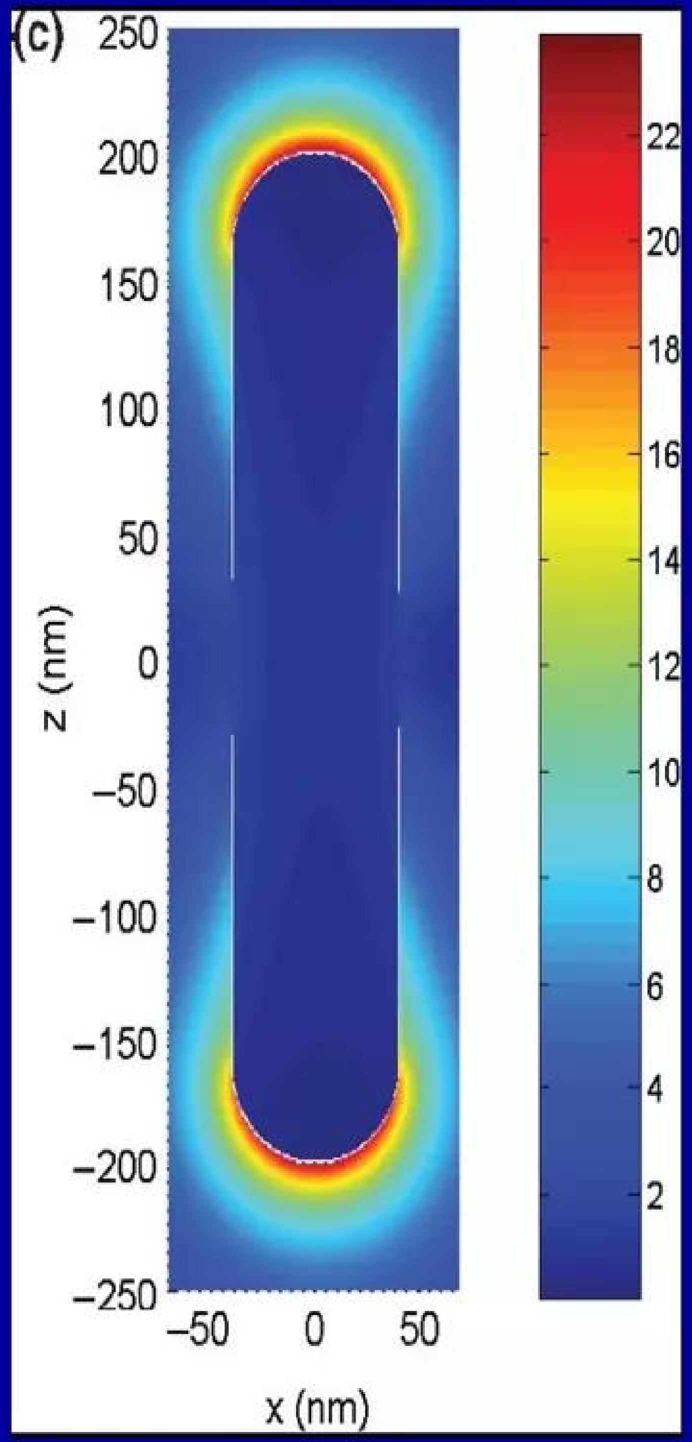
High E-fields important in condensed matter LENRs

Interactions between plasmons, E-M fields, and nanostructures - 13

Summary:

- ✓ Condensed matter LENRs and the interdisciplinary field of nanotechnology are effectively joined at the hip; also, collective many-body classical, and coherent Q-M, effects occur in both
- ✓ Like nanotech, LENRs occur at the intersection of many different scientific disciplines that include: chemistry; solid-state, surface, and nuclear physics; materials science; plasmonics; etc., etc.
- ✓ Various 'species' of nanotechnologists have the necessary knowledge and expertise to make important theoretical and experimental contributions to expanding our present understanding of intensely multidisciplinary LENRs and the fascinating regions of parameter space in which they occur
- ✓ Lattice has been and is presently applying and utilizing selected aspects of nanotechnology in its effort to commercialize LENRs; for obvious reasons, this work is nonpublic and proprietary

Distribution of nearfield enhancement for fundamental antenna resonance



A. Pucci et al., ISBN 978-0-387-74131-4. Springer - New York, Fig. 8.1(c) pp. 182 (2008)

Other theoretical support for heavy-mass e^* electrons?

Theoretical work of Prof. Dimiter Alexandrov - 1

- ✓ **Using a somewhat different theoretical approach, Prof. Dimiter Alexandrov (Lakehead Univ., Thunder Bay, Ontario, Canada) has also concluded that effective electron masses may be substantially increased by E-M fields in a variety of different condensed matter systems, i.e., that $e \rightarrow e^*$**

- ✓ **Please see his paper cited to right (be aware that it is a conference presentation and has yet not been peer-reviewed to our knowledge)**

- ✓ **On the first page of his paper, he says (quoting), "The author's research progress in determining the electron band structures of disordered semiconductors is the basis of this paper. Previously calculated electron band structures of disordered nitride semiconductor compound alloys are used and the existence of energy pockets for electrons in conduction bands is found. These energy pockets are found to be potential energy valleys in the conduction bands having dimensions in the range of the primitive cell. Interaction of external electrical field with electron located in energy pocket is investigated and the corresponding electron wave function of the confined electron in a free electron approximation is determined. Formula for effective mass of a confined electron in pocket is derived and conclusions are drawn about the existence of heavy electrons. The interaction of the heavy electrons with protons is discussed."**

***Paper*:**

D. Alexandrov, "Heavy Electrons in Nano-Structure Clusters of Disordered Solids," ICCF-14 International Conference on Condensed Matter Nuclear Science. Washington, DC (2008)

***Free copy at URL*:**

http://www.lenr-canr.org/acrobat/Alexandrovheavyelect.pdf

***Abstract*:**

"Existence of heavy electrons is found theoretically in nano-structure clusters of disordered solids. The basis of the investigation is the electron band structures of disordered semiconductors previously determined by the author. The existence of electron energy pockets is found for the electrons in the conduction bands of these semiconductors that are nano-confining potential valleys of dimensions in the range of the primitive cell. The electron wave function of the confined electron is determined in when the electron interacts with local electrical field that is external for the energy pocket, and the average velocity of the electron is found. An expression for electron mass of an electron localized in pocket is derived. It is found that this electron mass is greater than the electron mass at rest and the confined electrons are designated heavy electrons. The possibility of interactions of protons with heavy electrons is discussed."

Other theoretical support for heavy-mass *e** electrons?

Theoretical work of Prof. Dimiter Alexandrov - 2

On page 6, Alexandrov summarizes as follows:

> **"The results are summarized in Table 1. It is important to be noted that the impact of the heavy electrons on the electrical properties can be expected to be significant in nano-structures having low concentrations of light electrons. Also this impact is higher in wide energy band gap disordered materials because the influence of the defects on the conductivity is small. Existence of heavy electrons in non-metal nano-layers – for example in nano-structures of metallic hydrides on metal surfaces – can be expected as well … It can be seen in Table 1 that the effective mass of the heavy electrons can reach high values in some materials. However it depends on the local field."**

We now reproduce without further comment Alexandrov's Table 1. on page 6, "Effective masses and effective Bohr radii of heavy electrons in several disordered solids":

Table 1	m_{eff} in m_0 units (e^* in W-L)		$a_{B\ eff}$, Angstroms	
Formula	weak [E-M] field	strong [E-M] field	weak [E-M] field	strong [E-M] field
$In_xGa_{1-x}N$	851.02	50.89	0.62×10^{-3}	0.0104
$In_xAl_{1-x}N$	3.41	1.28	0.1553	0.4134
InO_yN_{1-y}	11.96	2.96	0.0442	0.1788
InN:In	286.41	24.61	0.0018	0.0215

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Commercializing a Next-Generation Source of Safe Nuclear Energy

Internally growing dendrites and Li-ion battery fires

Lithium metal 'classic' dendrites growing in solid polymer electrolyte

'Mossy'-type Lithium dendrite growing in solid polymer electrolyte

<u>Source</u>: G. Stone et al., Lawrence Berkeley National Laboratory, APS March 17, 2010 Abstract: Q16.00005: "Retarding Dendrite Formation in Rechargeable Lithium Metal Batteries with Block Copolymer Electrolytes"

<u>Source</u>: J. Tarascon and M. Armand, "Issues and challenges facing rechargeable lithium batteries" *Nature* 414, pp. 359-367 (2001)

"Real advanced technology – on-the-edge sophisticated technology – issues not from knowledge but from something I will call *deep craft*. Deep craft is more than knowledge. It is a set of knowings … Knowing what methods to use, what principles are likely to succeed, what parameter values to use in a given technique … how to manipulate newly discovered and poorly understood phenomena. Deep knowings in one technology can be levered into deep knowings in another."

W. Brian Arthur, "The Nature of Technology – What it is and how it evolves," Free Press 2009

New technique allows in situ NMR monitoring of dendrite growth - 1

- ✓ **About 18 months ago, based on W-L theory we conjectured that: (a) LENRs might occur in high electric fields created by nanoscale "lightning rod effects" in discharge arcs (i.e., electrical shorts) emanating from nm- to micron-scale Lithium metal dendrites that grow inside Li-ion batteries; and that (b) rapid (~10 - 200 nanoseconds) multi-Watt heat-energy releases from nm to micron-scale LENR-active 'patches' could potentially provide a triggering mechanism for some subset of Lithium-ion battery failures and fires**

- ✓ **New experimental paper recently published in *Nature Materials* (see citation to right) reports on a new analytical technique that uses NMR to be able to non-invasively monitor and measure growth of dendritic and 'mossy' Lithium-metal nano- and microstructures on surfaces *inside* sealed Li-ion batteries dynamically, while they are being charged and discharged --- *this is an important development!***

- ✓ **They state, "In conclusion, we have shown that NMR spectroscopy carried out *in situ* in conjunction with electrochemical cycling is capable of dynamically monitoring the growth and stripping of Lithium microstructures … we show that it is possible to quantify the amount of mossy/dendritic Lithium formed … and now have a simple and accurate method for monitoring early stages on dendrite formation in Lithium batteries."**

***Reference*:**

*R. Bhattacharyya et al., "In situ NMR observation of the formation of metallic Lithium microstructures in Lithium batteries," Nature Materials **9** pp. 504-510 (2010)*

***Paper available for purchase of US$32 at URL*:**

http://www.nature.com/nmat/journal/v9/n6/abs/nmat2764.html

***Free supplementary information at URL*:**

http://www.nature.com/nmat/journal/v9/n6/extref/nmat2764-s1.pdf

***Abstract*:** *"Lithium metal has the highest volumetric and gravimetric energy density of all negative-electrode materials when used as an electrode material in a lithium rechargeable battery. However, the formation of lithium dendrites and/or 'moss' on the metal electrode surface can lead to short circuits following several electrochemical charge–discharge cycles, particularly at high rates, rendering this class of batteries potentially unsafe and unusable owing to the risk of fire and explosion. Many recent investigations have focused on the development of methods to prevent moss/dendrite formation. In parallel, it is important to quantify Li-moss formation, to identify the conditions under which it forms. Although optical and electron microscopy can visually monitor the morphology of the lithium -electrode surface and hence the moss formation, such methods are not well suited for quantitative studies. Here we report the use of in situ NMR spectroscopy, to provide time-resolved, quantitative information about the nature of the metallic lithium deposited on lithium-metal electrodes."*

New technique allows in situ NMR monitoring of dendrite growth - 2

Quoting further from R. Bhattacharyya et al.,

"Lithium-ion batteries (LIBs), because of their very high gravimetric and volumetric energy densities, are widely used as electrical-energy-storage devices. Owing to their increasing power and energy capabilities, together with their enhanced cycle life, LIBs are now also being developed for use in the automobile industry. With these new applications for LIBs comes an even larger demand for more energy from these devices, and thus for electrode materials that store more Li. In principle, Li metal represents the ultimate LIB negative electrode (anode), with a factor of 10 higher specific energy density than lithiated graphite. However, it suffers from at least one serious disadvantage: on several charge and discharge cycles in non-aqueous electrolytes, dendritic and/or mossy structures of lithium metal are formed on the lithium-metal anode, which poses a potentially disastrous safety issue. The dendritic structures first reported as early as 1980 may disassociate from the anode and remain as floating structures in the electrolyte (known as dead lithium). These dead-lithium fibres, along with fibres that grow directly from the electrode, may result in short circuits, causing spontaneous high-rate discharge. This can result in rapid overheating of the battery, leading to fire hazards associated with the flammable organic electrolyte. These issues have been a significant impediment to the commercialization of lithium-metal batteries. However, the comparatively low volumetric and gravimetric capacities of LIBs using a graphite anode have created a resurgence of interest in lithium-metal batteries. Indeed, the high capacities that are quoted for Li-air and Li-sulphur batteries, which have attracted considerable recent attention, are based on the use of lithium-metal negative electrodes."

"Considerable effort has been devoted to prevent moss and dendrite formation on lithium-metal anodes during cycling and to understand the negative impacts of dendritic growth on the various aspects of battery cycling. It has been shown, by using scanning electron microscopy, that there is a direct correlation between dendrite formation and the current density, with larger amounts of dendritic deposits forming at higher current densities. However, the scanning electron microscopy method does not provide a way of accurately quantifying the amount of such microstructures."

Reference:

*R. Bhattacharyya et al., "In situ NMR observation of the formation of metallic Lithium microstructures in Lithium batteries," Nature Materials **9** pp. 504-510 (2010)*

Other selected quotes from their paper:

"Li NMR spectroscopy, when carried out in situ during electrochemical cycling, is a non-invasive method for investigating the structural changes that can occur in electrode materials. As the ^7Li signal (spin = 2 ; 92:5% [natural] abundance) can be acquired on a timescale that is much faster than the typical charge-discharge cycle (because of the high sensitivity of ^7Li NMR), the structural changes that occur in the active material at various states-of-charge can be detected and quantified by recording spectral snapshots at suitable time intervals."

"Skin depth, d (14.7 microns), is almost an order of magnitude larger than the reported thickness of mossy or dendritic whiskers of 1 - 2 microns, and therefore the penetration of these structures can be assumed to be total. Thus, unlike the bulk, the [NMR] signal from these Li microstructures is directly proportional to their volume or mass ... NMR method does not directly distinguish between the moss and the dendrites, and hence we use the term `microstructure' to cover both these morphologies."

"Three cells are investigated: a $LiCoO_2$-Li cell with a standard $LiPF_6$, ethylene carbonate (EC)/dimethylcarbonate (DMC) electrolyte, and … two symmetric Li-Li cells (that is, cells with Li on both electrodes), but with two different ionic liquids with reportedly very different abilities to suppress dendrite growth … Best fit is achieved for deposition of approximately 90% of the Li metal as (dendritic/mossy) microstructures (M_{micro}), and …10% as a smooth deposition (M_{SD}) on the Li electrode."

LENRs may cause problems via ULM neutron capture on Li

Unbeknownst to battery manufacturers, here is what may actually be happening inside some subset of failing Li-ion batteries:

- ✓ **High electric fields in vicinity of nanoscale dendrites create heavy-mass e^* electrons which then react with nearby protons, creating ultra low momentum (ULM) neutrons. ULM neutrons then capture on nearby Lithium atoms in an LENR Lithium reaction (see right), causing micron-scale and smaller 'hot spots' to occur on the surface of a Li dendrite**
- ✓ **Importantly, 5,000+ K temperatures inside a tiny LENR 'hot spot' can vaporize an immediately adjacent volume of battery material into a tiny ball of hot plasma. Among other things, conductive ions in the hot plasma would start shorting-out nearby battery microstructures. Worse yet, such intense heat can liberate free Oxygen from any nearby Oxides (e.g., Li_2FePO_4 found in battery cathodes), which then reacts with any Lithium metal present, starting an internal oxygen-fueled Lithium fire**
- ✓ **If too many of such LENR "hot spot" events were to occur essentially simultaneously, it could potentially trigger an unstoppable cascading runaway of exothermic chemical reactions that could damage or totally ruin a battery, or entire battery-pack, via severe overheating**
- ✓ **In worst case events where Li-ion batteries actually explode, they would NOT be LENR explosions per se. An intense nanoscale nuclear energy release simply superheats a tiny region inside a battery which in turn triggers an escalating cascade of prosaic chemical oxidation reactions. This situation is akin to what happens when the sharp sound (acoustic energy) of a single gunshot can trigger a huge avalanche of snow that engulfs an entire side of a mountain. In this fashion (which might occur episodically), large multi-cell Li-ion battery packs used in vehicles could potentially 'ignite' and be destroyed by thermal fratricide**

***References*:**

See our EPJC or Primer papers for details

***LENRs involving Lithium could potentially cause heating*:**

One example of a LENR nuclear reaction chain with a high Q-value is as follows. Let us assume that the surface is a Lithium microstructure inside a battery. Successive capture of ULM neutrons by nearby Lithium atoms located in tiny surface 'patches' will result in:

$$
\begin{aligned}
{}^{6}_{3}Li + n &\rightarrow {}^{7}_{3}Li \\
{}^{7}_{3}Li + n &\rightarrow {}^{8}_{3}Li \\
{}^{8}_{3}Li &\rightarrow {}^{8}_{4}Be + e^- + \bar{\nu}_e \\
{}^{8}_{4}Be &\rightarrow {}^{4}_{2}He + {}^{4}_{2}He. \qquad (35)
\end{aligned}
$$

Overall, above series of ULM neutron captures and decays takes place in under a second and releases a lot of energy; the Q-value shown below is more than a million times larger than those of the chemical reactions that normally take place inside an operating battery:

$$Q[{}^{6}_{3}Li + 2n \rightarrow 2\,{}^{4}_{2}He + e^- + \bar{\upsilon}_e]$$

$$Q \approx 26.9\ MeV$$

It should not be surprising that LENRs can potentially cause rapid, intense heating in tiny, micron-and-smaller-sized 'patches' located on the surfaces of Lithium-metal microstructures inside Li-ion batteries

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Internally growing dendrites and Li-ion battery fires

Overheating of Lithium batteries is longstanding issue

Long history of significant problems with Li-ion batteries:

- ✓ **For years, there have been poorly understood (in many cases unexplained) catastrophic failures of Li-ion batteries and battery-packs that resulted in casing ruptures, fires, and/or at worst, explosions**
- ✓ **Numerous product recalls with consumer batteries used in portable electronic systems have occurred, e.g. May 14, 2009, when HP announced a recall of 70,000 laptop batteries due to a "fire hazard"**
- ✓ **Effective January 1, 2008, the US DOT Hazmat Safety Rule placed carry-on and baggage limits on loose Li-ion batteries not actually installed in portable electronic systems**
- ✓ **On top of that, substantial energy density advantages of Li-ion battery technologies are now fostering utilization of very large Li-ion battery packs in electric vehicles (e.g., Tesla Motors) and other types of mobile platforms. Unfortunately, identical types of failures have also sporadically occurred in these complex, vastly more expensive large-scale systems**
- ✓ **For example, a Toyota Prius vehicle owned by Central Electric Power Cooperative of Columbia, SC, modified to use Li-ion batteries was destroyed by an unexplained fire during routine test drive on June 7, 2008**
- ✓ **In an even larger Li system used in an experimental 60-ton battery-powered US Navy submarine (the Advanced SEAL Delivery System - subsequently cancelled), an unexplained battery fire occurred during charging that destroyed much of the sub's interior on November 9, 2008**
- ✓ ***No one is aware that LENRs could potentially cause such problems***

Speculative question - did Bhattacharyya et al. observe an unexpected anomaly that may represent potential evidence for LENRs in their experiments?

On pp. 508 they make a very interesting remark:

"Third cell (Fig. 5) contains 1-butyl-methylpyrrolidinium bis(trifluoromethanesulphonyl)imide (C_4mpyr TFSI) + LiTFSI, which has been shown to suppress dendrite formation and can be cycled up to a current density of 1.25 mA cm^2 (ref. 9). Now, no growth of the Li microstructures is observed, even for very high currents: cycling the cell up to 0:5 mA cm^2 results in uniform lithium plating and stripping. ***At the highest current used (~1.0 mA cm^2), surprisingly a decrease in the total Li mass is seen****, which is ascribed to the heating effects associated with these large currents and voltages, but it may also be associated with the surfaces of the electrodes becoming smoother. This may occur because the initial Li foil is not perfectly smooth, because the brushing procedure used to remove native impurities (oxides, carbonates and so on) from the metal may result in a roughened surface."*

Comment: *First, it is well known experimentally that higher electric currents are associated with higher rates of LENRs. Second, they only observed the* ***unexpected decrease in the total mass of Lithium microstructures*** *at the highest levels of current.*

While Bhattacharyya et al. do offer a very reasonable prosaic explanation for the surprising anomaly, given the above, there is another alternative explanation that also fits the data; namely,

What if, at high currents, Lithium atoms are capturing ULM neutrons and being transmuted to another element, which would account for the decrease in the mass of dendrite-related Lithium? *Unfortunately, it would require detailed post-experiment analysis of dendrite surfaces with SIMS or Cameca nanoSIMS to determine the correct explanation for this anomalous observation*

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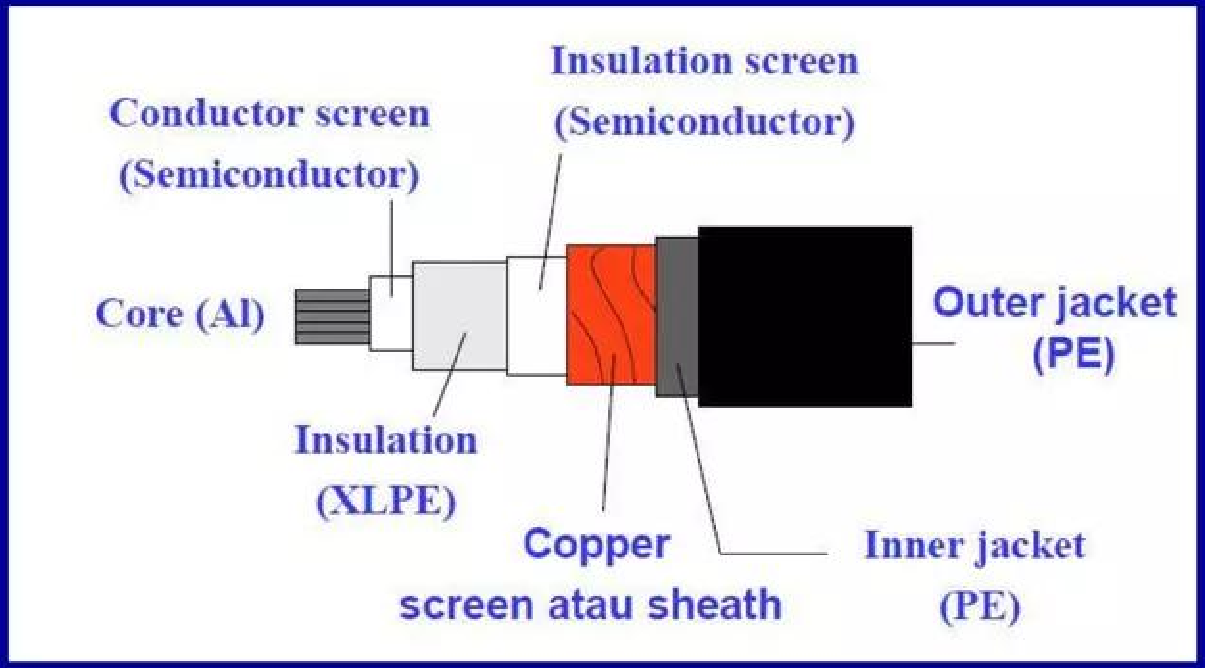
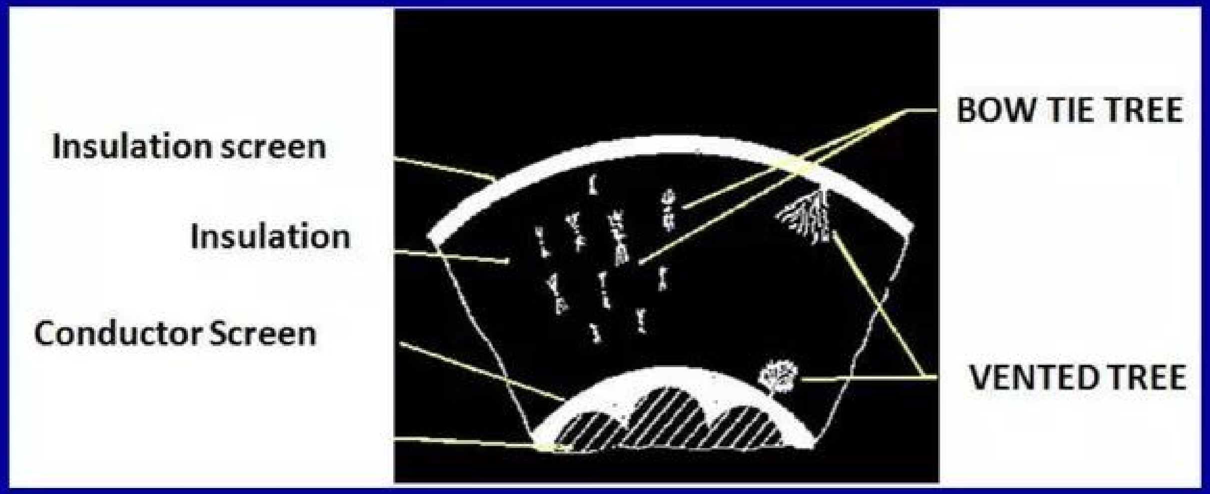
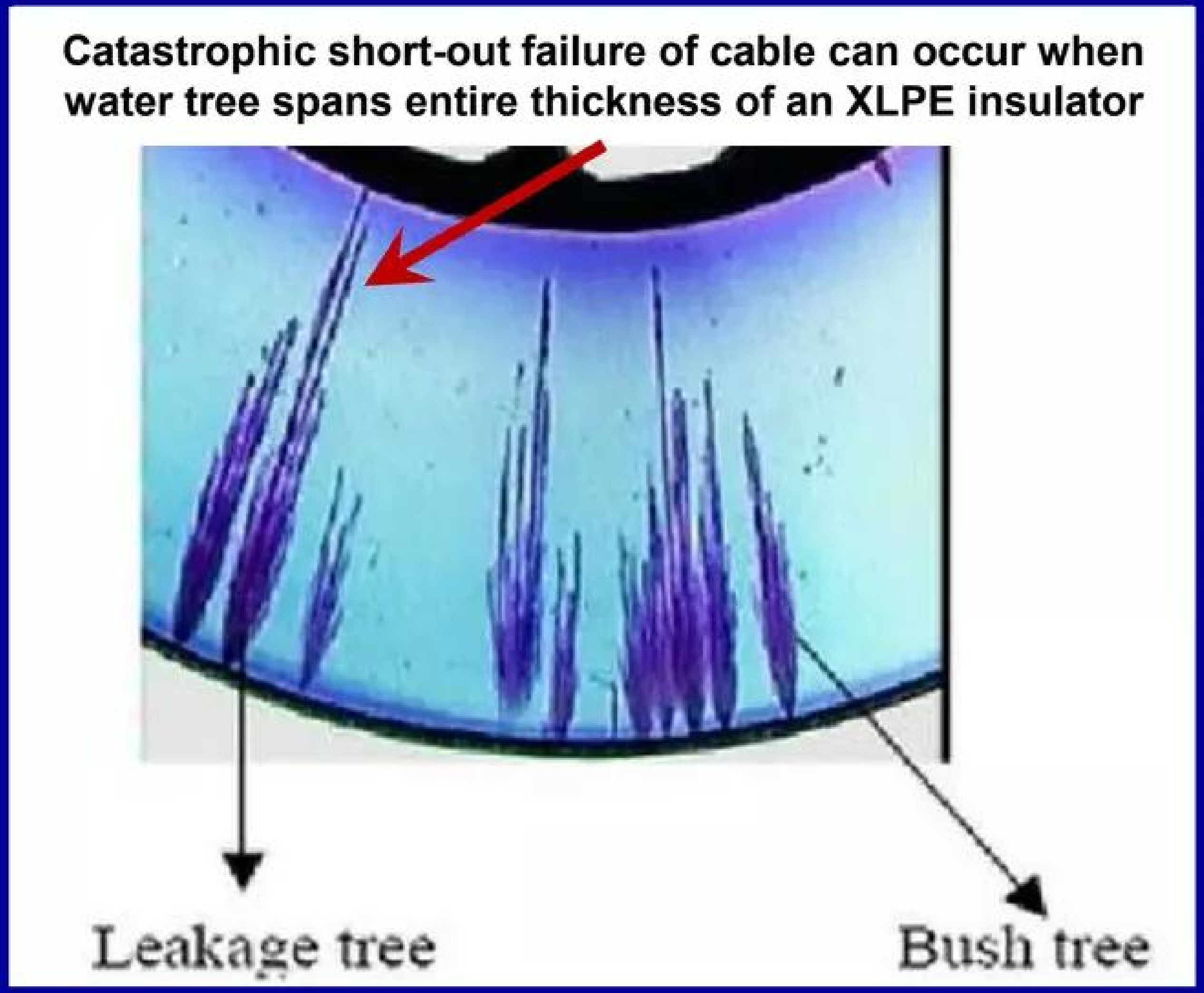
LENRs in "water trees" that can grow in XLPE cables



Source URL = http://tnbelectricaleng.blogspot.com/2010/01/cable-construction-1-core-xlpe.html





Above: two types of 'vented' water trees

Source URL = http://tnbelectricaleng.blogspot.com/2010/01/cable-construction-1-core-xlpe.html

Source: study by Elforskdagen in 2004

"Real advanced technology – on-the-edge sophisticated technology – issues not from knowledge but from something I will call *deep craft*. Deep craft is more than knowledge. It is a set of knowings … Knowing what methods to use, what principles are likely to succeed, what parameter values to use in a given technique … how to manipulate newly discovered and poorly understood phenomena. Deep knowings in one technology can be levered into deep knowings in another."

W. Brian Arthur, "The Nature of Technology – What it is and how it evolves," Free Press 2009

Unexpected degradation/failure of underground power cables

- ✓ During the mid-1960s, a number of different electrical equipment manufacturers developed technology for producing durable underground AC or DC (copper or aluminum as the conductor) power cables carrying up to 450 kV using cross-linked polyethylene (XLPE) that replaced layers of paper-oil for insulation. When widespread global deployment of such power cables began in the mid-1970s, it was widely believed they might enjoy trouble-free in-ground lifetimes of at least 40 - 50 years before experiencing significant rates of failure. Much to everyone's surprise, unexpectedly high rates of premature cable failures began to appear worldwide by the mid-1980s. This is can be an expensive problem for utilities with large deployments of underground cable within their grids, particularly in case of high-current, high voltage underground cables (up to 450 kV) used in many countries such as Japan. Unexpected service disruptions and expenses associated with digging-up and repairing failed high-capacity underground power cables is an issue for many electric utilities scattered around the world

- ✓ After extensive analysis, it was determined that a significant number of such cable failures were caused by structural 'defects' that 'grew' over time in XPLE sheathing after in-ground installation. Such defects came to be known in the electric utility business as "water trees." These so-called water (or electrochemical) trees are complex, branching 3-D dendritic structures that grow outward from conductor-XLPE interfaces in hydrophobic polymers in the presence of electric fields and water. Evidence indicates that in damaged regions of XLPE sheaths, water trees consist of random 'tracks'' of oxidized polymer that interconnect a series of microvoids. The greater the density of such microvoids in XLPE sheathing, the greater the likelihood that water trees, once formed, will continue to grow and connect, eventually causing significant degradation of XLPE insulation's effectiveness and eventually, potentially catastrophic cable failure

- ✓ Until very recently, specifics of the conditions under which water trees form and grow in XLPE cables, as well as the physico-chemical mechanisms underlying such phenomena, were something of a mystery. Early work on failed cables determined that a variety of different anomalous 'contaminants' were present in and around water trees. This was initially thought to result from problems with either quality control in the XLPE chemical manufacturing process and/or in the bonding chemistry at the interface between the XLPE and the metallic conductive cable (copper or aluminum). Oddly, additional study appeared to rule-out those possibilities as the source of the anomalous 'contaminants' associated with water trees. Further investigation over the past 5 years now suggests that *'contaminants" in water trees were not present anywhere in the cables prior to being buried underground and used to carry electric power*. In 2005 and 2008, Kumazawa et al. of Chubu Electric Power Co., Tatsuta Electric Wire & Cable Co., Ltd., and Osaka Prefecture University reported experimental detection of nuclear transmutation products in water trees in excellent papers published in the refereed Wiley InterScience journal, *Electrical Engineering in Japan*

Important Japanese experiments help unravel mystery - 1

‘Clean room’ - sample contamination not a significant issue:

Please note that Kumazawa et al.’s carefully controlled laboratory experiments with "water trees" described in this reference were conducted under rigorous electronic 'clean room' conditions, so contamination from outside sources is not a problematic issue in their mass spectroscopy measurements, that is, their detection of LENR nuclear transmutation products in and around the "water trees" growing inside the XLPE power cable insulation in their experiments

Quoting directly from their 2005 paper:

“Various models have been proposed regarding the mechanism by which water trees, an important form of deterioration in XLPE cable, are created and propagated. Initially, theories which modeled the physical breakdown mechanism of XLPE (cross-linked polyethylene) based on Maxwell stress and dielectrophoresis in the concentric field were frequently seen. ... On the other hand, because no general correlation has been seen between the development of water trees and oxidation products, there have also been reports suggesting an unknown chemical reaction that XLPE, oxygen, or ions participate in. **Given this background, the authors attempted to discover experimentally whether or not an unknown breakdown mechanism could exist separate from conventional ideas. The focus of this attempt is impurities frequently detected in regions with water tree deterioration. In particular, inorganic elements (metallic ions) are known to participate significantly in the occurrence and development of water trees**. This is thought to suggest that an important message for understanding the key to this mechanism is hidden in these 'traces.' Thus, **the authors generate water trees in XLPE samples in as clean an environment as possible, and then explore in detail the concentration of inorganic elements and the changes to their isotopic content present in the samples** … the authors discuss the source and features of these variable elements.”

Reference:

T. Kumazawa[1], W. Nakagawa[2], and H. Tsurumaru[2], "A Study on Behavior of Inorganic Impurities in Water Tree,“ Electrical Engineering in Japan 153, No. 2, 2005

Translated from Denki Gakkai Ronbunshi, Vol. 124-A, No. 9, September 2004, pp. 827–836

1 Chubu Electric Power Co., Inc., Japan
2 Tatsuta Electric Wire & Cable Co., Ltd., Japan

Abstract:

*"It is well known that water tree propagation in XLPE cable is significantly influenced by inorganic impurities in water. Therefore, **we investigated both changes in concentration and deviation of isotopic content of inorganic elements in XLPE samples by water tree experiments in a clean [room] environment.** The concentration of several kinds of elements (e.g., Li, Na, Mg, Al, K, Ca, Fe, Ni, Pb, and Bi) in water-treed sample showed anomalous increase or decrease dependent on cation (K+, Na+, or Ag+) in water solution compared with blank or original samples. **Furthermore, the isotopic content of Zn deviated over 6% from natural abundance. These results suggest that water tree propagation is related to unknown physical or electrochemical reactions**."*

Lattice Energy LLC

LENRs in "water trees" that can grow in XLPE cables

Important Japanese experiments help unravel mystery - 2

Quoting further from Kumazawa et al.'s 2005 paper:

- ✓ "In order to clarify the behavior of inorganic elements present in XLPE samples that create water trees, **impurities were removed to the utmost extent possible during the manufacture of samples**. As can be seen in Fig. 1, XLPE pellets for high-voltage cable were sealed in a PTFE film 0.5 mm thick free of dust and dirt in a clean room (clean air filter: class 100)."
- ✓ "During pretreatment …ultrasonic cleaning was performed using **superpure water**. Next, after (3) drying again, (4) the samples were prepared by cutting off disks 14 cm in diameter in the clean room. In order to easily create the water needle electrode where the water tree starts, (5) the **top surface was scratched using an Au wire brush**. Next, (6) cleaning and drying were performed by following the processes in (2) and (3), and then (7) **Au was deposited as a ground electrode onto the bottom surface of the sample …sample was (8) cleaned using superpure water in a clean room,** and then (9) was dried."
- ✓ "Adjusting the dipping solution: an **aqueous solution for sample dipping was prepared on a clean bench (clean air filter: class 100) set up in a clean room. Table 2 lists the three highly purified metallic salt reagents for use as solutes.** These metallic salts are known to promote the creation and development of water trees … **superpure water (less than 1 ppt of impurities for all elements) used in the solutions was created using a superpure water manufacturing device (Simpli Lab from Japan Milipore Corp.). Distilled water was used as a water source (water undergoing primary processing) for the superpure water manufacturing device.** These reagents and the solution were combined, forming three types of dipping solutions each at a 0.1 mol/l concentration."

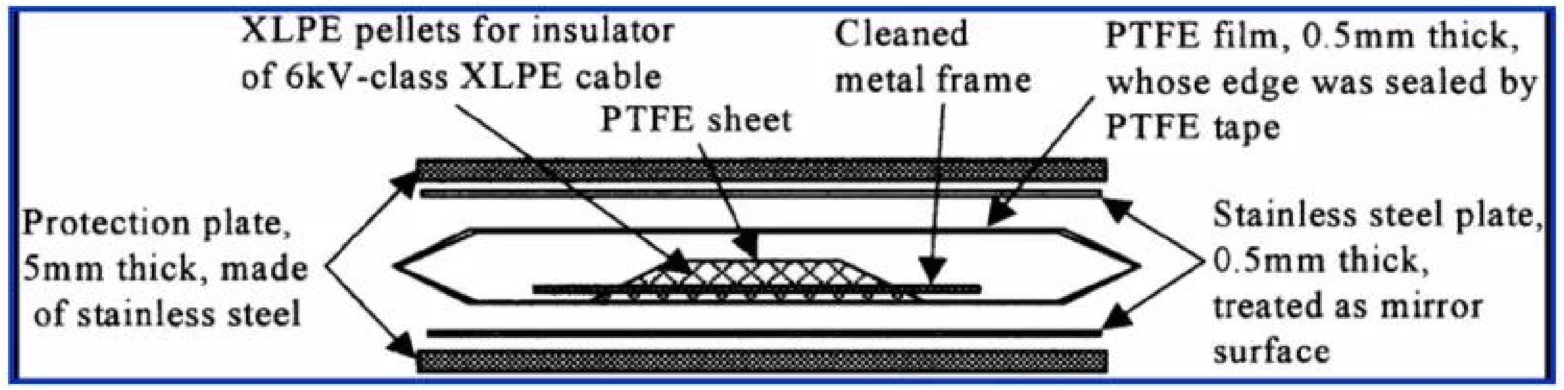


Fig. 1. Manufacture of XLPE sample - Kumazawa et al. (2005)

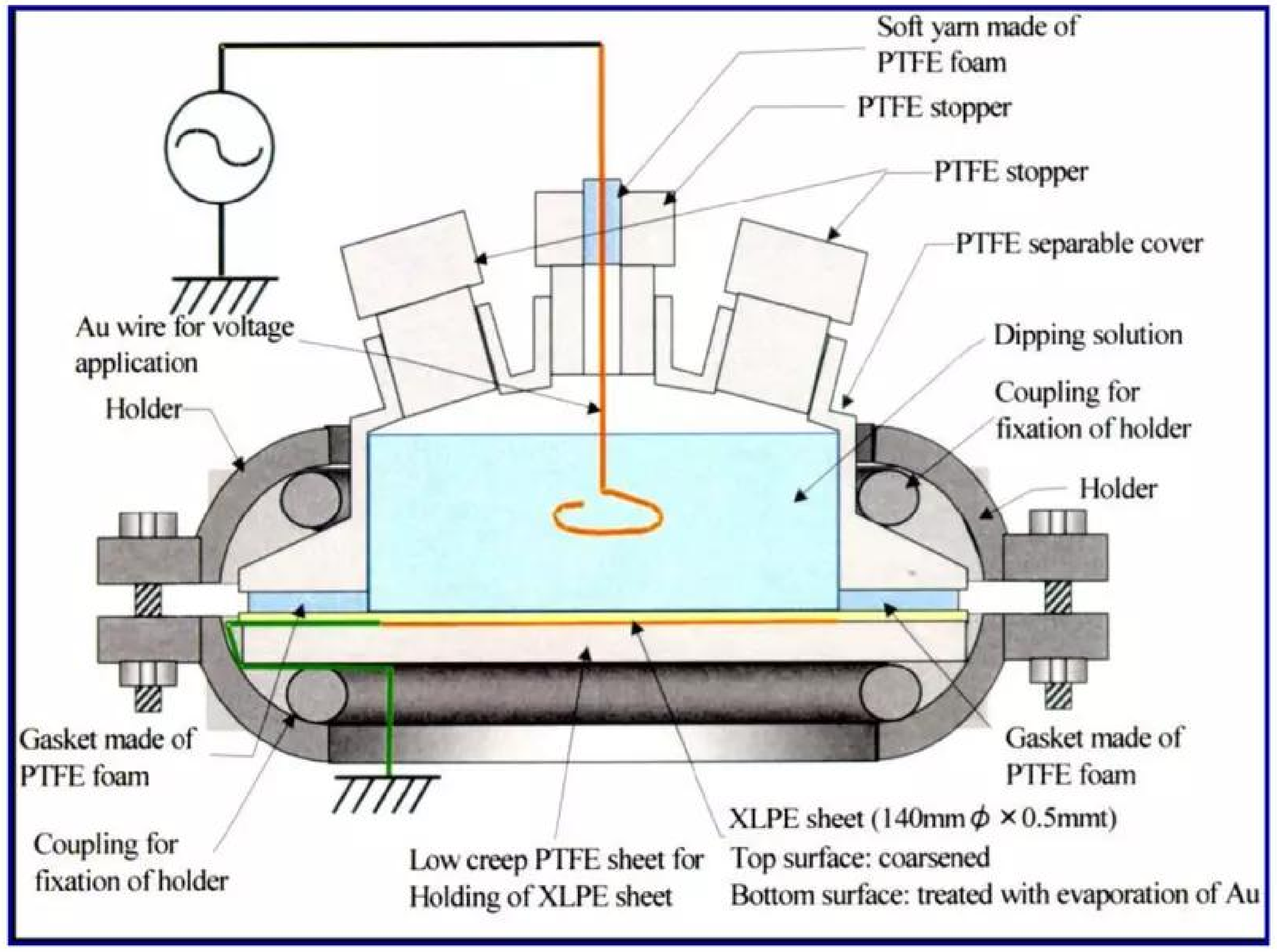


Fig. 2. Cell for voltage application - Kumazawa et al. (2005)

Important Japanese experiments help unravel mystery - 3

Quoting further from Kumazawa et al.’s 2005 paper:

- ✓ “The ratio of isotopes in the elements that comprise matter is virtually constant in the natural world. However, **there seems to be a message related to the mechanism behind the formation and development of water trees suggesting that the isotope ratio for inorganic elements has changed.** The authors therefore attempted an isotope analysis of the inorganic elements present in the samples.“

Table 7. Result of measurement for isotopic content of inorganic elements in aged or blank sample (dipped in KCl solution)

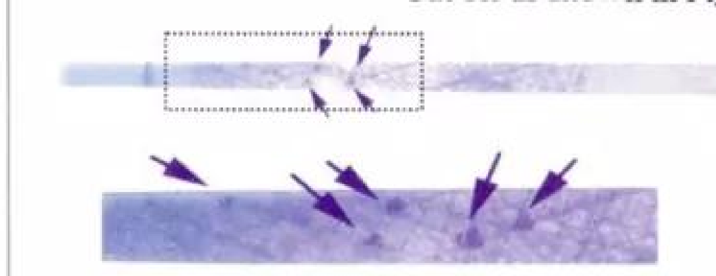
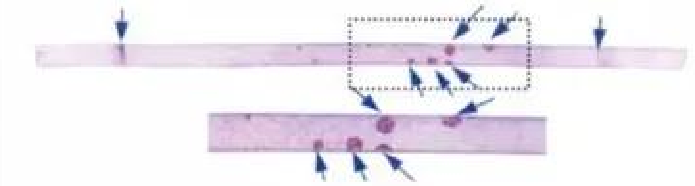
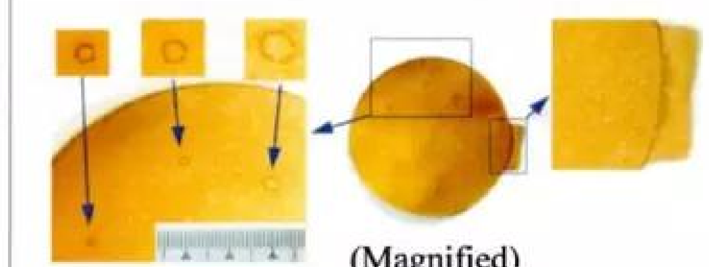
Element	Mass number	Isotopic content [%](*) Sample-A	Sample-B	Average	Blank sample	Natural abundance(**)
Mg	24	80.2±0.32	80.3±1.4	80.25	80.2±0.65	79.0
	25	9.79±0.08	9.93±0.19	9.86	9.76±0.19	10.0
	26	10.1±0.09	9.77±0.19	9.94	10.1±0.11	11.0
Fe	54	6.15±0.14	6.20±0.11	6.18	6.19±0.09	5.81 (5.82)
	56	87.9±1.3	89.8±1.8	88.85	91.0±0.60	91.8 (92.0)
	57	5.98±0.11	3.95±0.13	4.97	2.82±0.05	2.15 (2.16)
	58	—	—	—	—	0.29 (0)
Zn	64	53.2±0.98	56.9±1.9	55.05	51.8±1.6	48.9 (48.9)
	66	26.7±0.42	25.0±0.68	25.85	27.9±0.61	27.9 (28.1)
	67	3.18±0.69	2.36±0.09	2.77	3.09±0.10	4.10 (4.13)
	68	16.9±0.69	15.8±0.46	16.35	17.3±0.71	18.8 (18.9)
	70	—	—	—	—	0.62 (0)

(*) The number behind ± shows [%] relative standard deviation.

(**) The isotopic contents of Fe and Zn calculated by excluding ^{70}Zn and ^{58}Fe, respectively are shown in parentheses.

- ✓ “A small change was seen for Fe. In concrete terms, although 54Fe did not vary, **56Fe fell and 57Fe rose**. This change was 2.2% on average for samples A and B with respect to the blank sample (2.8 to 3.2% with respect to the natural abundance) ... **On the other hand, a significant change was seen for Zn. In concrete terms, 64Zn rose, 66Zn and 68Zn fell.** The increase in 64Zn was 3.3% on average for samples A and B with respect to the blank sample (6.2% with respect to the natural abundance) … decrease in 66Zn and 68Zn was 2.1% and 1.0%, respectively, on average for samples A and B (2.3% and 2.6% with respect to the natural abundance) … for 67Zn, there was a 0.3% decrease (1.4% with respect to the natural abundance).”

Table 4. Kumazawa et al. (2005)

Dipping solution	View from upside of aged sample (The arrows show water-treed region)
KCl	Cut off as shown in Fig.4  (Magnified)
NaCl	Cut off as shown in Fig.4  (Magnified)
AgNo$_3$	 (Magnified)

"Table 4 shows the results of water tree observation for the various samples. **Water tree formation was confirmed in all samples**. **Although the distribution was scattered, the density of formation was very high along the edges of the samples**. For the $AgNO_3$ aqueous solution, the water tree formed a circular colony with a diameter of 2 to 3 mm. At the very least, this cannot be considered a result of the small scratches that served as the starting points for the water trees having accidentally formed a circle, and so the cause of this is unknown at the present.”

Important Japanese experiments help unravel mystery - 4

Quoting the entire conclusions from Kumazawa et al.'s 2005 paper:

"The authors used experiments to investigate in detail the behavior of inorganic impurities contributing significantly to the development and evolution of water trees. The following results were obtained. (1) **In XLPE samples in which water trees occurred, unusual increases or decreases in Li, Na, Mg, Al, K, Ca, Fe, Ni, Pb, and Bi were observed (depending on K+, Na+, and Ag+, the main constituent cations in the dipping solution).** (2) A distinctive relationship was found for the mass numbers for these elements, one that is difficult to explain in terms of inadvertent mixing, adhesion, or scattering. At the present time, their source and transitions cannot be explained logically. (3) **A significant shift exceeding 6% with respect to the natural abundance was observed for the isotopic content of some of the inorganic elements.** (4) The possibility of an unknown physical or electrochemical reaction accompanying the development and evolution of water trees is indicated**. Even now, 30 years after their discovery, there are still many unexplained aspects to the phenomenon of water trees. For instance, the matter of the basic mechanism of "how and from where the energy involved in the creation and development of water trees is supplied" still remains.** One answer resulting from repeated thought experiments on this subject is "nuclear reactions in solids." As has been described in this paper, the similarity at the molecular and atomic level of the details of the experimental environment is the primary reason for this idea. The (unusual) experimental data in this experiment was to be expected, and in this sense it underscores the results of thought experiments. **Naturally, the point of these experiments is to explore the relationship between the water tree phenomenon and the unknown phenomenon of "nuclear reactions in solids" and not to prove the existence of low-energy nuclear reactions.** Therefore, the authors have avoided to the utmost extent possible any emphasis on or support for such reactions. In addition, the authors have used terminology such as "nuclear reactions in solids" and added some explanation in the final portion of the Discussion section in order to avoid the development of unexpected ideas. There has been considerable criticism over the history of research proceeding from "cold fusion" to today's "nuclear reactions in solids," but such ideas may represent a new way to clarify the phenomenon of water trees."

Reference - follow-up work to their 2005 publication:

T. Kumazawa[1] and R. Taniguchi[2], "Detection of weak radiation involving generation and progress of water tree," Electrical Engineering in Japan ***164*** *(2) pp. 1 - 9, published online April 24, 2008*

1 Chubu Electric Power Co., Inc., Japan
2 Osaka Prefecture University, Japan

Abstract - this time, saw very weak, 'bursty' radiation:

" It is well known that generation and progress of water trees in XLPE cables are strongly enhanced by inorganic impurities. We have investigated the effect of such impurities in the water treeing process and reported the experimental results as follows: (1) the anomalous increase or decrease in several kinds of inorganic elements was observed in water treed XLPE samples, (2) a distinctive relationship was found for the mass numbers for the elements, and (3) the isotopic content of the elements such as Zn deviated over 6% from the naturally occurring level. ***These results suggest that some unknown phenomena play a role in the formation of water trees, such as cold fusion or nuclear transmutation in condensed matter.*** *In order to study the relationship between water trees and these phenomena, we attempted to detect neutrons, -rays, or X-rays accompanying the generation and progress of water trees in XLPE samples.* ***In the experiments, weak and burst-like radiation, apparently low-energy gamma-rays or X-rays, was often detected by*** BF_3 ***and/or CdZnTe counter. The radiation tended to be detected in the samples with a large number of water trees generated by supplying sufficient amounts of inorganic cations."***

Early LENR transmutation experiments in 1920s

Prof. Hantaro Nagaoka, famous Japanese physicist (1865 - 1950)

"The [high-current electric arc] experimental procedure here sketched cannot be looked upon as the only one for effecting transmutation [of other elements into Gold]; probably different processes will be developed and finally lead to industrial enterprises … Experiments with various elements may lead to different transmutations, which will be of significance to science and industry. Meagre as is the result, I wish to invite the attention of those interested in the subject so that they may repeat the experiment with more powerful means than are available in the Far East."

Prof. Hantaro Nagaoka in *"Letters to the Editor," Nature*, July 18, 1925

Early LENR transmutation experiments in 1920s

High current exploding wires: Wendt & Irion, USA (1922)

- ✓ **Early 1900s: from about 1905 - 1927 some of the most famous people in British science (J.J. Thomson, Ramsay, etc.) published a number of experimental reports in premier refereed journals, e.g., *Nature*, *Proceedings of the Royal Society* that, when viewed through the lens of W-L theory, clearly described nuclear transmutation products that were observed spectroscopically during electrical discharge experiments, e.g., high-current arcs in gases**

- ✓ **1922: Wendt and Irion, two chemists at the University of Chicago, reported results of experiments consisting of exploding tungsten wires with a very large current pulse under a vacuum inside of flexible sealed glass 'bulbs.' Controversy erupted when they claimed to observe anomalous helium inside sealed bulbs after the tungsten wires were exploded, suggesting that transmutation of hydrogen into helium had somehow occurred during the "disintegration of tungsten." Their article in *Amer. Chem. Soc.* 44 (1922) triggered a response from the scientific establishment in the form of a negative critique of Wendt and Irion's work by Ernest Rutherford that promptly published in *Nature* 109 pp. 418 (1922). We have since determined that Rutherford was wrong – see our preprint**

Please see:

J. J. Thomson (who discovered the electron in 1897), "On the appearance of Helium and Neon in vacuum tubes," where he says, "At the last meeting of the Chemical society, William Ramsay … describes some experiments which they regard as proving the transmutation of other elements into Helium and Neon …"
*Nature **90** pp. 645 - 647 (1913)*

Quoting:

"The energy produced by breaking down the atom is a very poor kind of thing. Anyone who expects a source of power from the transformations of these atoms is talking moonshine."

- Ernest Rutherford (1933)

More recently, our arXiv preprint:

"Energetic electrons and nuclear transmutations in exploding wires" in which we state that, "It is presently clear that nuclear transmutations can occur under a much wider range of physical conditions than was heretofore thought possible,"

arXiv:nucl-th/0709.1222 Widom, Srivastava, and Larsen (2007)

Early LENR transmutation experiments in 1920s

High current discharge: Wendt & Irion and Millikan, USA (1922 - 1923)

- ✓ **1922 - 1923: After reporting on their experiments at a regional American Chemical Society meeting held at Northwestern University in Evanston, there was widespread *global media coverage* in the form of scores of breathless newspaper headlines about "transmutations of elements." These sensational newspaper headlines prompted a critical response by Rutherford that was promptly published in *Nature*. Being a giant of physics, Ernest Rutherford resoundingly won the contemporary debate about the controversial experimental results: he was believed. Wendt and Irion, 'mere' chemists and comparative nobodies from the University of Chicago, were not. After 1923, Wendt and Irion abandoned their exploding wire experiments and turned to other lines of research. Sadly, Wendt died a few years later; Irion then left the U. of C to teach chemistry at a small college**

- ✓ **1923: Note that "transmutations" were not considered 'fringe science' during the 1920s. Au contraire, there was a lively back-and-forth global debate on the subject involving many preeminent scientists of that era! For example, in a *Scribner's* magazine article published in 1923, Prof. Robert Millikan (U. of Chicago and then of Caltech; Nobel prize in physics, 1923) said, "As early as 1912, Dr. Winchester and I thought we had good evidence that we were knocking hydrogen out of aluminum and other metals by very powerful electric discharges in vacuo … How much farther can we go in this artificial transmutation of elements? This is one of the supremely interesting problems of modern physics upon which we are all assiduously working" --- at that point Millikan was setting-up a high voltage laboratory at Caltech to test his ideas about discharges. Inexplicably, the decades of debate about triggering transmutations and related experimentation mostly ended without a final resolution *before* Chadwick verified neutron's existence experimentally (1932)**

Please see the original publications from 1922 as follows:

*(1.) Wendt and Irion's seminal paper, "Experimental Attempts to Decompose Tungsten at High Temperatures," from the American Chemical Society **44** (1922)*

*(2.) Rutherford's critical comments about their work in Nature **109** pp. 418 (1922) - also reprinted with permission in Science*

*(3.) Wendt's subsequent response to Rutherford in Science **55** pp. 567 (1922)*

For readers' convenience, all three original documents have been combined into a single Adobe Acrobat file that can be downloaded free from the following URL:

http://www.newenergytimes.com/v2/library/1900s/1922Wendt-Irion.pdf

Quote source for Millikan's 1923 remarks:

W. Shea, "Otto Hahn and the rise of nuclear physics," D. Reidel Publishing, Dordrecht, Holland (1983) pp. 77 - 79

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Early LENR transmutation experiments in 1920s

High current discharge: Hantaro Nagaoka, Japan (1924 - 1926) - 1

- ✓ **Unlike, the comparatively unknown Wendt & Irion team at the U. of Chicago, Nagaoka was a world-renowned physicist and one of the most preeminent scientists in Japan when he began his high-current discharge transmutation experiments in September 1924**

  For an appreciation of his high scientific stature, please see Wikipedia article:

  - **http://en.wikipedia.org/wiki/Hantaro_Nagaoka**

  Nagaoka was contemporary *competitor* of Ernest Rutherford; Hantaro's "Saturn model" of the atom was only competing model cited by Rutherford in his seminal 1911 paper on the nucleus

- ✓ **Given the very international character of science even at that time, it is very likely that Nagaoka was aware of worldwide controversy swirling around Wendt & Irion's exploding wire experiments and of Rutherford's short but devastating attack on them in *Nature***

- ✓ **It is also quite likely that Hantaro was aware of Robert Millikan's well-publicized views on subject of triggering transmutations with electric arcs (also, Millikan had just won a Nobel prize in physics)**

- ✓ **Lastly, he must have known about Miethe & Stammreich's work in Germany; who claimed to have changed Mercury into Gold in a high-voltage Mercury vapor lamp, "The reported transmutation of Mercury into Gold," *Nature* 114 pp. 197-198 (9 August 1924)**

Please see:

*H. Nagaoka, "Preliminary note on the transmutation of Mercury into Gold," Nature **116** pp. 95 - 96 (18 July 1925)*

Available for purchase on Nature archives:

http://www.nature.com/nature/journal/v116/n2907/abs/116095a0.html

Abstract:

*"The experiment on the transmutation of mercury was begun in September 1924, with the assistance of Messrs. Y. Sugiura, T. Asada and T. Machida. **The main object was to ascertain if the view which we expressed in NATURE of March 29, 1924, can be realised by applying an intense electric field to mercury atoms. Another object was to find if the radio-active changes can be accelerated by artificial means. From the outset it was clear that a field of many million volts/cm. is necessary for the purpose.** From our observation on the Stark effect in arcs of different metals (Jap. Journ. Phys., vol. 3, pp. 45â€“73) we found that with silver globules the field in a narrow space very near the metal was nearly 2 Ã - 105 volts/cm. with terminal voltage of about 140. **The presence of such an intense field indicated the possibility of obtaining the desired strength of the field for transmutation, if sufficient terminal voltage be applied.** Though the above ratio of magnification would be diminished with high voltage, the experiment was thought worth trying, even if we could not effect the transmutation with the apparatus at hand."*

High current discharge: Hantaro Nagaoka, Japan (1924 -1926) - 2

Essence of Nagaoka's experiments:

- ✓ **In simplest terms, Prof. Nagaoka created a powerful electric arc discharge between a spark gap comprising two metallic, Thorium-oxide-free Tungsten (W) electrodes (supplied by Tokyo Electric Company) bathed in a dielectric liquid "paraffin" (today referred to as "transformer oil;" general formula C_nH_{2n+2}) that was 'laced' with liquid Mercury (Hg)**
- ✓ **Depending on the experiment, arcing between Tungsten electrodes in oil was continued for 4 - 15 hours until, quoting, " … the oil and mercury were mixed into a black pasty mass." Please note that Mercury readily forms amalgams with many different metals, including Gold (Au) and Tungsten (W)**
- ✓ **Small flecks of Gold were sometimes quite visible to the naked eye in "black masses" produced at the end of a given experiment. They also noted that, "The Gold obtained from Mercury seems to be mostly adsorbed to Carbon."**
- ✓ **Microscopic assays were conducted by, "heating small pieces of glass with the Carbon," to form a so-called "Ruby glass" that can be used to infer the presence of gold colloids from visual cues apparent under a microscope**
- ✓ **Critics complained about the possibility that the Gold observed was some sort of "contamination." Responding to that, Nagaoka et al. further purified literally everything they could think of and also made certain that the lab environs were squeaky clean; they still kept seeing anomalous Gold. In some experiments they also observed, "a minute quantity of white metal." Two years later in 1926, Nagaoka reported to *Scientific American* that they had finally been able to identify the "white metal" --- it was Platinum (Pt)**

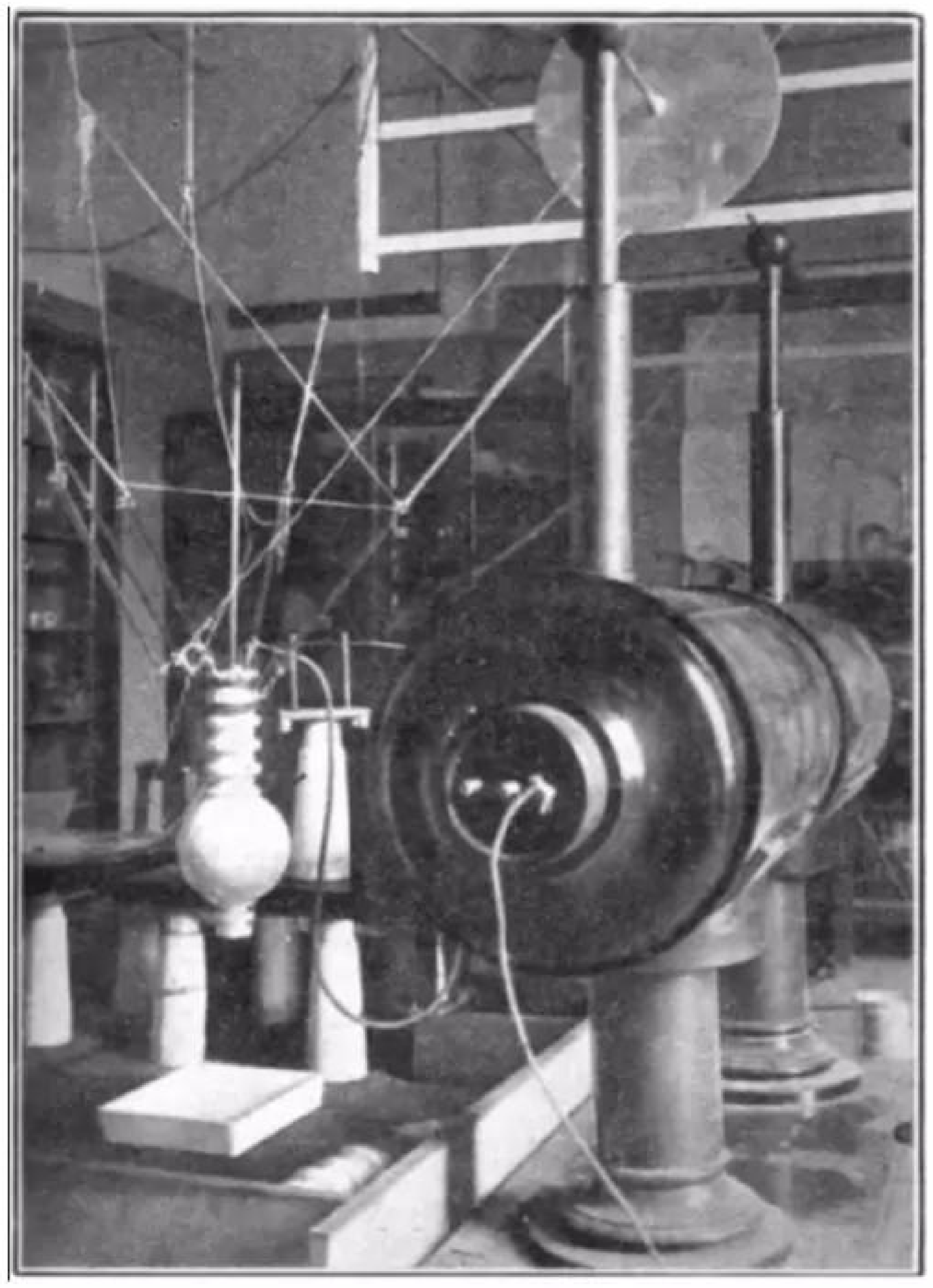


Fig. 1 – Apparatus for the electric discharge (H. Nagaoka, *Nature*, July 18, 1925)

***Free Internet resource**: for readers interested in finding more references to old transmutation experiments, Robert Nelson has compiled many of them at:*

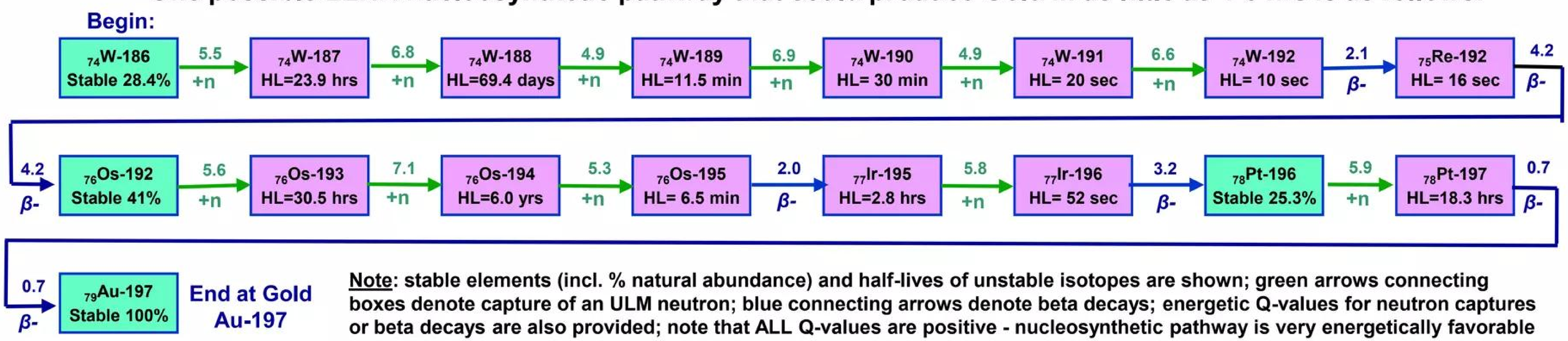
http://www.levity.com/alchemy/nelson_contents.html

High current discharge: Hantaro Nagaoka, Japan (1924 -1926) - 3

Based on W-L theory, what might have happened in Nagaoka's experiments to produce the Gold?

- ✓ **All of the 'ingredients' for LENRs to occur were in fact present (please refer back to an earlier Slide): hydride-forming metal found therein was Tungsten (sadly, Nagaoka was unaware that Mercury was really a 'red herring'); which was in contact with abundant Hydrogen (protons) in transformer oil (C_nH_{2n+2}); the Born-Oppenheimer approximation broke-down on surfaces of electrodes; and finally, there were large non-equilibrium fluxes of charged particles --- electrons in the high-current arc discharges. Unbeknownst to Nagaoka, his high-current arcs probably also produced small amounts of fullerenes, carbon nanotubes, and perhaps even a little graphene. ULM neutron production rates via W-L weak interaction could have been quite substantial in his experimental system**
- ✓ **What could have happened in his experiments was that a Tungsten-seed, ULM neutron-catalyzed nucleosynthetic network spontaneously formed. What follows is one example of an energetically favorable network path that could produce detectable amounts of the only stable Gold isotope, $_{197}$Au, within ~4 hours (shortest arc discharge period after which Au was observed). Other alternative viable LENR pathways can produce unstable Gold isotopes, e.g., $_{198}$Au with half-life = 2.7 days and $_{199}$Au with HL = 3.1 days (both would be around for a time at end of an experiment)**

One possible LENR nucleosynthetic pathway that could produce Gold in as little as 4-5 hrs is as follows:



Note: stable elements (incl. % natural abundance) and half-lives of unstable isotopes are shown; green arrows connecting boxes denote capture of an ULM neutron; blue connecting arrows denote beta decays; energetic Q-values for neutron captures or beta decays are also provided; note that ALL Q-values are positive - nucleosynthetic pathway is very energetically favorable

High current discharge: Hantaro Nagaoka, Japan (1924 -1926) - 4

Final comments:

- ✓ **Plausible LENR nucleosynthetic pathway shown in the previous Slide suggests that Nagaoka et al.'s claimed observations of macroscopically visible particles of Gold in their 1924 electric arc experiments could very well have been correct**
- ✓ **It is puzzling why this seemingly fruitful line of inquiry appears to have died-out worldwide by the time Chadwick experimentally verified the neutron's existence in 1932. Oddly, it does not appear that anyone else ever tried to exactly duplicate Nagaoka's experiments. However, there were well-publicized failures to replicate Miethe & Stammreich's Gold experiments that were extensively chronicled in *Scientific American*. Interestingly, Miethe's experimental apparatus consisted of Mercury arc lamps with Tungsten electrodes inside evacuated quartz tubes. No transformer oil was present in those arcs. Perhaps Nagaoka's decision to use oil was exceedingly fortuitous: by doing so, he inadvertently guaranteed that his apparatus contained enormous quantities of hydrogen for making ULM neutrons**
- ✓ **Do readers have any thoughts as to why all this research suddenly just stopped?**
- ✓ **Please take note of the quotation from Prof. Nagaoka reproduced on the cover slide for this section of our presentation. He clearly believed that some sort of commercial transmutation technology would be developed at some point in the future. Thus, in our opinion not only was he a humble, brilliant scientist; he was also a rather bold visionary thinker --- truly a man ahead of his own time**
- ✓ **Interestingly, in the present era it is possible that minute quantities of Gold are being produced in automobile catalytic converters via the transmutation of Platinum: at right, please see citation to a 2003 paper in *Applied Geochemistry* and URL to yet another Lattice SlideShare presentation dated June 25, 2010**

Regarding other anomalous Gold please see:

*G. Dongarra, D. Varrica, and G. Sabatino, "Occurrence of Platinum, Palladium, and Gold in pine needles of Pinus pinea from the city of Palermo (Italy)," Applied Geochemistry **18** pp. 109-116 (2003)*

Quoting: *"Preliminary data on the presence of Pt, Pd and Au in airborne particulate matter from the urban area of Palermo (Sicily, Italy) are presented. They were obtained by analysing 40 samples of pine needles (Pinus pinea L.) collected in and around the city. Observed concentrations range from 1 to 102 μg/kg for Pt, 1 to 45 μg/kg for Pd and **22 to 776 μg/kg for Au. Platinum and Pd concentrations in pine needles are up to two orders of magnitude higher than their crustal abundances. They exhibit a high statistical correlation (R^2=0.74)** which suggests a common origin. Precious metal concentrations measured within the city centre are much higher than those occurring outside the town. The distribution patterns of Pt and Pd in the study area are compared to the distributions of Au and Pb. **Gold is enriched at the same sites where Pt and Pd are enriched, while Pb shows some discrepancies. The most probable local source of all of these elements is traffic.** Average Pt and Pd emissions in the city area are estimated to be about 136 and 273 g/a, respectively."*

Discussed at URL:

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-len-rs-in-catalytic-convertersjune-25-2010

Back to the future: W → … → Au - Cirillo and Iorio, Italy (2006) - 1

- Quoting: "… electrodes are cylindrical rods with a diameter of 2.45 mm, and a length of 17.5 cm … both are made of pure Tungsten [W] …cathode is partially covered with a ceramic sleeve, which allows … control [of] the dimensions of … exposed cathode surface submerged in … solution."
- In their experiments, Rhenium (Re), Osmium (Os), and Gold (Au) were observed post-experimentally as nuclear transmutation products on the Tungsten (W) cathode surface; other LENR transmutation products were also observed (please see our Comment on the next Slide)
- According to W-L theory, ULM neutron production and successive ULM neutron captures interspersed with beta decays could potentially produce a nucleosynthetic pathway of ***W → Re → Os → Ir → Pt → Au***; in fact, Re, Os, and Au were apparently observed in these experiments
- Similar to Nagaoka's experiments in 1920s in that various LENR transmutation products were observed, Gold (Au) in particular, that can be explained with neutron captures and $beta^-$ decays beginning with Tungsten (W) as a "seed"

Paper (conference presentation - not peer-reviewed):

D. Cirillo and V. Iorio, "Transmutation of metal at low energy in a confined plasma in water" on pp. 492-504 in "Condensed Matter Nuclear Science – Proceedings of the 11th International Conference on Cold Fusion," J-P. Biberian, ed., World Scientific 2006

Free copy of paper available at:

http://www.lenr-canr.org/acrobat/CirilloDtransmutat.pdf

Abstract:

"Energetic emissions have been observed from an electrolytic cell when tungsten [W] electrodes are used to generate a confined plasma close to the cathode immersed an alkaline solution. In addition, energy generation has been observed, always close to the cathode, along with the appearance of new chemical elements in the experimental apparatus. These elements were not present in the cell before the experiment. This observation is proof of nuclear transmutations occurring within the cell. The results of this research and a theoretical model of the phenomenon were shown for the first time on April 18, 2004 during the second Grottammare (Ap) ONNE meeting in Italy."

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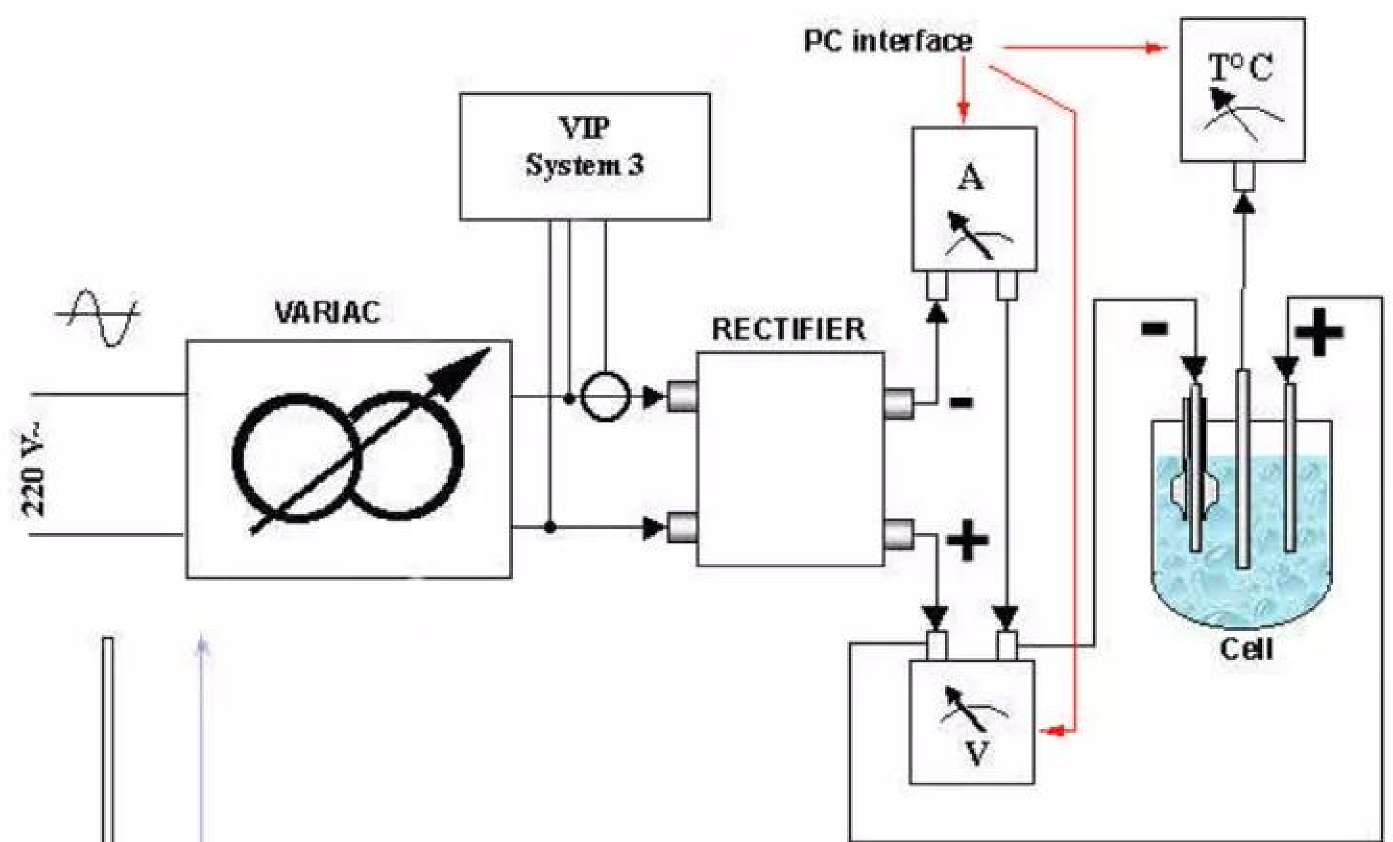
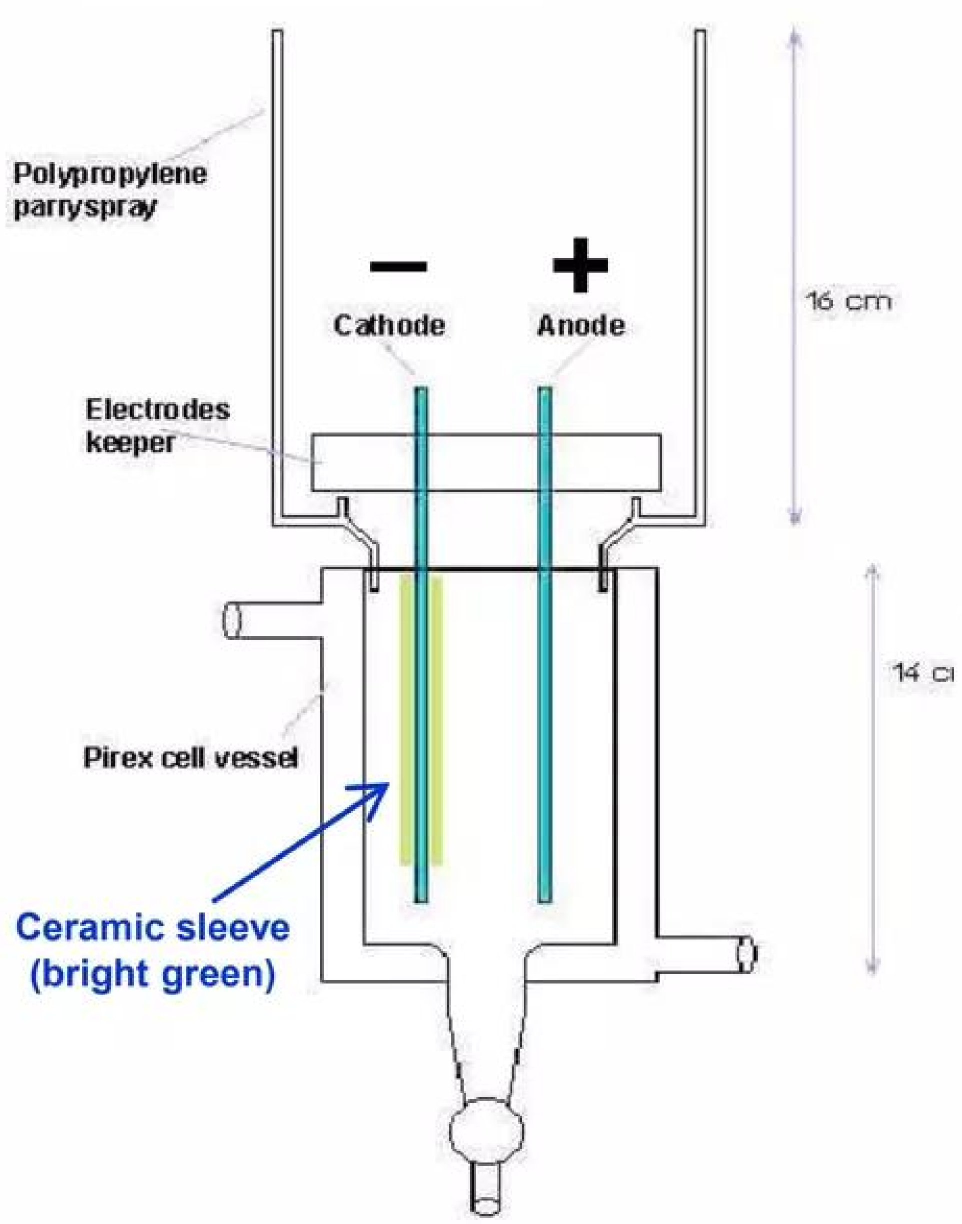
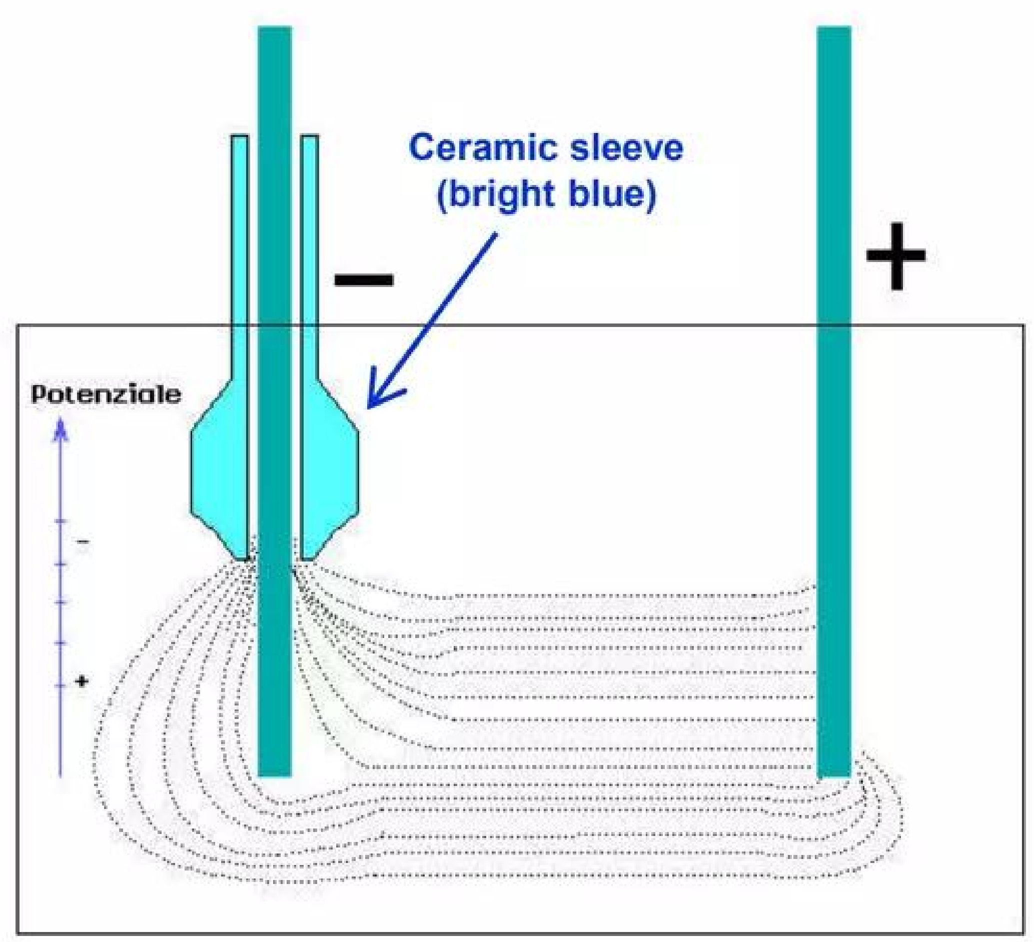
Early LENR transmutation experiments in 1920s

Back to the future: W → … → Au - Cirillo and Iorio, Italy (2006) - 2

<u>Comment</u>: this LENR experiment involves formation of a dense plasma in a double-layer confined to the surface of tungsten (W) cathode (-) by a liquid electrolyte







<u>Comment on their experimental data</u>:

Unbeknownst to the experimenters, they may have had either Barium (Ba) titanate and/or Dysprosium (Dy) as component(s) in the composition of the dielectric ceramic sleeve that was partially covering the cathode immersed in the electrolyte; Ba and/or Dy are often present in such ceramics. Under the stated experimental conditions, Ba and Dy could easily 'leach-out' from the surface of the ceramic into the electrolyte, creating yet another 'target' element that could migrate onto the surface of their Tungsten (W) cathode. Since none of the potential intermediate transmutation products such as Nd (Neodymium), Sm (Samarium), and Gd (Gadolinium) were observed, it is possible that there may have been LENR ULM neutron captures starting with Dy → Er (Erbium) → Tm (Thulium) → Yb (Ytterbium), LENR transmutation products that were also observed in their experiments

Early LENR transmutation experiments in 1920s

Back to the future: W → … → Au - Cirillo and Iorio, Italy (2006) - 3

Rhenium (Re)

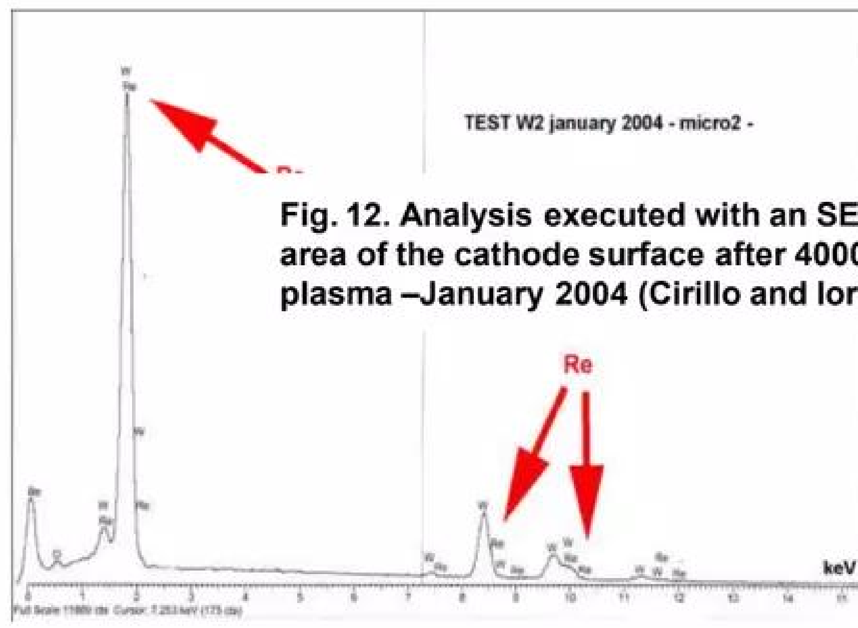


Fig. 12. Analysis executed with an SEM on an area of the cathode surface after 4000 sec. of plasma –January 2004 (Cirillo and Iorio, 2006)

Osmium (Os)

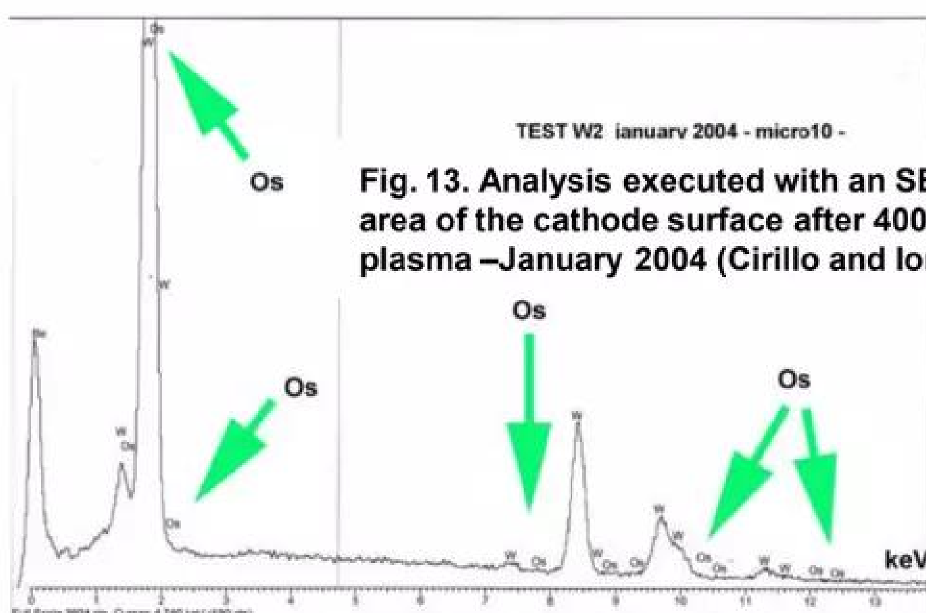


Fig. 13. Analysis executed with an SEM on an area of the cathode surface after 4000 sec. of plasma –January 2004 (Cirillo and Iorio, 2006)

Gold (Au) and Thulium (Th) see comment on previous Slide re Th

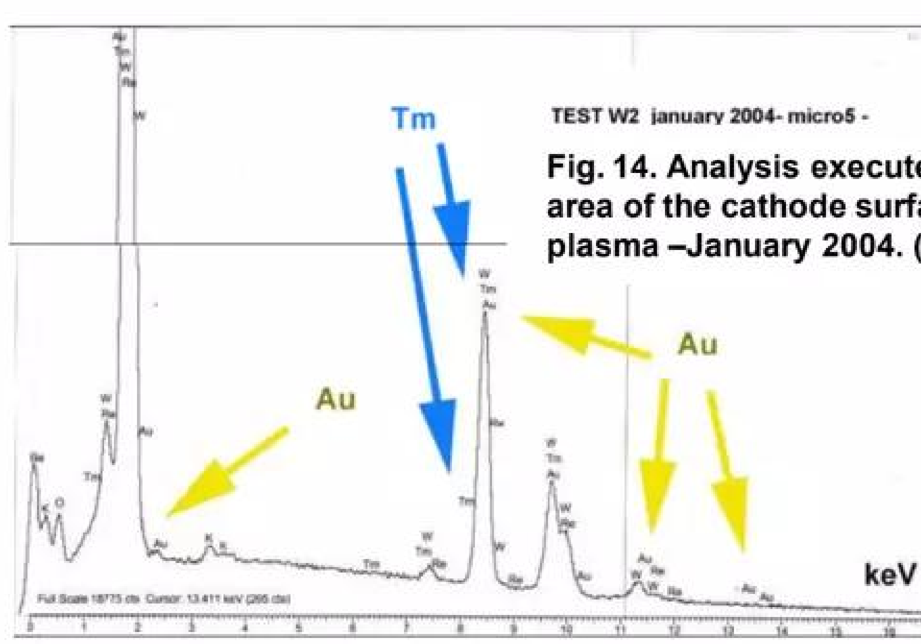


Fig. 14. Analysis executed with an SEM on an area of the cathode surface after 4000 sec. of plasma –January 2004. (Cirillo and Iorio, 2006)

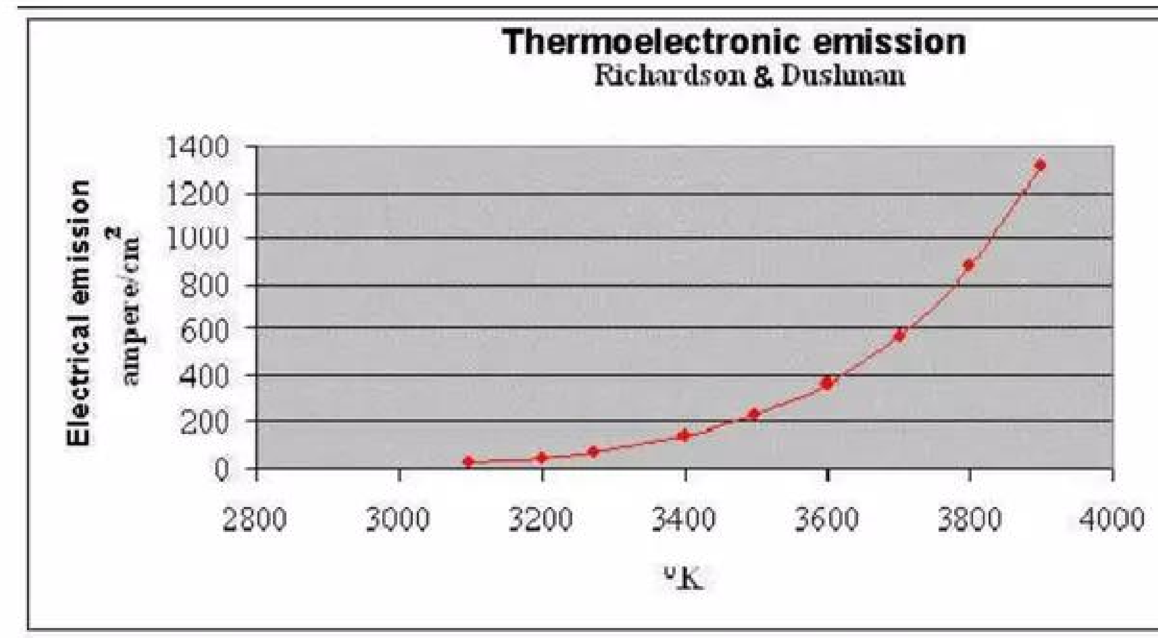


Fig. 10 – Tungsten thermionic emission (Cirillo and Iorio, 2006)

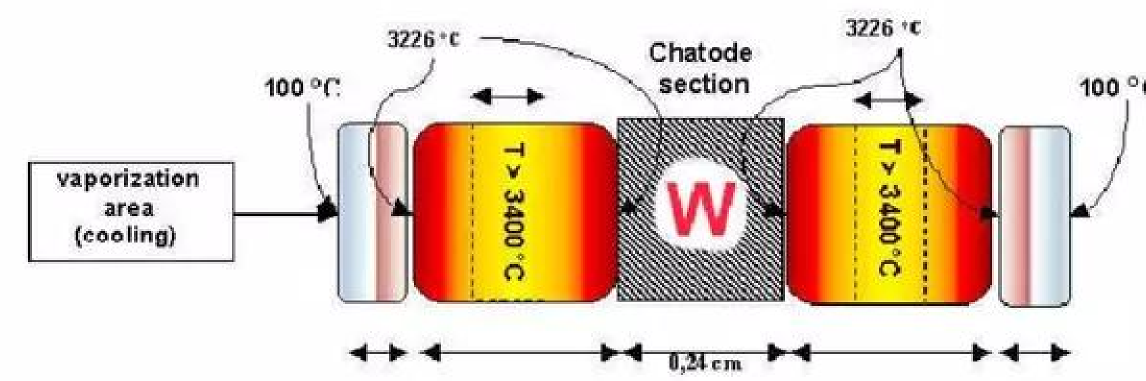


Fig. 11 – View of the plasma heat transfer mechanism (Cirillo and Iorio, 2006)

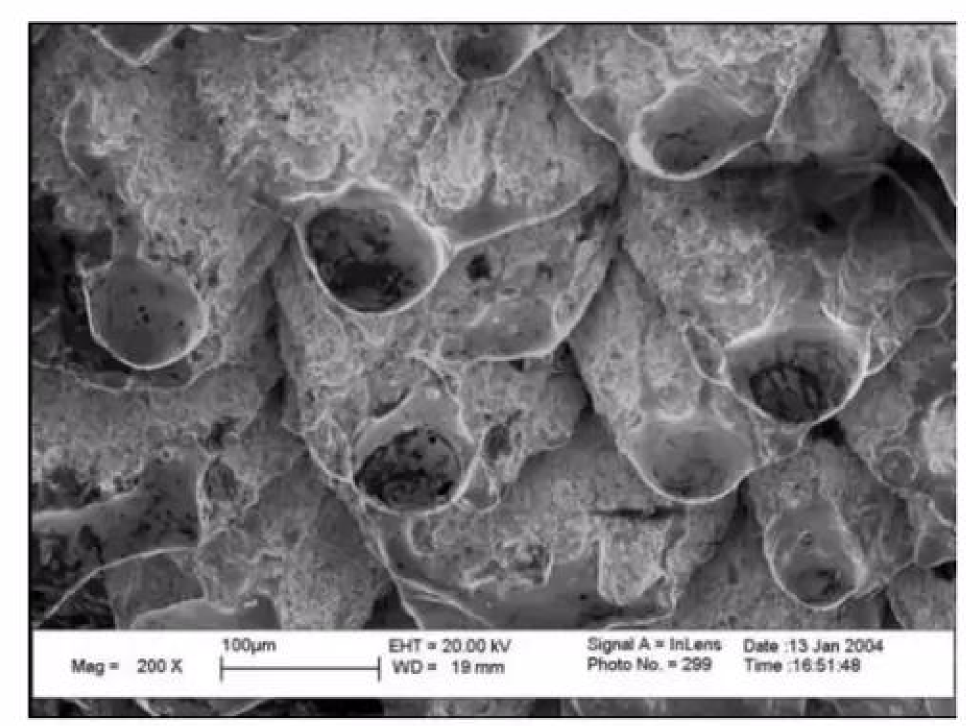


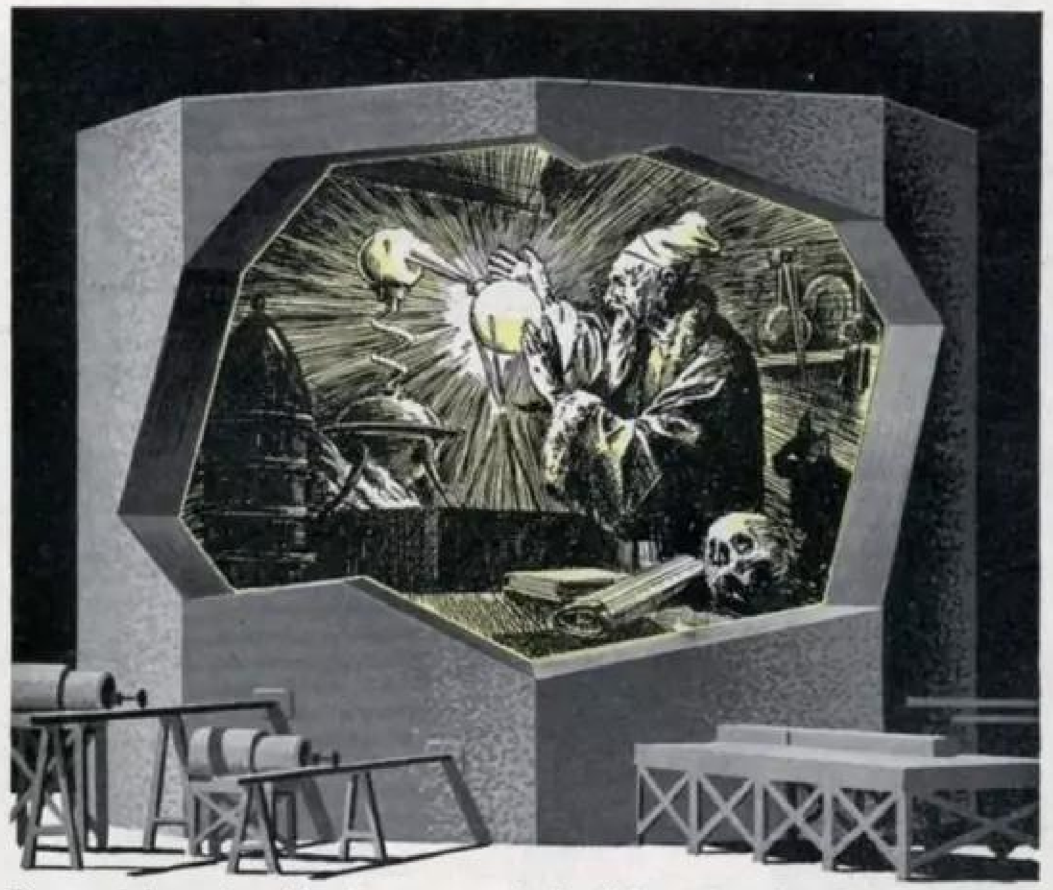
Fig. 9 – Tungsten fusion area [after 4,000 sec.] (Cirillo and Iorio, 2006)

Alchemy redux: world of today (2010)

"Alchemy, derived from the Arabic word '*al-kimia*' is both a philosophy and an ancient practice focused on the attempt to change base metals into gold, investigating the preparation of the 'elixir of longevity', and achieving ultimate wisdom, involving the improvement of the alchemist as well as the making of several substances described as possessing unusual properties. The practical aspect of alchemy generated the basics of modern inorganic chemistry, namely concerning procedures, equipment and the identification and use of many current substances. Alchemy has been practiced in ancient Egypt, Mesopotamia (modern Iraq), India (modern Indian subcontinent), Persia (modern Iran), China, Japan, Korea, the classical Greco-Roman world, the medieval Islamic world, and then medieval Europe up to the 20th century, in a complex network of schools and philosophical systems spanning at least 2,500 years."

Source: Wikipedia article as of July 7, 2010

<u>Comment</u>: according to W-L theory, LENRs and chemistry intersect on nm - μ length-scales in condensed matter systems under comparatively 'mild' conditions compared to interiors of stars, nuclear weapons, and fuel rods of operating fission reactors. Production of Gold from lower-Z elements such as Tungsten is not just some alchemist's fevered delusion. It is an understandable result of ULM neutron-captures on W and subsequent beta decays, both of which are presently well-accepted in nuclear science



Dreams of the ancient alchemists come true in the chain-reacting pile at Oak Ridge, Tenn.

U. S. Alchemists Make Gold

Applying atomic magic to aid medicine and research, radiochemists duplicate nature's elements and create new ones.

By Alden P. Armagnac

Drawings by Ray Pioch

AT Oak Ridge, Tenn., the United States Atomic Energy Commission has gone into the business of manufacturing synthetic gold. The atomic pile is the Philosopher's Stone, long sought by the ancient alchemists, which has the 24-carat touch.

Most curious part of the new enterprise is the odd behavior of the man-made gold. Though locked in the strongest vault, most of it would disappear within a week's time. Strange to say, this extraordinary way of acting actually enhances the gold's value. What makes it so desirable is the fact that it is radioactive. Hence the ray-emitting "radiogold" offers medical men a priceless tool for treating such maladies as leukemia, lymphoma and Hodgkin's disease. At one institution alone, Vanderbilt University Medical School in Nashville, Tenn., it has benefited 61 patients in the first year of use.

For therapy and for "tagging" chemicals used in research, Oak Ridge's alchemists—or "radiochemists," as they call themselves—produce scores of artificially radioactive elements like radiogold. But they are by no means limited to "freak" products that have no counterpart in nature.

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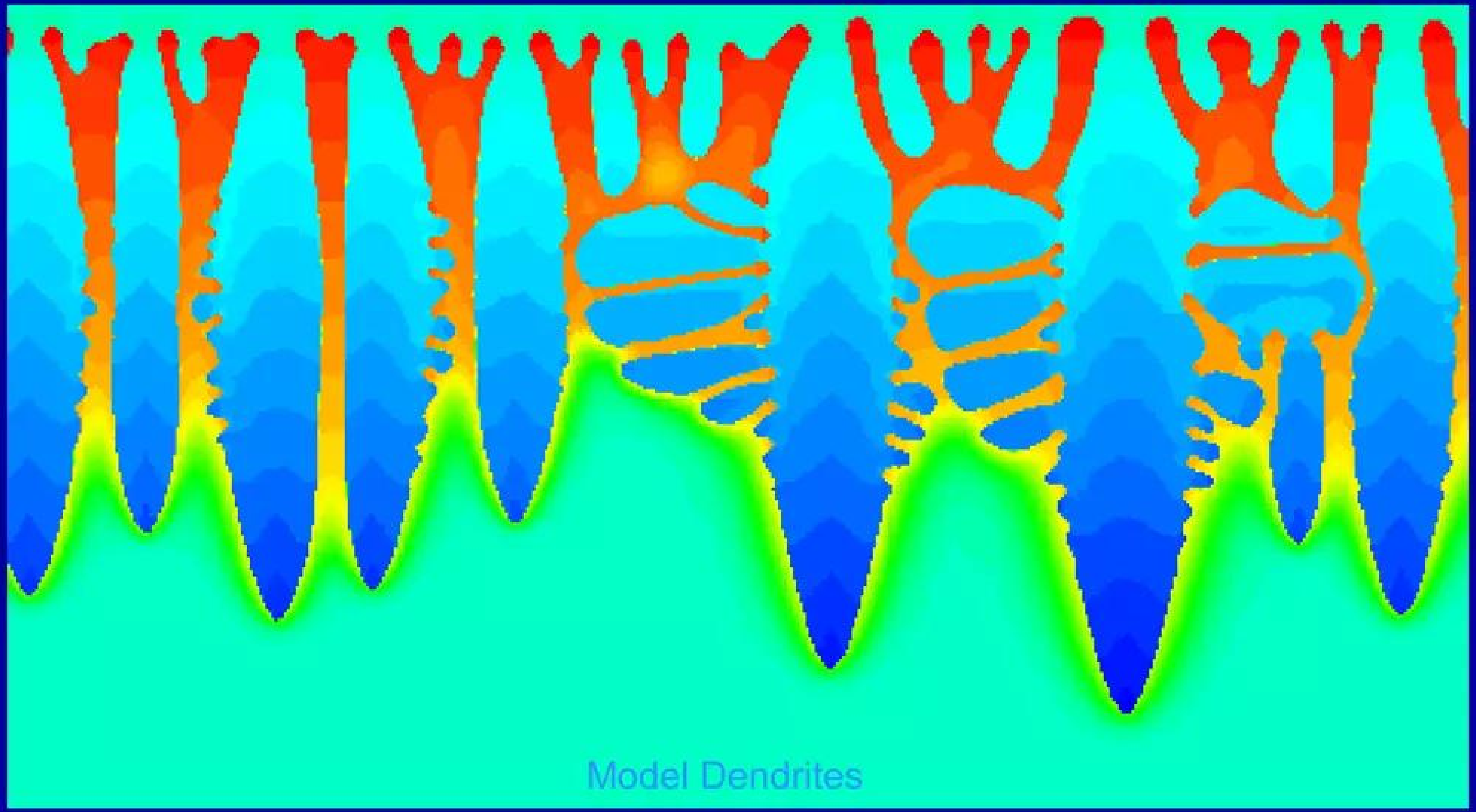
"Popular Science" magazine article, March 1948

Further thoughts, concerns, and future possibilities



Model Dendrites

"Nothing is too wonderful to be true, if it be consistent with the laws of nature; and in such things as these experiments is the best test of such consistency."

Michael Faraday

Laboratory journal entry #10,040, March 19, 1849

Further thoughts, concerns, and future possibilities

- ✓ Local E-M fields high enough to create heavy-mass e^* electrons required to produce ULM neutrons needed for LENRs a la the W-L theory are readily achievable on micron to nanometer length-scales in a variety of different condensed matter systems
- ✓ Enormous mutual synergies exist between the science of nanotechnology and that of LENRs; Lattice has 'mined' and applied knowledge originally developed in nanotech for many years with outstanding results
- ✓ Based on our research, it appears likely that LENRs could be involved in some indeterminate subset of Lithium-ion battery failures and fires. If this proves to be correct, it raises additional questions about the safety, cost, and longevity of huge Li-ion battery packs used in present and planned electric vehicle applications --- battery makers may unknowingly be encountering LENRs
- ✓ LENR-related issues about batteries that we raise herein are applicable to ANY type of advanced battery chemistry in which there is a possibility of "lightning rod effect" electric discharges between various types of microstructures inside a battery that are also in the vicinity of flammables
- ✓ It appears likely that LENRs may also be involved in "water trees" that can damage buried underground power cables over time. Using W-L theory, Lattice has developed a proprietary technical strategy that may help mitigate such effects for cable manufacturers and electric utilities
- ✓ It appears plausible that Prof. Hantaro Nagaoka of Japan could have produced Gold from Tungsten electrodes in seminal experiments that he conducted in 1924 and duly reported in *Nature* in 1925
- ✓ In 10 years of research, Lattice has developed a unique body of proprietary knowledge that it is applying to commercialization of battery-like LENR devices. Today, battery and LENR technologies already partially overlap. The difference is that fully developed LENR technology should eventually be able provide customers with power sources >1,000x better than any chemical batteries

Historical perspective: 1901 quote from Rutherford

"For Mike's sake Soddy, don't call it transmutation.

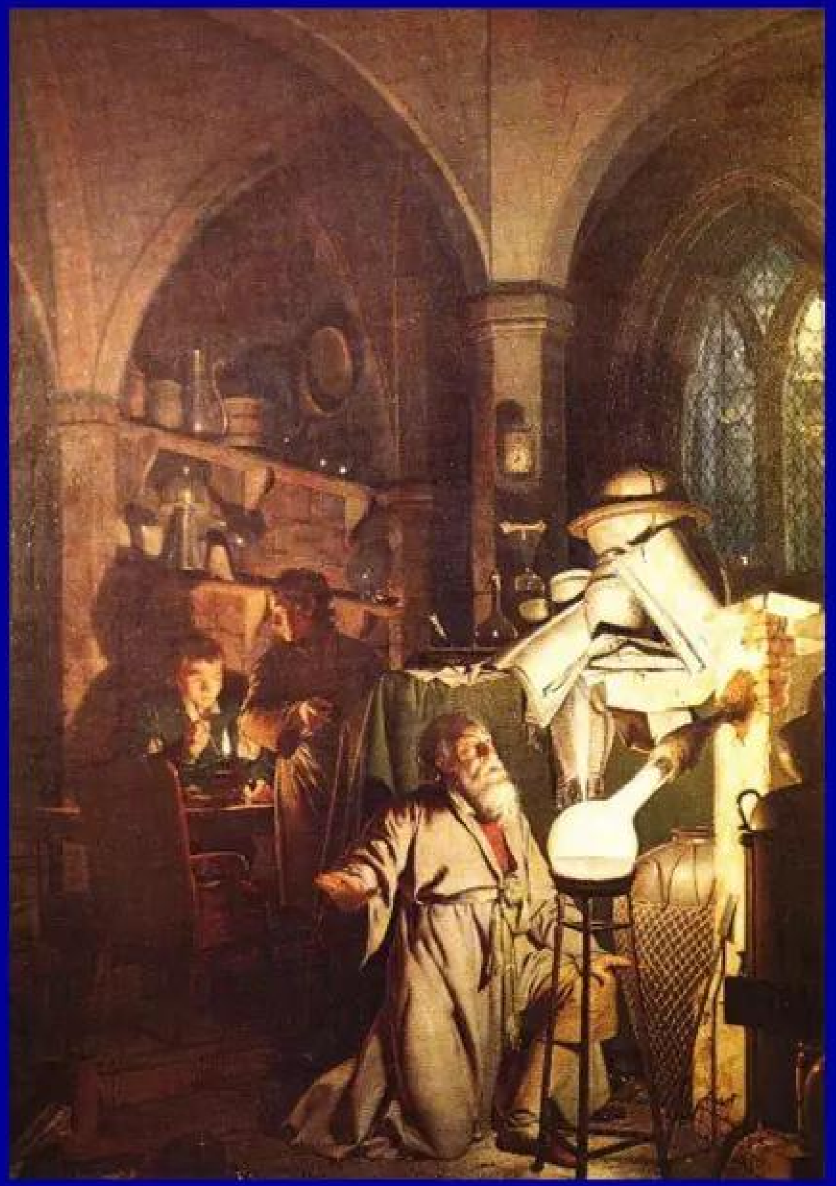
They'll have our heads off as alchemists."

Remark made by Ernest Rutherford to an astonished Frederic Soddy (1901)

"The Alchemist's Workshop" by Jan van der Straet (1570)

"In 1901, twenty-four year-old chemist Frederick Soddy and Ernest Rutherford were attempting to identify a mysterious gas that wafted from samples of radioactive thorium oxide. They suspected that this gas - they called it an 'emanation' - held a key to the recently discovered phenomenon of radioactivity. Soddy had passed the puzzling gas over a series of powerful chemical reagents, heated white-hot. When no reactions took place, he came to a startling realization. As he told his biographer many years later, ´I remember quite well standing there transfixed as though stunned by the colossal import of the thing and blurting out-or so it seemed at the time, *'Rutherford, this is transmutation: the thorium is disintegrating and transmuting itself into argon gas.'* Rutherford's reply was typically aware of more practical implications."

J. Magill, "Decay Engine" at www.nucleonica.net



"The Alchymist in Search of the Philosophers' Stone Discovers Phosphorous" by Joseph Wright of Derby (1771)

