

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
9 November 2006 (09.11.2006)

PCT

(10) International Publication Number  
**WO 2006/119080 A2**

(51) International Patent Classification:  
**G21H 1/00** (2006.01)

(21) International Application Number:  
PCT/US2006/016379

(22) International Filing Date: 28 April 2006 (28.04.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
60/676,264 29 April 2005 (29.04.2005) US  
60/715,622 9 September 2005 (09.09.2005) US

(71) Applicants and

(72) Inventors: **LARSEN, Lewis, G.** [US/US]; 175 North Harbor Drive, Suite 3205, Chicago, Illinois 60601 (US).  
**WIDOM, Alan** [US/US]; 76 Strathmore Road, Brighton, Massachusetts 02135 (US).

(74) Agent: **MANZO, Edward, D.**; Cook, Alex, Mcfarron, Manzo, Cummings & Mehler, 200 West Adams Street, Suite 2850, Chicago, Illinois 60606 (US).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Published:**

— *without international search report and to be republished upon receipt of that report*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: APPARATUS AND METHOD FOR GENERATION OF ULTRA LOW MOMENTUM NEUTRONS

(57) Abstract: Method and apparatus for generating ultra low momentum neutrons (ULMNs) using surface plasmon polariton electrons, hydrogen isotopes, surfaces of metallic substrates, collective many-body effects, and weak interactions in a controlled manner. The ULMNs can be used to trigger nuclear transmutation reactions and produce heat. One aspect of the present invention effectively provides a "transducer" mechanism that permits controllable two-way transfers of energy back-and-forth between chemical and nuclear realms in a small-scale, low-energy, scalable condensed matter system at comparatively modest temperatures and pressures.

WO 2006/119080 A2

**APPARATUS AND METHOD FOR GENERATION OF ULTRA LOW MOMENTUM  
NEUTRONS**

**Co-Inventors: Lewis G. Larsen, Allan Widom**

Cross Reference and Priority Claim

[0001] The present application claims the benefit of the following provisional patent applications by the present inventors: (a) "Apparatus and Method for Generation of Ultra Low Momentum Neutrons," filed at the U.S. Patent and Trademark Office on April 29, 2005 and having serial number 60/676,264; and (b) "Apparatus and Method for Absorption of Incident Gamma Radiation and Its Conversion to Outgoing Radiation at Less Penetrating, Lower Energies and Frequencies," filed at the U.S. Patent and Trademark Office on September 9, 2005 having serial number 60/715,622.

Background of the Invention

[0002] The present invention concerns apparatus and methods for the generation of extremely low energy neutrons and applications for such neutrons. Neutrons are uncharged elementary fermion particles that, along with protons (which are positively charged elementary fermion particles), comprise an essential component of all atomic nuclei except for that of ordinary hydrogen. Neutrons are well known to be particularly useful for inducing various types of nuclear reactions because, being uncharged, they are not repelled by Coulombic repulsive forces associated with the positive electric charge contributed by protons located in an atomic nucleus. Free neutrons are inherently unstable outside of the immediate environment in and around an atomic nucleus and have an accepted mean life of about 887 to 914 seconds; if they are not captured by an atomic nucleus, they break up via beta decay into an electron, a proton, and an anti-neutrino.

Neutrons are classified by their levels of kinetic energy; expressed in units measured in MeV,

-2-

meV, KeV, or eV --- Mega-, milli-, Kilo- electron Volts. Depending on the mean velocity of neutrons within their immediate physical environment, energy levels of free neutrons can range from: (1) ultracold to cold (nano eVs to 25 meV); (2) thermal (in equilibrium with environment at an  $E \text{ approx.} = kT = 0.025 \text{ eV}$ ); (3) slow (0.025 eV to 100 eV --- at around 1 eV they are called epithermal); (4) intermediate (100 eV to about 10 KeV); (5) fast (10 KeV to 10 MeV), to ultrafast or high-energy (above 10 MeV). The degree to which a given free neutron possessing a particular level of energy is able to react with a given atomic nucleus/isotope via capture (referred to as the reaction capture "cross section" and empirically measured in units called "barns") is dependent upon: (a) the specific isotope of the nucleus undergoing a capture reaction with a free neutron, and (b) the mean velocity of a free neutron at the time it interacts with a target nucleus.

**[0003]** It is well known that, for any specific atomic isotope, the capture cross section for reactions with externally supplied free neutrons scales approximately inversely proportional to velocity ( $1/v$ ). This means that the lower the mean velocity of a free neutron (i.e., the lower the momentum) at the time of interaction with a nucleus, the higher its absorption cross section will be, i.e., the greater the probability that it will react successfully and be captured by a given target nucleus/isotope.

**[0004]** Different atomic isotopes can behave very differently after capturing free neutrons. Some isotopes are entirely stable after the capture of one or more free neutrons (e.g., isotopes of Gadolinium (Gd), atomic number 64:  $^{154}\text{Gd}$  to  $^{155}\text{Gd}$  to  $^{156}\text{Gd}$ ). (As used herein, superscripts at the top left side (or digits to the left side) of the elemental symbol represent atomic weight.) Some isotopes absorb one or more neutrons, forming a more neutron-rich isotope of the same element, and then beta decay to another element. Beta decay strictly involves the weak interaction, because it results in the production of neutrinos and energetic electrons (known as  $\beta$ -particles). In beta decay, the neutron number (N) goes

-3-

down by one; the number of protons (atomic number =  $Z$  = nuclear charge) goes up by one; the atomic mass ( $A = Z + N$ ) is unchanged. Higher- $Z$  elements are thus produced from lower- $Z$  “seed” elements. Other atomic isotopes enter an unstable excited state after capturing one or more free neutrons, and “relax” to a lower energy level by releasing the excess energy through the emission of photons such as gamma rays (e.g., the isotope Cobalt-60 [ $^{60}\text{Co}$ ], atomic number 27). Yet other isotopes also enter unstable excited states after capturing one or more free neutrons, but subsequently “relax” to lower energy levels through spontaneous fission of the “parent” nucleus. At very high values of  $A$ , de-excitation processes start being dominated by fission reactions (involving the strong interaction) and alpha particle (Helium-4 nuclei) emission rather than beta decays and emission of energetic electrons and neutrinos. Such fission processes can result in the production of a wide variety of “daughter” isotopes and the release of energetic particles such as protons, alphas, electrons, neutrons, and/or gamma photons (e.g., the isotope  $^{252}\text{Cf}$  of Californium, atomic number 98). Fission processes are commonly associated with certain very heavy (high  $A$ ) isotopes that can produce many more neutrons than they “consume” via initial capture, thus enabling a particular type of rapidly escalating cascade of neutron production by successive reactions commonly known as a fission “chain reaction” (e.g., the uranium isotope  $^{235}\text{U}$ , atomic number 92; or the plutonium isotope  $^{239}\text{Pu}$ , atomic number 94). For  $^{235}\text{U}$ , each external free “trigger” neutron releases another 100 neutrons in the resulting chain reaction. Isotopes that can produce chain reactions are known as fissile. Deliberately induced neutron-catalyzed chain reactions form the underlying basis for existing nuclear weapons and fission power plant technologies. Significant fluxes of free neutrons at various energies are useful in a variety of existing military, commercial, and research applications, with illustrative examples as follows. It should be noted that an advantage of the present invention is mentioned in the following Table I:

End-Use Application for Neutron Source	Energy Range and Flux of Free Neutrons (n per sec) used in Application	Are Reactants and Operating Conditions Suitable for Supporting Runaway Chain Reactions?	Examples of Existing Apparatus Used to Produce Free Neutrons in Application	Comments
Existing Nuclear Weapons for the Military	Thermal to Ultrafast	Yes, highly accelerated runaway chain reactions are one of the design goals	Nuclear Weapons Components	Need relatively "fast" neutrons because desired reactions must occur very rapidly to have appropriate explosive effects
Existing Nuclear Power Plants that Generate Electricity	Thermal	Yes, however reaction rates are tightly controlled with various types of moderators	Fission Reactor optimized for heat production used to generate steam that spins a turbine	Desired result is sustained heat production at highly controlled reaction rates so "slower" neutrons must be used
Producing Useful Isotopes via Transmutation	Thermal	No, generally not in most isotopes produced for various applications	Fission Reactor optimized for characteristics of neutron flux	Bombard target materials with thermal neutrons in reactor to create new isotopes
Materials Properties Research	Various	No	Larger (some are GeV Class) Particle Accelerators	Includes so called "spallation" neutron sources
Materials Properties Research; Well Bore Hole Logging	Range from epithermal to ultrafast; fluxes average around $10^8$	No	Small Portable Accelerators	Can utilize D-D and D-T reactions; good examples in Thermo Electron product line
Neutron Sources for Applications Such as Biomedical	Range from epithermal to ultrafast; fluxes from $10^6$ to $10^{12}$	No	Isotope sources in shielded apparatus, or IEC fusion devices	For IEC devices, with D-D reaction neutrons are 2.45 MeV; D-T neutrons are 14 MeV
Basic Research on Neutron Properties	Ultracold (UCNs)	No	Large fission reactor connected to UCN "trap" via a series of moderators	The invention enables production of large fluxes of neutrons that have even lower momentum than UCNs

Table I

[0005]

[0006] Locations and Reaction Products of Fluxes of Free Neutrons Found in Nature:

[0007] Minor natural sources of free neutrons are produced by relatively rare accumulations of long-lived radioactive isotopes incorporated in a variety of minerals (e.g., Uraninite -  $\text{UO}_2$ ; with U comprised of about 99.28% of  $^{238}\text{U}$  and 0.72%  $^{235}\text{U}$  and a trace of  $^{234}\text{U}$ ) found in planetary crusts, asteroids, comets, and interstellar dust. In addition to such radioactive isotopes and various man-made sources of free neutrons noted earlier, natural sources of significant fluxes of free neutrons are found primarily in stellar environments. In fact, since the Big Bang, nearly all of the elements and isotopes found in the Universe besides hydrogen and helium have been created by a variety of cosmic nucleosynthetic processes associated with various stages of stellar evolution.

[0008] Stellar nucleosynthesis is a complex collection of various types of nuclear processes and associated nuclear reaction networks operating across an extremely broad range of astrophysical environments, stellar evolutionary phenomena, and time-spans. According to current thinking, these processes are composed of three broad classes of stellar nucleosynthetic reactions as follows:

[0009] 1. Various nuclear reactions primarily involving fusion of nuclei and/or charged particles that start with hydrogen/helium as the initial stellar "feedstock" and subsequently create heavier isotopes up to  $^{56}\text{Fe}$  (iron), at which the curve of nuclear binding energy peaks. At masses above  $^{56}\text{Fe}$ , binding energies per nucleon progressively decrease; consequently, nucleosynthesis via fusion and charged particle reactions are no longer energetically favored. As a result, isotopes/elements heavier than  $^{56}\text{Fe}$  must be created via neutron capture processes.

[0010] 2. S-Process – short-hand for the Slow (neutron capture) Process; it is

thought to occur in certain evolutionary stages of cool giant stars. In this process, “excess” neutrons (produced in certain nuclear reactions) are captured by various types of “seed” nuclei on a long time-scale compared to  $\beta$ -decays. Heavier nuclides are built-up via successive neutron captures that ascend the so-called beta-stability valley from  $^{56}\text{Fe}$  (a common initial “seed” nucleus in stellar environments) all the way up to  $^{209}\text{Bi}$  (Bismuth). Masses above  $^{209}\text{Bi}$  require much higher neutron fluxes to create heavier elements such as Uranium (e.g.  $^{238}\text{U}$ ).

[0011] 3. R-Process – short-hand for the Rapid (neutron capture) Process; it is thought to occur in Type II supernovae and various high-energy events on and around neutron stars. In this process, intermediate products comprising very neutron-rich nuclei are built up by very large neutron fluxes produced under extreme conditions that are captured by various types of “seed” nuclei. These intermediate products then undergo a series of  $\beta$ -decays accompanied by fission of the heaviest nuclei. Ultimately, this process produces nuclei having even larger masses, i.e. above  $^{209}\text{Bi}$ , that are located on the neutron-rich side of the “valley of nuclear stability”.

[0012] As evident from the Table I discussed above, various types of neutron generators have been known for many years. However, the neutron generators of the prior art do not produce ultra low momentum neutrons. Two prior publications have mentioned or involve “ultracold” neutrons (which are created at significantly higher energies and much greater momenta than “ultra low momentum” neutrons), but these are easily distinguished from the present invention. Specifically, RU2160938 (entitled “Ultracold Neutron Generator,” by Vasil et al., dated December 20, 2000) and RU2144709 (entitled “Ultracold Neutron Production Process,” by Jadernoj et al., dated January 20, 2000) both utilize either large macroscopic nuclear fission reactors or accelerators as neutron sources to create thermal

-7-

neutrons, which are then subsequently extracted and brought down to “ultracold” energies with certain neutron moderators that are cooled-down to liquid helium temperatures.

[0013] An object of the present invention is to provide method and apparatus for directly producing large fluxes of ultra low momentum neutrons (ULMNs) that possess much lower momentum and velocities than ultracold neutrons. Illustratively, such fluxes of ULMNs produced in the apparatus of the Invention may be as high as  $\sim 10^{16}$  neutrons/sec/cm<sup>2</sup>.

[0014] Another object of the present invention is to generate ULM neutrons at or above room temperature in very tiny, comparatively low cost apparatus/devices.

[0015] A further object of the present invention is to generate ULM neutrons without requiring any moderation; that is, without the necessity of deliberate “cooling” of its produced neutrons using any type of neutron moderator.

[0016] A further object of the present invention is to utilize controlled combinations of starting materials and successive rounds of ULM neutron absorption and beta decays to synthesize stable, heavier (higher-A) elements from lighter starting elements, creating transmutations and releasing additional energy in the process.

[0017] Yet another object of the present invention is to produce neutrons with extraordinarily high absorption cross-sections for a great variety of isotopes/elements. Because of that unique characteristic, the ULMN absorption process is extremely efficient, and neutrons will very rarely if ever be detected externally, even though large fluxes of ULMNs are being produced and consumed internally within the apparatus of the invention. One specific object of the present invention is to produce neutrons at intrinsically very low energies, hence the descriptive term “ultra low momentum” neutrons. ULM neutrons have special properties because, according to preferred aspects of the invention, they are formed



collectively at extraordinarily low energies (which is equivalent to saying that at the instant they are created, ULMNs are moving at extraordinarily small velocities,  $v$ , approaching zero). Accordingly, they have extremely long quantum mechanical wavelengths that are on the order of one to ten microns (i.e., 10,000 to 100,000 Angstroms). By contrast, a “typical” neutron moving at thermal energies in condensed matter will have a quantum mechanical wavelength of only about 2 Angstroms. By comparison, the smallest viruses range in size from 50 to about 1,000 Angstroms; bacteria range in size from 2,000 to about 500,000 Angstroms. The great size of the domain of their wave function is the source of ULMNs’ extraordinarily large absorption cross-sections; it enables them to be almost instantly absorbed by different local nuclei located anywhere within distances of up to 10,000 Angstroms from the location at which they are created.

#### Summary of the Invention

**[0018]** The present invention has numerous features providing methods and apparatus that utilize surface plasmon polariton electrons, hydrogen isotopes, surfaces of metallic substrates, collective many-body effects, and weak interactions in a controlled manner to generate ultra low momentum neutrons that can be used to trigger nuclear transmutation reactions and produce heat. One aspect of the present invention effectively provides a “transducer” mechanism that permits controllable two-way transfers of energy back-and-forth between chemical and nuclear realms in a small-scale, low-energy, scalable condensed matter system at comparatively modest temperatures and pressures.

One aspect of the invention provides a neutron production method in a condensed matter system at moderate temperatures and pressures comprising the steps of providing collectively oscillating protons, providing collectively oscillating heavy electrons, and providing a local electric field greater than approximately  $10^{11}$  volts/meter.

Another aspect of the invention provides a method of producing neutrons comprising the steps of: providing a hydride or deuteride on a metallic surface; developing a surface layer of protons or deuterons on said hydride or deuteride; developing patches of collectively oscillating protons or deuterons near or at said surface layer; and establishing surface plasmons on said metallic surface.

Another aspect of the invention provides a method of producing ultra low momentum neutrons ("ULMNs") comprising: providing a plurality of protons or deuterons on a working surface of hydride/deuteride-forming materials; breaking down the Born-Oppenheimer approximation in patches on said working surface; producing heavy electrons in the immediate vicinity of coherently oscillating patches of protons and/or deuterons; and producing said ULMNs from said heavy electrons and said protons or deuterons.

According to another aspect of the invention, a nuclear process is provided using weak interactions comprising: forming ultra low momentum neutrons (ULMNs) from electrons and protons/deuterons using weak interactions; and locally absorbing said ULMNs to form isotopes which undergo beta-decay after said absorbing.

According to a further aspect of the invention, a method of generating energy is provided. At first sites, the method produces neutrons intrinsically having, upon their creation, ultra low momentum (ULMNs). A lithium target is disposed at a second site near said first sites in a position to intercept said ULMNs. The ULMNs react with the Lithium target to produce Li-7 and Li-8 isotopes. The lithium isotopes decay by emitting electrons and neutrinos to form Be-8; said Be-8 decaying to He-4. This reaction produces a net heat of reaction.

The foregoing method of producing energy may further comprise producing helium isotopes by reacting helium with ULMNs emitted from said first sites to form He-5 and He-6;

-10-

the He-6 decaying to Li-6 by emitting an electron and neutrino; the helium-to-lithium reactions yielding a heat of reaction and forming a nuclear reaction cycle.

The present invention also provides a method of producing heavy electrons comprising: providing a metallic working surface capable of supporting surface plasmons and of forming a hydride or deuteride; fully loading the metallic surface with H or D thereby to provide a surface layer of protons or deuterons capable of forming coherently oscillating patches; and developing at least one patch of coherently or collectively oscillating protons or deuterons on the surface layer.

In addition, the present invention also provides apparatus for a nuclear reaction. Such apparatus comprises: a supporting material; a thermally conductive layer; an electrically conductive layer in contact with at least a portion of said thermally conductive layer; a cavity within said supporting material and thermally conductive layer; a source of hydrogen or deuterium associated with said cavity; first and second metallic hydride-forming layers within said cavity; an interface between a surface of said first hydride-forming layer, said interface being exposed to hydrogen or deuterium from said source; a first region of said cavity being located on one side of said interface and having a first pressure of said hydrogen or deuterium; a second region of said cavity being located on one side of said second hydride-forming layer and having a second pressure of said hydrogen or deuterium; said first pressure being greater than said second pressure; said apparatus forming a sea of surface plasmon polaritons and patches of collectively oscillating protons or deuterons, and ultra low momentum neutrons in a region both above and below said interface. Optionally, a laser may be positioned to irradiate said sea and said interface. An electrically conductive layer may form a portion of an inside wall of the cavity.

Another aspect of the present invention provides a neutron generator for producing

-11-

ultra low momentum neutrons (“ULMNs”) comprising: a metallic substrate having a working surface capable of supporting surface plasmons and of forming a hydride or deuteride, located above the substrate. The metallic substrate is fully loaded with hydrogen or deuterium; a surface layer of protons or deuterons. At least one region of collectively oscillating protons or deuterons is on said surface layer, and surface plasmons are located above the surface layer and said region. A flux of protons or deuterons is incident on said surface plasmons, surface layer, and working surface. Optionally, a plurality of target nanoparticles can be positioned on the working surface.

Preferably, in the ULMN generator just mentioned, the Born-Oppenheimer approximation breaks down on the upper working surface. The invention may further comprise laser radiation incident on said working surface to stimulate and transfer energy into said surface plasmons.

#### Brief Description of the Drawings

[0019] In describing examples of preferred embodiment of the present invention, reference is made to accompanying figures in which:

[0020] Figure 1 is a representative side view of a ULMN generator according to aspects of the present invention;

[0021] Figure 2 is a representative top view of the ULMN generator of Figure 1;

[0022] Figure 3 is a representative side view of a ULMN generator according to aspects of the present invention, including optional nanoparticles;

[0023] Figure 4 is a representative top view of the ULM generator of Figure 3 with randomly positioned nanoparticles affixed to the working surface;

[0024] Figure 5 is a representative schematic side sketch of one alternative preferred embodiment of a ULMN power generation system according to aspects of the present

invention;

[0025] Figure 6 is a representative schematic block diagram of another alternative preferred embodiment of a ULMN power generation system according to aspects of the present invention;

[0026] Figure 7 is a representative schematic block diagram of another alternative preferred embodiment of a ULMN power generation system according to aspects of the present invention; and

[0027] Figure 8 is a sketch useful in understanding some of the physics used in aspects of the present invention.

#### Description of Preferred Embodiments of the Present Invention

[0028] One feature of the present invention provides a method for the creation of (preferably large fluxes of) ultra low momentum neutrons in condensed matter systems, preferably at very moderate temperatures and pressures in various preferred types of very compact, comparatively low cost apparatus. Absorption of ULMNs by nuclei within the invention's apparatus initiates the formation of complex, coupled networks of local, neutron-catalyzed nuclear reactions that are broadly referred to herein as Low Energy Nuclear Reactions or LENRs.

[0029] Commercially, fluxes of such ULMNs can be utilized to trigger ULMN-catalyzed LENRs in preferred target materials for the generation of excess heat and/or for inducing transmutation reactions that are used to create other desired isotopes of commercial value. Excess heat can be converted into other usable forms of energy using various preferred types of energy conversion technologies used in power generation.

[0030] Thus, an apparatus or method according to one aspect of the present invention forms neutrons from protons or deuterons and heavy electrons using the weak interaction.

According to another aspect, it produces neutrons that intrinsically have very low momentum. According to yet another aspect, the heavy electrons that react with protons or deuterons to produce ULM neutrons and neutrinos serve a dual role by also effectively serving as a “gamma shield” against energetic gamma- and hard X-ray photons that may be produced as a result of ULM neutron absorption by nuclei and/or as a result of subsequent nuclear decay processes.

[0031] Preferably, in practicing the present invention, ULMNs are created solely through weak interactions between protons or deuterons and “heavy” electrons as defined in a paper by A. Widom and L. Larsen, the present inventors, entitled: “Ultra Low Momentum Neutron Catalyzed Nuclear Reactions on Metallic Hydride Surfaces,” available on the Cornell pre-print server as arXiv:cond-mat/0505026 v1 dated May 2, 2005, and further published in *The European Physical Journal C- Particles and Fields* (Digital Object Identifier 10.1140/epjc/s2006-02479-8). This contrasts sharply with the substantially “faster” (much higher momentum and kinetic energy) fission neutrons that are created via strong interactions involving high-A isotopes that are utilized in the existing nuclear power industry for generation of heat and transmutation of selected materials/isotopes.

[0032] According to another aspect of the invention, heavy electrons may serve as a built-in gamma shield, as defined in a paper by A. Widom and L. Larsen, the present inventors, entitled: “Absorption of Nuclear Gamma Radiation by Heavy Electrons on Metallic Hydride Surfaces,” also available on the Cornell pre-print server as arXiv:cond-mat/0509269 v1 dated September 10, 2005. Heavy electrons formed in the preferred practice of the present invention have a unique property in that they have the ability to fully absorb a gamma ray photon coming from any direction and re-emit the absorbed energy in the form of an appropriately large number (based upon the conservation of energy) of lower-energy

-14-

photons, mostly in the infrared, IR, with a small amount of radiation in the soft X-ray bands. In the range of heavy electron masses covered by the invention, gamma photons in the energy range of ~0.5 MeV to ~10.0 MeV are effectively “shielded” and converted into primarily infrared photons which are then in turn absorbed by nearby surrounding materials, thus producing heat. Since gamma photon energies from over 95% of all nuclear reactions fall within the natural active “shielding range” of the heavy electrons of the invention, very few energetic gammas will ever be detected outside the invention’s apparatus. Consequently, from a biosafety perspective, the present invention requires little or no shielding against hard radiation produced by LENRs within the apparatus.

[0033] In comparison to thermal and fast neutrons (defined in Table I above), ULMNs have enormously larger absorption cross sections for virtually any given isotope of an element. Accordingly, according to another aspect of the present invention, ULMNs produced by the present invention are captured with extremely high efficiency in neighboring target materials in close proximity to their creation site, thus forming neutron-rich isotopes. Specifically, since large fluxes of ULM neutrons with very large absorption cross-sections are produced in the invention, multiple neutrons can be absorbed by a many nuclei before the next beta decay, thus creating extremely neutron-rich, unstable intermediate isotope products. With very few exceptions, such unstable, ultra neutron-rich isotopes decay extremely rapidly via chains of successive beta decays, forming stable higher-A isotopes as end-products. This novel feature of the invention results in there being little or no residual long-lived radioactivity after ULM neutron production shuts down. This attribute of the invention, in conjunction with extremely efficient absorption of ULMNs, production of large fluxes of ULMNs (as much as  $10^{16}$  ULMNs/sec/cm<sup>2</sup>), and intrinsic suppression of hard radiation emission, will enable the development of a new type of much safer, lower-cost nuclear power

generation technology that is based primarily on the weak interaction (neutron absorption and beta decays) rather than the strong interaction (fission, fusion).

[0034] It is well known that neutron-rich isotopes of many elements (excluding certain very high-A elements such as uranium, plutonium) are short-lived and decay mainly via weak interaction beta processes. Individual beta decays can be very energetic, and can have positive Q-values ranging up to ~20 MeV. Q-values of many beta decays thus compare favorably to net Q-values that are achievable with D-D/ D-T fusion reactions (total ~25 MeV). Chains of energetic beta decays can therefore be utilized for generating power.

[0035] The present invention's novel approach to nuclear power generation is based primarily on utilization of the weak interaction. Preferably, chains of reactions characterized mainly by absorption of ULMNs and subsequent beta decays are employed (LENRs). In some cases, preferred ULMN-catalyzed chains of nuclear reactions may have biologically benign beta decays interspersed with occasional "gentle" fissions of isotopes of other elements and occasional alpha-particle decays. These may have Q-values ranging up to several MeV, in sharp contrast to the very energetic 200+ MeV Q-value of the fission of very high-A, <sup>235</sup>U. It is important to note that significant fluxes of very high energy fission neutrons have never once been detected experimentally in LENR systems.

[0036] Importantly, since the invention utilizes primarily low energy, weak interaction nuclear processes, any production of large, biologically dangerous fluxes of hard radiation (very energetic X- and gamma rays), energetic neutrons, and long-lived highly radioactive isotopes can be avoided. Thus, the necessity for expensive shielding and containment of the invention's apparatus, and related waste disposal problems are obviated, in sharp contrast to existing nuclear fission and fusion technologies based on the strong interaction. Since no Coulomb barrier is involved in weak interactions and absorption of



ULMNs, the invention's LENRs can take place under moderate physical conditions, unlike currently envisioned D-T (deuterium-tritium) fusion reactors.

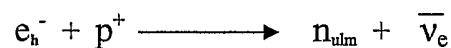
[0037] Further scientific aspects of the present invention are set forth in the above-referenced paper by A. Widom and L. Larsen, the present inventors, entitled: "Ultra Low Momentum Neutron Catalyzed Nuclear Reactions on Metallic Hydride Surfaces." The referenced Widom-Larsen paper is incorporated by reference, is intended to form part of this disclosure, and is attached hereto. The abstract of the referenced paper states: "Ultra low momentum neutron catalyzed nuclear reactions in metallic hydride system surfaces are discussed. Weak interaction catalysis initially occurs when neutrons (along with neutrinos) are produced from the protons which capture "heavy" electrons. Surface electron masses are shifted upwards by localized condensed matter electric fields. Condensed matter quantum electrodynamic processes may also shift the densities of final states allowing an appreciable production of ultra low momentum neutrons which are thereby efficiently absorbed by nearby nuclei. No Coulomb barriers exist for the weak interaction neutron production or other resulting catalytic processes."

[0038] Similarly, further aspects of the present invention are set forth in the above-referenced paper by A. Widom and L. Larsen, the present inventors, entitled: "Absorption of Nuclear Gamma Radiation by Heavy Electrons on Metallic Hydride Surfaces," available on the Cornell pre-print server as arXiv:cond-mat/0509269 v1 dated September 10, 2005. The referenced Widom-Larsen paper is incorporated by reference, is intended to form part of this disclosure, and is also attached hereto. The abstract of the referenced paper states: "Low energy nuclear reactions in the neighborhood of metallic hydride surfaces may be induced by heavy surface electrons. The heavy electrons are absorbed by protons producing ultra low momentum neutrons and neutrinos. The required electron mass renormalization is provided

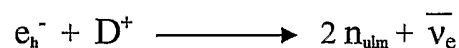
-17-

by the interaction between surface electron plasma oscillations and surface proton oscillations. The resulting neutron catalyzed low energy nuclear reactions emit copious prompt gamma radiation. The heavy electrons which induce the initially produced neutrons also strongly absorb the prompt nuclear gamma radiation. Nuclear hard photon radiation away from metallic hydride surfaces is thereby strongly suppressed.”

[0039] While it is well known to use the strong interaction to achieve their primary utility as neutron generators, the present invention according to one of its aspects utilizes weak interactions between protons ( $p^+$ ) and “heavy” electrons ( $e_h^-$ ) to produce a neutron ( $n_{ulm}$ ) and a neutrino ( $\bar{\nu}_e$ ) as follows:



[0040] The first referenced paper by Widom and Larsen explains the physics of how, under the appropriate conditions, a proton is able to capture a “heavy” electron to create an ultra low momentum neutron ( $n_{ulm}$ ) and a neutrino (photon). Similarly, they show how a deuteron (“D”) can capture one “heavy” electron to create two ultra low momentum neutrons and a neutrino as follows:



[0041] Importantly, the Coulomb barrier is not a factor in either of these reactions. In fact, in this situation, unlike charges actually help these reactions to proceed.

[0042] The second referenced paper by Widom and Larsen explains the physics of how, under the appropriate conditions in certain condensed matter systems, a heavy, mass renormalized electron can fully absorb a high-energy gamma photon and re-radiate the absorbed energy as a much larger number of much lower-energy photons, mostly in the infrared along with a small amount of soft X-rays.

-18-

[0043] As noted earlier, quantum mechanical wave functions of ULMNs are very large, e.g., ~10,000 to 100,000 Angstroms (1 – 10 microns); this is approximately the same size as coherent surface domain of oscillating protons or deuterons. According to Dr. S. K. Lamoreaux of Los Alamos National Laboratory, it would likely take roughly 1/10 to 2/10 of a millisecond for such a ULMN to interact with surrounding phonons in nearby materials and thermalize. As a newly created ULMN is “spooling-up” to much higher thermal energies, the spatial extent of its wave function (as well as implicitly, its capture cross section) will be contracting to dimensions (~2 Angstroms) and a related cross section that are “normal” for neutrons at such energies. However, the ULMN absorption process is so rapid and efficient that thermal neutrons will rarely if ever be released and detected outside the apparatus of the invention.

[0044] “LENRs” represents a broad descriptive term encompassing a complex family of low energy nuclear reactions catalyzed by ULMNs. As explained in the referenced papers by Widom and Larsen, creation of ULMNs on surfaces requires a breakdown of the Born-Oppenheimer approximation, collectively oscillating “patches” of protons or deuterons, as well as excited surface plasmons and fully loaded metal hydrides. Creation of ULMNs and resulting LENRs (as ULMNs are absorbed by nearby atoms) occurs in and around small, solid-state nanodomains (dimensions on the order of tens of microns or less) located on or very near metallic surfaces or at interfaces between a metal and a dielectric such as a ceramic solid-state proton conductor. In these small scale, nuclear-active domains, production of high local fluxes of ULMNs enables LENRs to be triggered in nearby materials. In certain preferred embodiments, preferred local isotopic compositions can generate substantial amounts of excess heat that can then, for example, be transferred to another device and converted into electricity or rotational motion.

[0045] Turning now to the drawings, Figure 1 is a representative side view of a ULMN generator according to aspects of the present invention. It consists of: randomly positioned surface "patches" from one to ten microns in diameter comprising a monolayer of collectively oscillating protons or deuterons **10**; a metallic substrate **12** which may or may not form bulk hydrides; collectively oscillating surface plasmon polariton electrons **14** that are confined to metallic surface regions (at an interface with some sort of dielectric) within a characteristic skin depth averaging 200 - 300 Angstroms for typical metals such as copper and silver; an upper working region **16** which may be filled with a liquid, gas, solid-state proton conductor, or a mild vacuum; other substrate **18** which must be able to bond strongly with the metal substrate **12** and have good thermal conductivity but which may or may not be permeable to hydrogen or deuterium and/or form hydrides; and the working surface **20** of the metallic substrate **12** which may or may not have nanoparticles of differing compositions affixed to it. The upper working region **16** either contains a source of protons/deuterons or serves as a transport medium to convey ions, and/or electrons, and/or photons to the working surface **20** upon which the SPPs **14** are found.

[0046] Figure 2 is a representative top view of the apparatus of Fig. 1 according to aspects of the present invention. It shows randomly positioned "patches" of collectively oscillating protons or deuterons **10** located on top of the metallic substrate **12** and its working surface **20**.

[0047] Figure 3 is a representative side view of a ULMN generator according to aspects of the present invention. It shows the ULM generator of Figure 1 with randomly positioned nanoparticles **22** affixed to the working surface **20**. It is important that the maximum dimensions of the nanoparticles are less than the skin depth **14**.

[0048] Figure 4 is a representative top view of a ULMN generator according to

-20-

aspects of the present invention. It shows the ULM generator of Figure 3 with randomly positioned nanoparticles 22 affixed to the working surface 20.

[0049] Figure 5 is a representative schematic side view of one alternative preferred embodiment of a ULMN power generation system according to aspects of the present invention. It shows a pressurized reservoir of hydrogen or deuterium gas 24 connected via a valve 26 and related piping with an one-way check valve and inline pump 28 that injects gas under pressure ( $> 1$  atmosphere) into a sealed container with two open cavities 30, 32 separated and tightly sealed from each other by a one or two layer ULM neutron generator. The side walls 34 of the cavities 30, 32 are thermally conductive, relatively inert, and serve mainly to provide support for the ULM neutron generator. The top and bottom walls 36, 38 of the two cavities 30, 32 are preferably constructed of materials that are thermally conductive. Optionally, in other alternative embodiments in which a laser 40 and electrical connector 42 is not optionally installed on the top wall 36, then the top 36 and bottom 38 walls can be made electrically conductive and a desired electrical potential gradient can be imposed across the ULM generator. If an additional chemical potential in the ULM generator is desirable, the ULM generator can optionally be constructed with two layers 12, 18, both of which must be able to form bulk metallic hydrides, but their materials are selected to maximize the difference in their respective work functions at the interface between them. Each layer 12, 18 of the ULM generator must preferably be made thicker than the skin depth of surface plasmon polaritons, which is about 20 – 50 nanometers in typical metals. If a semiconductor laser 40 is optionally installed, it should be selected to have the highest possible efficiency and its emission wavelengths chosen to closely match the resonant absorption peaks of the SPPs found in the particular embodiment. The pressure gradient (from 1 up to 10 atmospheres) across the ULM generator insures that a sufficient flux of

-21-

protons or deuterons is passing through the generator's working surface 20. Finally, the outermost walls of the container 44, completing enclosing the ULM generator unit (except for openings necessary for piping, sensors, and electrical connections), can be either solid-state thermoelectric/thermionic modules, or alternatively a material/subsystem that has an extremely high thermal conductivity such as copper, aluminum, Dylyn diamond coating, PocoFoam, or specially engineered heat pipes. In the case of the alternative embodiment having a ULM generator integrated with thermoelectric/thermionic devices, high quality DC power is generated directly from the ULM generator's excess heat; it serves as a fully integrated power generation system. In the other case where the container is surrounded by some type of thermal transfer components/materials/subsystems, the ULM generator functions as an LENR heat source that can be integrated as the "hot side" with a variety of different energy conversion technologies such as small steam engines (which can either run an electrical generator or rotate a driveshaft) and Stirling engines.

[0050] Figure 6 is a representative schematic block diagram of another alternative preferred embodiment of a ULMN power generation system according to aspects of the present invention. It shows a subsystem 46 containing a ULM generator heat source (such as illustrated in Fig. 5) combined with a thermal transfer subsystem 48 that transfers heat to a steam engine 50 that converts heat into rotational motion that can either be used turn a driveshaft or an AC electrical generator. Overall operation of the ULM-based integrated power generation system is monitored and controlled by another subsystem 52 comprised of sensors, actuators, and microprocessors linked by communications pathways 54.

[0051] Figure 7 is a representative schematic block diagram of another alternative preferred embodiment of a ULMN power generation system according to aspects of the present invention. It shows a subsystem 46 containing a ULM generator heat source

-22-

combined with a thermal transfer subsystem 48 that transfers heat to a Stirling engine 56 that converts heat into rotational motion that can either be used turn a driveshaft or an AC electrical generator. Overall operation of the ULM-based integrated power generation system is monitored and controlled by another subsystem 52 comprised of sensors, actuators, and microprocessors linked by communications pathways 54.

#### Methods of Operation

[0052] In the case of a metallic substrate 12 that forms a bulk hydride, the first step in the operation of the Invention is to deliberately “load” 90 - 99% pure hydrogen or deuterium into a selected hydride-forming metallic substrate 12 such as palladium, nickel, or titanium. Examples of alternative preferred methods for such loading (some can be combined) include a: 1. Pressure gradient; 2. Enforced difference in chemical potential; and/or 3. Imposition of electrochemical potential across the working surface.

[0053] When a metallic hydride substrate 12 is “fully loaded” (that is, the ratio of H or D to metal lattice atoms in the metallic hydride substrate reaches a preferred value of 0.80 or larger), protons or deuterons begin to “leak out” and naturally form densely covered areas in the form of “patches” 10 or “puddles” of positive charge on the working surface 20 of the metallic hydride substrate 12. The appearance of these surface patches of protons or deuterons can be seen clearly in thermal neutron scattering data. These surface patches 10 of protons or deuterons have dimensions that are preferably from one to ten microns in diameter and are scattered randomly across the working surface 20. Importantly, when these surface patches 10 form, the protons or deuterons that comprise them spontaneously begin to oscillate together, collectively, in unison.

[0054] The Born-Oppenheimer approximation will automatically break down in local regions of the working surface 20 that are in close proximity to surface patches 10 of

-23-

collectively oscillating protons or deuterons. At this point, the collective motions of the electrons comprising the surface plasmon polaritons 14 become loosely coupled to the collective oscillations of local surface “patches” 10 of protons or deuterons. Energy can now be transferred back-and-forth between the surface patches 10 of protons or deuterons and the entire “sea” of SPPs covering the working surface 20.

[0055] Electromagnetic coupling between SPP electrons 14 and collectively oscillating patches of protons or deuterons dramatically increases strength of electric fields in the vicinity of the patches 10. As the local electric field strength of a patch increases, per the theory of Quantum Electrodynamics, the masses of local SPP electrons 14 exposed to the very high fields (preferably  $> 10^{11}$  Volts/meter) are renormalized upward (their real mass is increased). Such field strengths are essentially equivalent to those normally experienced by inner-shell electrons in typical atoms. Thus, in practicing the present invention, heavy electrons,  $e^*$ - are created in the immediate vicinity of the patches 10 in and around the working surface 20. SPP electrons 14 in and around the patches can be heavy, those located away from the patches are not.

[0056] Beyond the initial loading phase to form a fully-loaded hydride substrate 12, electric fields in the vicinity of the H or D patches 10 must be further increased by injecting additional energy into the “sea” of surface plasmon polaritons 14. Ultimately, this has the effect of further increasing the rate of ultra low momentum neutron, ULMN production. This can be accomplished by using one or more the following preferred methods (some can be combined):

[0057] 1. Creating a nonequilibrium flux of protons or deuterons as ions across the working surface interface 20 defined by the surface of the metallic hydride substrate (this is a rigid requirement in the case of a metallic substrate 12 that forms bulk hydrides); and/or,



-24-

[0058] 2. Optionally, irradiating the metallic substrate's working surface 20 with laser 40 radiation of the appropriate wavelength that is matched to the photon absorption resonance peaks of the SPPs 14; this also has related surface roughness requirement to insure momentum coupling with the laser photons; and/or,

[0059] 3. Optionally, irradiating the metallic substrate's 12 working surface 20 with an appropriately intense beam of either energetic electrons or other preferred types of energetic positive ions besides protons or deuterons.

[0060] When the renormalized masses of local SPP heavy electrons 14 reach critical threshold values, as described in the included Widom and Larsen papers referenced above, they will react spontaneously with collectively oscillating protons or deuterons in adjacent patches 10 in a weak interaction, thus producing ultra low momentum neutrons, ULMNs and neutrinos. As stated earlier, the two types of weak interaction nuclear reactions between protons or deuterons and heavy electrons that produce ULM neutrons and neutrinos are as follows:



[0061] It must be emphasized that the strength of electric fields just above the patches is crucial to the production of ULM neutrons. If the local electric fields are not high enough (e.g.,  $\ll 10^{11}$  V/m) critical field strength thresholds will not be reached and the SPP electrons 14 will be short of the minimum mass necessary to react spontaneously with protons or deuterons to form ULM neutrons. It is well known in nanotechnology and the semiconductor industry that micron- and nano-scale surface features/topology and the size/geometry/placement of nanoparticles on surfaces can have dramatic effects on local E-M fields. The size regime for such effects starts at tens of microns and extends down to the

-25-

nanoscale at roughly 5 nanometers. For example, it is known in nanotechnology that the relative size, composition, geometry, and relative placement (positioned to touch each other in a straight line versus a more close-packed arrangement) of nanoparticles on surfaces can cause the local electric fields to vary by 10<sup>5</sup>. That factor is easily the difference between reaching the necessary thresholds to create ULM neutrons or not. The implication of these facts is that to successfully produce substantial percentages of good working ULMN neutron generator devices and operate them for significant periods of time, techniques must be used that are capable of nanoscale control of initial fabrication steps and materials/designs/methods must be selected that can maintain key surface properties during extended device operation. In that regard, ULM generators with an upper working region 16 that is filled with hydrogen or deuterium gas are more tractable from a surface stability standpoint, as compared to electrolytic ULM generators using an aqueous electrolyte in which the nanoscale surface features of the cathodes typically change dramatically over time.

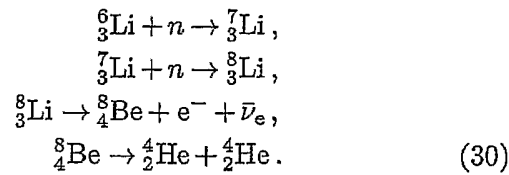
[0062] Figures 3 and 4 illustrate a ULM generator in which nanoparticles 22 are fabricated and affixed to its working surface 20. Figure 3 is a representative side view, not drawn to scale; Figure 4 is a representative top view, also not drawn to scale. According to this particular embodiment, a ULM neutron generator would be constructed with a metallic substrate 12 that forms hydrides or deuterides, such as palladium, titanium, or nickel, or alloys thereof. Above that substrate is a working surface 20 capable of supporting surface plasmon polaritons 14 and the attachment of selected nanoparticles 22. The thickness of the substrate 12 and the diameter of the surface nanoparticles 22 should be fabricated so that they do not exceed the skin depth of the SPPs 14. The substrate 12 is fully loaded with H or D and the working surface 20 has an adequate coverage of patches 10 of protons or deuterons. In this embodiment the surface nanoparticles 22 serve as preferred target materials for ULM

-26-

neutron absorption during operation of the generator. One example of a preferred nanoparticle target material for ULMN power generation applications are a variety of palladium-lithium alloys.

[0063] Palladium-lithium alloys represent an example of a preferable nanoparticle target material because: (a.) certain lithium isotopes have intrinsically high cross-sections for neutron absorption; (b.) nanoparticles composed of palladium-lithium alloys adhere well to palladium substrates; (c.) palladium-lithium alloys readily form hydrides, store large amounts of hydrogen or deuterium, and load easily; and finally (d.) there is a reasonably small, neutron-catalyzed LENR reaction network starting with Lithium-6 that produces substantial amounts of energy and forms a natural nuclear reaction cycle. Specifically, this works as follows (the graphic is excerpted from the referenced Widom-Larsen paper that published in *The European Physical Journal C – Particles and Fields*):

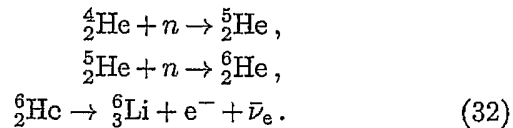
-27-



The chain (30) yields a quite large heat  $Q$  for the net nuclear reaction

$$Q\{ {}^6_3\text{Li} + 2n \rightarrow 2 {}^4_2\text{He} + e^- + \bar{\nu}_e \} \approx 26.9 \text{ MeV}. \tag{31}$$

Having produced  ${}^4_2\text{He}$  products, further neutrons may be employed to build heavy helium "halo nuclei" yielding



The chain (32) yields a moderate heat for the net  ${}^6_3\text{Li}$  producing reaction

$$Q\{ {}^4_2\text{He} + 2n \rightarrow {}^6_3\text{Li} + e^- + \bar{\nu}_e \} \approx 2.95 \text{ MeV}. \tag{33}$$

The reactions (30) and (32) taken together form a nuclear reaction cycle. Other possibilities include the direct lithium reaction

The net amount of energy ( $Q$ ) released in the above LENR network compares favorably with that of strong interaction fusion reactions, yet it does not result in the production of energetic neutrons, hard radiation, or long-lived radioactive isotopes. Thus, substantial amounts of heat energy can be released safely by guiding the course of complex LENR nucleosynthetic and decay processes.

[0064] Figure 8 is a representative sketch useful in understanding some of the scientific principles that are involved in various aspects of the present invention. As can be seen in Fig. 8, heavy electrons are produced in very high local collectively oscillating patches of protons or deuterons. These heavy electrons combine with the protons or deuterons to form the desired neutrons. These ULM neutrons, having extremely large cross sections of absorption, are quickly absorbed by the materials or targets in or upon the metallic substrate.

As isotopes are produced, neutrinos and other reaction products are produced.

Commercial Utility of the Invention

[0065] There are important commercial uses for low cost, compact sources of high fluxes of ULMNs produced according to the present invention. ULMN production within such devices according to the teachings of the invention, in conjunction with methods for selection/fabrication of appropriate seed materials (nuclei/isotopes) and utilization of related LENR pathways, enables:

[0066] (a) High volume manufacturing of compact devices that can sustain in situ operation of ULMN-catalyzed networks of LENRs. Devices taught by the invention can be designed to exploit differences between the aggregate nuclear binding energies of preferred initial seed materials and the final products (isotopes) of the reaction networks to create an overall net release of energy, primarily in the form of excess heat. This heat would be generated primarily by preferred weak interactions such as beta decays. When integrated with a variety of preferred energy conversion technologies, LENR heat source devices enabled by the invention could prove to be valuable in a variety of commercial applications. The invention may have a substantial commercial advantage in comparison to competing nuclear power generation technologies (fission and fusion) that rely primarily on the strong interaction. In commercial power generation systems based on the Invention, disposal of hazardous waste products, radiation shielding, and related environmental and biosafety problems will not be significant concerns. The absence of any requirement for heavy shielding on the invention's LENR ULM neutron generator systems further enables the possibility of developing revolutionary low cost, very compact, long-lived, battery-like portable power sources; and

[0067] (b) Transmutation of various types of preferred seed materials/isotopes to

produce significant recoverable quantities of specific, commercially useful isotopes.

[0068] Further modifications and changes will become apparent to persons skilled in the art after consideration of this description and drawings. The scope of the invention is preferred to be defined by the appended claims and equivalents thereof.

## Ultra Low Momentum Neutron Catalyzed Nuclear Reactions on Metallic Hydride Surfaces

A. Widom

*Physics Department, Northeastern University, 110 Forsyth Street, Boston MA 02115*

L. Larsen

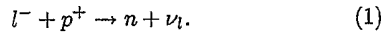
*Lattice Energy LLC, 175 North Harbor Drive, Chicago IL 60601*

Ultra low momentum neutron catalyzed nuclear reactions in metallic hydride system surfaces are discussed. Weak interaction catalysis initially occurs when neutrons (along with neutrinos) are produced from the protons which capture "heavy" electrons. Surface electron masses are shifted upwards by localized condensed matter electromagnetic fields. Condensed matter quantum electrodynamic processes may also shift the densities of final states allowing an appreciable production of extremely low momentum neutrons which are thereby efficiently absorbed by nearby nuclei. No Coulomb barriers exist for the weak interaction neutron production or other resulting catalytic processes.

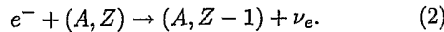
PACS numbers: 24.60.-k, 23.20.Nx

### INTRODUCTION

It is very well known that a proton  $p^+$  can capture a charged lepton  $l^-$  and produce a neutron and a neutrino from the resulting process[1]



A common form of nuclear transmutation in condensed matter is understood in terms of Eq.(1). An electron  $e^-$  which wanders into a nucleus with  $Z$  protons and  $N = A - Z$  neutrons can be captured producing an electron neutrino  $\nu_e$  and leaving behind a nucleus with  $Z - 1$  protons and  $N + 1 = A - (Z - 1)$  neutrons. The electron capture process in a condensed matter nucleus may be described by the nuclear transmutation reaction[2, 3]



Note the absence of a Coulomb barrier to such a weak interaction nuclear process. In fact, a strong Coulomb attraction which can exist between an electron and a nucleus helps the nuclear transmutation Eq.(2) proceed. While the process Eq.(1) is experimentally known to occur when muons are mixed into Hydrogen systems[4, 5, 6], i.e.  $\mu^- + p^+ \rightarrow n + \nu_\mu$ , it is regarded as difficult for nature to play the same trick with electrons and protons at virtual rest. For Eq.(1) to spontaneously occur it is required that the lepton mass obey a threshold condition,

$$M_l c^2 > M_n c^2 - M_p c^2 \approx 1.293 \text{ MeV} \approx 2.531 M_e c^2, \quad (3)$$

which holds true by a large margin for the muon but is certainly not true for the vacuum mass of the electron. On the other hand, the electron mass in condensed matter can be modified by local electromagnetic field fluctuations. To see what is involved, one may employ a quasi-classical argument wherein the electron four momentum

$p_\mu = \partial_\mu S$  in an electromagnetic field  $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$  obeys the Hamilton-Jacobi equation[7]

$$-(p_\mu - \frac{e}{c} A_\mu)(p^\mu - \frac{e}{c} A^\mu) = M_e^2 c^2. \quad (4)$$

If the field fluctuations average to zero  $\overline{A_\mu} = 0$ , then the remaining mean square fluctuations can on average add mass to the electron  $M_e \rightarrow \tilde{M}_e$  according to a previously established rule[7, 8]

$$-\tilde{p}_\mu \tilde{p}^\mu = \tilde{M}_e^2 c^2 = M_e^2 c^2 + \left(\frac{e}{c}\right)^2 \overline{A^\mu A_\mu}. \quad (5)$$

For example laser light fields can "dress" an electron in a non-perturbation theoretical fashion with an additional mass as in Eq.(5). Such mass modifications must be applied to electrons and positrons when pairs can in principle be blasted out of the vacuum[9, 10] employing colliding laser beams. The mass growth in the theory appears in a classic treatise on quantum electrodynamics[8]. The theory in terms of condensed matter photon propagators is discussed below.

The mass modified hydrogen atom can decay into a neutron and a neutrino if the mass growth obeys a threshold condition given by

$$\beta \equiv \frac{\tilde{M}_e}{M_e} = \left[ 1 + \left( \frac{e}{M_e c^2} \right)^2 \overline{A^\mu A_\mu} \right]^{1/2} \\ \beta > 2.531 \text{ (neutron production)}. \quad (6)$$

The sources of the electron mass renormalization via electromagnetic field fluctuations on metallic hydride surfaces and the resulting neutron production are the main subject matters of this work. The surface states of metallic hydrides are of central importance: (i) Collective surface plasma[11] modes are involved in the condensed matter weak interaction density of final states. The radiation

frequencies of such modes range from the infrared to the soft X-ray spectra. (ii) The breakdown[12] of the conventional Born-Oppenheimer approximation for the surface hydrogen atoms contributes to the large magnitude of electromagnetic fluctuations. Some comments regarding nuclear transmutation reactions which result from ultra low momentum neutron production will conclude our discussion of neutron catalyzed reactions.

### ELECTROMAGNETIC FIELD FLUCTUATIONS

The rigorous definition of electron mass growth due to the metallic hydride electromagnetic fields depends on the non-local "self" mass  $\mathcal{M}$  in the electron Green's function[13]  $G$ , i.e.

$$-i\gamma^\mu \partial_\mu G(x, y) + \frac{c}{\hbar} \int \mathcal{M}(x, z) G(z, y) d^4z = \delta(x - y),$$

$$\mathcal{M}(x, y) = M_e \delta(x - y) + \frac{\hbar}{c} \Sigma(x, y), \quad (7)$$

wherein the non-local mass shift operator  $\Sigma$  depends on the difference between the photon propagator

$$D_{\mu\nu}(x, y) = \frac{i}{\hbar c} \langle A_\mu(x) A_\nu(y) \rangle_+ \quad (8)$$

in the presence of condensed matter and the photon propagator  $D_{\mu\nu}^{(0)}(x, y)$  in the vacuum. In Eq.(8), "+" denotes time ordering. The source of the differences in the photon propagators

$$D_{\mu\nu}(x, y) - D_{\mu\nu}^{(0)}(x, y) = \int \int D_{\mu\sigma}^{(0)}(x, x') \mathcal{P}^{\sigma\lambda}(x', y') D_{\lambda\nu}^{(0)}(y', y) d^4x' d^4y' \quad (9)$$

is the polarization response function  $\mathcal{P}^{\sigma\lambda}(x, y)$  arising from condensed matter currents

$$\mathcal{P}^{\mu\nu}(x, y) = \frac{i}{\hbar c^3} \langle J^\mu(x) J^\nu(y) \rangle_+ \quad (10)$$

The gauge invariant currents in Eq.(10) give rise to the electromagnetic fluctuations which only at first sight appear not to be gauge invariant. The average of the field fluctuations appearing in Eq.(6) is in reality what is obtained after subtracting the vacuum field fluctuations which partially induce the physical vacuum electron mass; i.e.

$$\overline{A^\mu(x) A_\mu(x)} = \langle A^\mu(x) A_\mu(x) \rangle - \langle A^\mu(x) A_\mu(x) \rangle_{vac},$$

$$\frac{i}{\hbar c} \overline{A^\mu(x) A_\mu(x)} = D_{\mu\mu}^\mu(x, x) - D_{\mu\mu}^{(0)\mu}(x, x). \quad (11)$$

In terms of the spectral function  $S(\mathbf{r}, \omega)$  defined by the electric field anti-commutator

$$2 \int_{-\infty}^{\infty} S_{\mathbf{E}\mathbf{E}}(\mathbf{r}, \omega) \cos(\omega t) d\omega = \overline{\{\mathbf{E}(\mathbf{r}, t); \mathbf{E}(\mathbf{r}, 0)\}}, \quad (12)$$

the local electronic mass enhancement factor Eq.(6) is given by

$$\beta(\mathbf{r}) = \left[ 1 + \left( \frac{e}{M_e c} \right)^2 \int_{-\infty}^{\infty} S_{\mathbf{E}\mathbf{E}}(\mathbf{r}, \omega) \frac{d\omega}{\omega^2} \right]^{1/2}. \quad (13)$$

The frequency scale  $\tilde{\Omega}$  of the electric field oscillations may be defined via

$$\frac{1}{\tilde{\Omega}^2} \overline{|\mathbf{E}(\mathbf{r})|^2} \equiv \int_{-\infty}^{\infty} S_{\mathbf{E}\mathbf{E}}(\mathbf{r}, \omega) \frac{d\omega}{\omega^2}, \quad (14)$$

so that

$$\beta(\mathbf{r}) = \sqrt{1 + \frac{\overline{|\mathbf{E}(\mathbf{r})|^2}}{\mathcal{E}^2}} \quad \text{wherein } \mathcal{E} = \left| \frac{M_e c \tilde{\Omega}}{e} \right| \quad (15)$$

which is an obviously gauge invariant result. When an electron wanders into a proton to produce a neutron and a neutrino, the electric fields forcing oscillations of the electrons are largely due to the protons themselves. Considerable experimental information about the proton oscillations in metallic hydride systems is available from neutron beams scattering off protons.

### PROTON OSCILLATIONS

A neutron scattering from  $N$  protons in metallic hydride systems probes the quantum oscillations of protons as described by the correlation function[14]

$$G(\mathbf{Q}, \omega) = \frac{1}{N} \sum_{k=1}^N \int_{-\infty}^{\infty} \langle e^{-i\mathbf{Q} \cdot \mathbf{R}_k(t)} e^{i\mathbf{Q} \cdot \mathbf{R}_k(0)} \rangle \frac{dt}{2\pi}. \quad (16)$$

Here,  $\mathbf{R}_k(t)$  is the position of the  $k^{\text{th}}$  proton at time  $t$ . The differential extinction coefficient for a neutron to scatter from the metallic hydride with momentum transfer  $\hbar\mathbf{Q} = \mathbf{p}_i - \mathbf{p}_f$  and energy transfer  $\hbar\omega = \epsilon_i - \epsilon_f$  is given by

$$\frac{d^2\hbar}{d\Omega_f d\epsilon_f} \approx \bar{\rho} \left[ \frac{d\sigma}{d\Omega_f} \right] G(\mathbf{Q}, \omega), \quad (17)$$

wherein  $\bar{\rho}$  is the mean number of protons per unit volume and  $d\sigma$  is the elastic differential cross section for a neutron to scatter off a single proton into a final solid angle  $d\Omega_f$ .

While the weak interaction neutron production may occur for a number of metallic hydrides, palladium hydrides are particularly well studied. For a highly loaded hydride, there will be a full proton layer on the hydride surface. The frequency scale  $\tilde{\Omega}$  of oscillating surface protons may be computed on the basis of neutron scattering data[15, 16]. The electric field scale in Eq.(15) may be estimated by

$$\mathcal{E} \approx 1.4 \times 10^{11} \text{ volts/meter (Hydrogen Monolayer)}. \quad (18)$$



The magnitude of the electric field impressed on the electronic system due to the collective proton layer oscillations on the surface of the palladium may be estimated by

$$\sqrt{|\mathbf{E}|^2} \approx \frac{4|e|\sqrt{|\mathbf{u}|^2}}{3a^3} \quad (\text{Hydrogen Monolayer}). \quad (19)$$

where  $\mathbf{u}$  is the displacement of the collective proton oscillations and the Bohr radius is given by

$$a = \frac{\hbar^2}{e^2 M_e} \approx 0.5292 \times 10^{-8} \text{ cm}. \quad (20)$$

Thus

$$\sqrt{|\mathbf{E}|^2} \approx 6.86 \times 10^{11} (\text{volts/meter}) \sqrt{\frac{|\mathbf{u}|^2}{a^2}}. \quad (21)$$

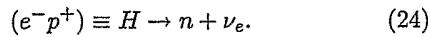
One may again appeal to neutron scattering from protons in palladium for the room temperature estimate

$$\sqrt{\frac{|\mathbf{u}|^2}{a^2}} \approx 4.2 \quad (\text{Hydrogen Monolayer}). \quad (22)$$

From Eqs.(15), (18), (21) and (22) follows the electron mass enhancement

$$\beta \approx 20.6 \quad (\text{Palladium Hydride Surface}). \quad (23)$$

The threshold criteria derived from Eq.(6) is satisfied. On palladium, surface protons can capture a heavy electron producing an ultra low momentum neutron plus a neutrino; i.e.



Several comments are worthy of note: (i) The collective proton motions for a completed hydrogen monolayer on the Palladium surface require a loose coupling between electronic surface plasma modes and the proton oscillation modes. The often assumed Born Oppenheimer approximation is thereby violated. This is in fact the usual situation for surface electronic states as has been recently discussed. It is not possible for electrons to follow the nuclear vibrations on surfaces very well since the surface geometry precludes the usual very short Coulomb screening lengths. (ii) The above arguments can be extended to heavy hydrogen ( $e^- p^+ n$ )  $\equiv$  ( $e^- d^+$ )  $\equiv$   $D$  wherein the neutron producing heavy electron capture has the threshold electron mass enhancement

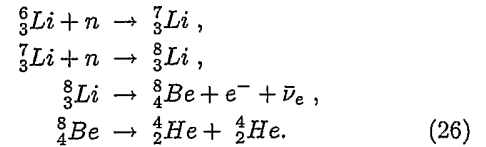
$$\frac{\tilde{M}'_e}{M_e} = \beta'(D \rightarrow n + n + \nu_e) > 6.88. \quad (25)$$

Eq.(25) also holds true. The value of  $\beta$  in Eq.(23) is similar in magnitude for both the proton and the deuterium oscillation cases at hand. Since each deuterium electron

capture yields two ultra low momentum neutrons, the nuclear catalytic reactions are somewhat more efficient for the case of deuterium. (iii) However, one seeks to have either nearly pure proton or nearly pure deuterium systems since only the isotopically pure systems will easily support the required coherent collective oscillations. (iv) An enforced chemical potential difference or pressure difference across a palladium surface will pack the surface layer to a single compact layer allowing for the required coherent electric field producing motions. (v) The proton electric field producing oscillations can be amplified by inducing an enhancement in the weakly coupled electronic surface plasma modes. Thus, appropriate frequencies of laser light incident on a palladium surface launching surface plasma waves can enhance the production of catalytic neutrons. (vi) The captured electron is removed from the collective surface plasma oscillation creating a large density of final states for the weak interactions. Most of the heat of reaction is to be found in these surface electronic modes. (vii) The neutrons themselves are produced at very low momenta, or equivalently, with very long wavelengths. Such neutrons exhibit very large absorption cross sections which are inversely proportional to neutron velocity. Very few of such neutrons will escape the immediate vicinity. These will rarely be experimentally detected. In this regard, ultra low momentum neutrons may produce "neutron rich" nuclei in substantial quantities. These neutrons can yield interesting reaction sequences[17]. Other examples are discussed below in the concluding section.

## LOW ENERGY NUCLEAR REACTIONS

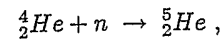
The production of ultra low momentum neutrons can induce chains of nuclear reactions in neighboring condensed matter[18, 19]. For example, let us suppose an initial concentration of lithium very near a suitable metallic hydride surface employed to impose a substantial chemical potential difference across the hydride surface. In that case, the existence of weak interaction produced surface neutrons allow for the following chain of reactions

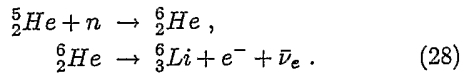


The chain Eq.(26) yields a quite large heat  $Q$  of the net nuclear reaction

$$Q\{ {}^6_3\text{Li} + 2n \rightarrow 2 {}^4_2\text{He} + e^- + \bar{\nu}_e \} \approx 26.9 \text{ MeV}. \quad (27)$$

Having produced  ${}^4_2\text{He}$  products, further neutrons may be employed to build heavy helium "halo nuclei" yielding

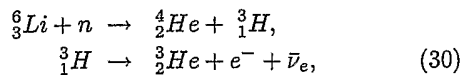




The chain Eq.(28) yields a moderate heat of the net  ${}^6_3\text{Li}$  producing reaction

$$Q\{ {}^4_2\text{He} + 2n \rightarrow {}^6_3\text{Li} + e^- + \bar{\nu}_e \} \approx 2.95 \text{ MeV}. \quad (29)$$

The reaction Eqs.(26) and (28) taken together form a nuclear reaction cycle. Other possibilities include the direct lithium reaction



with the heat of net reaction

$$Q\{ {}^6_3\text{Li} + n \rightarrow {}^4_2\text{He} + {}^3_2\text{He} + e^- + \bar{\nu}_e \} \approx 4.29 \text{ MeV}. \quad (31)$$

This reaction yields both  ${}^4_2\text{He}$  and  ${}^3_2\text{He}$  products. All of the above reactions depend on the original production of neutrons. Of the above possible reactions, the lithium beta decay  $Q\{ {}^8_3\text{Li} \rightarrow {}^8_4\text{Be} + e^- + \bar{\nu}_e \} \approx 16.003 \text{ MeV}$  in Eq.(26) yields the greatest of the above heats of nuclear fuel burning.

In summary, weak interactions can produce neutrons and neutrinos via the capture by protons of heavy electrons. The collective motions of the surface metallic hydride protons produce the oscillating electric fields which renormalize the electron self energy adding significantly to the effective mass. There is no Coulomb barrier obstruction to the resulting neutron catalyzed nuclear reactions. The final products  ${}^A_Z\text{X}$  in some reaction chains may have fairly high  $A$ . The above examples show that final products such as  ${}^4_2\text{He}$  do not necessarily constitute evidence for the direct fusion  $D + D \rightarrow {}^4_2\text{He}$ . Direct fusion requires tunneling through a high Coulomb barrier. By contrast, there are no such barriers to weak interactions and ultra low momentum neutron catalysis. Final products such as  ${}^4_2\text{He}$  and/or  ${}^3_2\text{He}$  and/or  ${}^3_1\text{H}$  may be detected.

- 
- [1] R.E. Marshak, Riazuddin and C.P. Ryan, *Theory of Weak Interaction of Elementary Particles*, Interscience, New York (1969).
  - [2] H. Yukawa, *Proc. Phys.-Mat. Soc. Japan* **17**, 48 (1935).
  - [3] C. Möller, *Physik. Z. Sowjetunion* **11**, 9 (1937).
  - [4] J.E. Rothberg, E.W. Anderson, E.J. Bleser, L.M. Lederman, S.L. Meyer, J.L. Rosen, I.-T. Wang, *Phys. Rev.* **132** 2664 (1963).
  - [5] A.A. Quaranta, A. Bertin, G. Matone, F. Palmonari, G. Torelli, P. Dalpiaz, A. Placci, E. Zavattini, *Phys. Rev.* **177**, 2118 (1969).
  - [6] S. Ando, F. Myhrer, K. Kubodera, *Phys. Rev.* **C63**, 015203 (2000).
  - [7] L.D. Landau and E.M. Lifshitz, *The Classical Theory of Fields*, Secs.17 and 47 Prob.2, Pergamon Press, Oxford (1975).
  - [8] V.B. Berestetskii, E.M. Lifshitz and L.P. Pitaevskii, *Quantum Electrodynamics*, Sec.40, Eq.(40.15), Butterworth Heinmann, Oxford (1997).
  - [9] A. Ringwald, *Phys. Lett. B* **510**, 107 (2001).
  - [10] V.S. Popov, *JEP T Lett.* **74**, 133 (2002).
  - [11] E.A. Sten and R.A. Ferrell, *Phys. Rev.* **110**, 130 (1960).
  - [12] J.D. White, J. Chen, D. Matsiev, D.J. Auerbach and A.M. Wadke, *Nature* **433**, 503 (2005).
  - [13] J. Schwinger, *Proceedings of the National Academy of Sciences* **37**, 452 (1951).
  - [14] G.L. Squires, *Introduction to the Theory of Thermal Neutron Scattering*, Dover Publications, New York (1996).
  - [15] B. Hauer, R. Hempelmann, T.J. Udovic, J.J. Rush, W. Kockelmann, W. Schäfer, R. Jansen and D. Richter *J. Phys: Condens. Matter* **16** 5205 (2004).
  - [16] M. Kemali, J.E. Totalici, D.K. Ross and I. Morrison, *Phys. Rev. Lett* **84**, 1531 (2000).
  - [17] Y. Iwamura, M.Sakano and T. Itoh, *Jap. J. Appl. Phys.* **41**, 4642 (2002).
  - [18] D. R. Lide, Editor *Handbook of Chemistry and Physics* 81<sup>st</sup> edition, Sec.11, CRC Press, Boca Raton (2000).
  - [19] R. Firestone and V. Shirley, Editors, *Table of Radioactive Isotopes*, John Wiley and Sons, New York (1999).

## Absorption of Nuclear Gamma Radiation by Heavy Electrons on Metallic Hydride Surfaces

A. Widom

*Physics Department, Northeastern University, 110 Forsyth Street, Boston MA 02115*

L. Larsen

*Lattice Energy LLC, 175 North Harbor Drive, Chicago IL 60601*

Low energy nuclear reactions in the neighborhood of metallic hydride surfaces may be induced by ultra-low momentum neutrons. Heavy electrons are absorbed by protons or deuterons producing ultra low momentum neutrons and neutrinos. The required electron mass renormalization is provided by the interaction between surface electron plasma oscillations and surface proton oscillations. The resulting neutron catalyzed low energy nuclear reactions emit copious prompt gamma radiation. The heavy electrons which induce the initially produced neutrons also strongly absorb the prompt nuclear gamma radiation, re-emitting soft photons. Nuclear hard photon radiation away from the metallic hydride surfaces is thereby strongly suppressed.

PACS numbers: 24.60.-k, 23.20.Nx

### I. INTRODUCTION

Low energy nuclear reactions (LENR) may take place in the neighborhood of metallic hydride surfaces[1, 2]. The combined action of surface electron density plasma oscillations and surface proton oscillations allow for the production of heavy mass renormalized electrons. A heavy electron, here denoted by  $\bar{e}^-$ , may produce ultra-low momentum neutrons via the reaction[3]

$$\bar{e}^- + p^+ \rightarrow n + \nu_e. \quad (1)$$

Once the ultra low momentum neutrons are created, other more complex low energy nuclear reactions may be catalyzed[4]. Typically, neutron catalyzed nuclear reactions release energy in large part by the emission of prompt hard gamma radiation. However, the copious gamma radiation and neutrons have not been observed away from the metallic hydride surface. Our purpose is to theoretically explain this experimental state of affairs. In particular, we wish to explore the theoretical reasons why copious prompt hard gamma radiation has *not* been observed for LENR on metallic hydride surfaces. The experimental fact that a *known* product particle is not observed far from the metallic hydride surface is related to the fact that the mean free path of the product particle to be converted to other particles is short. As an example of such arguments, we review in Sec. II, why the mean free path of an ultra low momentum neutron is so short. A short mean free path implies that the product particle never appears very far from the surface in which it was first created.

For hard gamma radiation, the mean free path computation in metals is well known[5, 6]. For normal metals, there exists *three* processes determining prompt gamma photon mean free path. The processes are as follows:

- (1) *The photoelectric effect:* The hard photon blasts a bound core electron out of the atom.
- (2) *Compton scattering from normal conduction elec-*

*trons:* The hard photon scatters off a very slowly moving conduction electron giving up a finite fraction of its energy to this electron.

$$\gamma + e_i^- \rightarrow \gamma' + e_f^- \quad (2)$$

The final photon  $\gamma'$  is nonetheless fairly hard.

(3) *Creation of electron-positron pairs:* The hard gamma photon creates an electron-positron pair. Kinematics disallows this one photon process in the vacuum. Pair production can take place in a metal wherein other charged particles can recoil during the pair production process. Roughly, the resulting mean free paths of hard prompt gamma photons is of the order of centimeters when all of the above above mechanisms are taken into account.

Let us now consider the situation in the presence of heavy electrons. The processes are as follows:

- (1) *The absence of a heavy electron photoelectric effect:* The surface heavy electrons are all conduction electrons. They do not occupy bound core states since the energy is much too high. Thus, there should be no heavy electron photoelectric effect. There will be an anomalously high surface electrical conductivity due to these heavy conduction electrons. This anomaly occurs as the threshold proton (or deuteron) density for neutron catalyzed LENR is approached.
- (2) *Compton scattering from heavy conduction electrons:* When the hard gamma photon is scattered from a heavy electron, the final state of the radiation field consists of very many very soft photons; i.e. the Compton Eq.(2) is replaced by

$$\gamma + \bar{e}_i^- \rightarrow \sum \gamma_{soft} + \bar{e}_f^-. \quad (3)$$

It is the final state soft radiation, shed from the mass renormalized electrons, that is a signature for the heavy electron Compton scattering.

- (3) *Creation of heavy electron-hole pairs:* In order to achieve heavy electron pair energies of several MeV, it

is not required to reach way down into the vacuum Dirac electron sea[7]. The energy differences between electron states in the heavy electron conduction states is sufficient to pick up the “particle-hole” energies of the order of MeV. Such particle-hole pair production in conduction states of metals is in conventional condensed matter physics described by electrical conductivity.

In Sec. III, the theory of electromagnetic propagation in metals is explored. We show that an optical photon within a metal has a very short mean free path for absorption. The short mean free path makes metals opaque to optical photons. The effect can be understood on the basis of the Bohr energy rule

$$\Delta E = \hbar\omega. \quad (4)$$

For optical frequencies,  $\hbar\omega$  is of the order of a few electron volts and typical particle-hole pair creation energies near the Fermi surface are also of the order of a few electron volts. The resulting strong electronic absorption of optical photons is most easily described by the metallic electrical conductivity. For hard photons with an energy of the order of a few MeV, there are ordinarily no electronic particle-hole solid state excitations with an energy spread which is so very large. A normal metal is thus ordinarily transparent to hard gamma rays.

On the other hand, the non-equilibrium neutron catalysis of LENR near metallic hydride surfaces is due to heavy electrons with a renormalized mass having energy spreads of several MeV. These large energy spreads for the heavy surface electrons yield the mechanism for hard gamma ray absorption. This mechanism is explained in detail in Secs. IV and V. In Sec. IV A, we review the reasons for which a single electron in the vacuum *cannot* absorb a hard single massless photon. In Sec. IV B, we review the reasons why a single electron within a plain wave radiation beam *can* absorb a hard single massless photon. The proof requires the well established exact solutions of the Dirac wave functions in a plane wave radiation field[8] and contains also the proof of the induced electron mass renormalization in this radiation field. The electrical conductivity of induced non-equilibrium heavy electrons on the metallic hydride surface as seen by hard photons will be explored in Sec. V. The energy spread of heavy electron-hole pair excitations implies that a high conductivity near the surface can persist well into the MeV photon energy range strongly absorbing prompt gamma radiation. An absorbed *hard* gamma photon can be re-emitted as a very large number of *soft* photons, e.g. infrared and/or X-ray. The mean free path of a hard gamma photon estimated from physical kinetics[9] has the form

$$L_\gamma \approx \left(\frac{3}{\pi}\right)^{1/3} \left(\frac{1}{4\alpha}\right) \frac{1}{\tilde{n}^{2/3}\tilde{l}} \approx \frac{33.7}{\tilde{n}^{2/3}\tilde{l}}, \quad (5)$$

where  $\tilde{n}$  is the number of heavy electrons per unit volume,  $\tilde{l}$  is the mean free path of a heavy electron and the

quantum electrodynamic coupling strength is

$$\alpha = \frac{e^2 R_{vac}}{4\pi\hbar} = \frac{e^2}{\hbar c} \approx \frac{1}{137.036}. \quad (6)$$

The number density of heavy electrons on a metallic hydride surface is of the order of the number density of surface hydrogen atoms when there is a proton or deuteron flux moving through the surface and LENR are being neutron catalyzed. These added heavy electrons produce an anomalously high surface electrical conductivity at the LENR threshold. Roughly,  $\tilde{n}^{2/3} \sim 10^{15}/\text{cm}^2$ ,  $\tilde{l} \sim 10^{-6}$  cm so that the mean free path of a hard prompt gamma ray is  $L_\gamma \sim 3.4 \times 10^{-8}$  cm. Thus, prompt hard gamma photons get absorbed within less than a nanometer from the place wherein they were first created. The energy spread of the excited particle hole pair will have a cutoff of about 10 MeV based on the mass renormalization of the original electron. The excited heavy electron hole pair will annihilate, producing very many soft photons based on the photon spectrum which produced such a mass renormalization. The dual role of the heavy electrons is discussed in the concluding Sec. VI. In detail, the heavy electrons are absorbed by protons creating ultra-low momentum neutrons and neutrinos which catalyze further LENR, e.g. subsequent neutron captures on nearby nuclei. The heavy electrons also allow for the strong absorption of prompt hard gamma radiation produced from LENR.

## II. NEUTRON MEAN FREE PATH

Suppose there are  $n$  neutron absorbers per unit volume with an absorption cross section  $\Sigma$ . The mean free path  $\Lambda$  of the neutron is then given by

$$\Lambda^{-1} = n\Sigma = \frac{4\pi\hbar n}{p} \Im m \mathcal{F}(0) = \frac{4\pi\hbar nb}{p}, \quad (7)$$

where  $p$  is the neutron momentum and  $\mathcal{F}(0)$  is the forward scattering amplitude. The imaginary part of the scattering length is denoted by  $b$ . In terms of the ultra low momentum neutron wave length  $\lambda = (2\pi\hbar/p)$ , Eq.(7) implies

$$\Lambda = \frac{1}{2n\lambda b}. \quad (8)$$

The ultra low momentum neutron is created when a heavy electron is absorbed by one of many protons participating in a collective surface oscillation. The neutron wave length is thus comparable to the spatial size of the collective oscillation, say  $\lambda \sim 10^{-3}$  cm. With (for example)  $b \sim 10^{-13}$  cm and  $n \sim 10^{22}$  cm<sup>-3</sup>, one finds a neutron mean free path of  $\Lambda \sim 10^{-6}$  cm. An ultra low momentum neutron is thus absorbed within about ten nanometers from where it was first created. The likelihood that ultra low momentum neutrons will escape capture and thermalize via phonon interactions is very small.

### III. OPTICAL PHOTON MEAN FREE PATH

Consider an optical photon propagating within a metal with conductivity  $\sigma$ . From Maxwell's equations

$$\begin{aligned} \text{curl} \mathbf{E} &= -\frac{1}{c} \frac{\partial \mathbf{B}}{\partial t}, \\ \text{div} \mathbf{B} &= 0, \\ \text{curl} \mathbf{B} &= \frac{1}{c} \left\{ \frac{\partial \mathbf{E}}{\partial t} + 4\pi \mathbf{J} \right\}, \end{aligned} \quad (9)$$

it follows that

$$\left\{ \frac{1}{c^2} \left( \frac{\partial}{\partial t} \right)^2 - \Delta \right\} \mathbf{B} - \frac{4\pi}{c} \text{curl} \mathbf{J} = 0. \quad (10)$$

Employing Ohm's law in the form

$$\begin{aligned} \mathbf{J} &= \sigma \mathbf{E} \\ \text{curl} \mathbf{J} &= -\frac{\sigma}{c} \left( \frac{\partial \mathbf{B}}{\partial t} \right), \end{aligned} \quad (11)$$

yields the wave equation with dissipative damping

$$\left\{ \left( \frac{\partial}{\partial t} \right)^2 + 4\pi\sigma \left( \frac{\partial}{\partial t} \right) - c^2 \Delta \right\} \mathbf{B} = 0. \quad (12)$$

The transition rate per unit time for the optical photon absorption is then  $4\pi\sigma$ . This argument yields an optical photon mean free path  $L$  given by

$$\frac{1}{L} = \frac{4\pi\sigma}{c} = R_{vac}\sigma \quad (13)$$

wherein  $R_{vac}$  is the vacuum impedance. In SI units, the optical photon mean free path is given by

$$L = \frac{1}{R_{vac}\sigma} \quad \text{where} \quad \frac{R_{vac}}{4\pi} \equiv 29.9792458 \text{ Ohm}. \quad (14)$$

For a metal with low resistivity

$$\sigma^{-1} \lesssim 10^{-5} \text{ Ohm cm}, \quad (15)$$

the mean free path length of an optical photon obeys

$$L \lesssim 3 \times 10^{-8} \text{ cm}. \quad (16)$$

An optical photon in a metal is absorbed in less than a nanometer away from the spot in which it was born. Thus, normal metals are opaque to visible light.

To see what is involved from a microscopic viewpoint, let us suppose an independent electron model in which occupation numbers are in thermal equilibrium with a Fermi distribution

$$f(E) = \frac{1}{e^{(E-\mu)/k_B T} + 1}. \quad (17)$$

If the conductivity is described in terms of elastic electron scattering from impurities or phonons, then the conductivity in a volume  $\Omega$  containing conduction electrons is described by the Kubo formula[10]

$$\begin{aligned} \Re\{\sigma(\omega + i0^+)\} &= -\frac{\pi}{6} \left( \frac{e^2}{\Omega} \right) \times \\ &\sum_{i,f} \left[ \frac{f(E_f) - f(E_i)}{E_f - E_i} \right] |\mathbf{v}_{fi}|^2 [\delta(\omega - \omega_{fi}) + \delta(\omega + \omega_{fi})], \\ \hbar\omega_{fi} &= E_f - E_i, \end{aligned} \quad (18)$$

wherein  $\mathbf{v}_{fi}$  is a matrix element of the electron velocity operator  $\mathbf{v}$ . If one starts from the interaction between an electron and a photon in the form

$$H_{int} = -\frac{e}{c} \mathbf{A} \cdot \mathbf{v}, \quad (19)$$

applies Fermi's Golden rule for photon absorption, averages over initial states and sums over final states, then the result for the frequency dependent optical photon mean free path  $L(\omega)$  is

$$\frac{1}{L(\omega)} = \frac{4\pi}{c} \Re\{\sigma(\omega + i0^+)\} = R_{vac} \Re\{\sigma(\omega + i0^+)\}, \quad (20)$$

where Eq.(18) has been taken into account. Eqs.(18) and (20) are merely the microscopic version of Eq.(13) which followed directly from Maxwell's equations and Ohm's law. In thermal equilibrium, the energy differences between electron states are of the order of electron volts. As the photon frequency is increased to the nuclear physics scale of MeV, the electrical conductivity  $\Re\{\sigma(\omega + i0^+)\}$  rapidly approaches zero. Thus, a metal in thermal equilibrium is almost transparent to hard nuclear gamma radiation. As will be discussed in what follows, for the surfaces of metallic hydrides in non-equilibrium situations with heavy electrons, strong absorption of nuclear gamma radiation can occur.

### IV. HARD PHOTONS - HEAVY ELECTRONS

Heavy electrons appear on the surface of a metallic hydride in non-equilibrium situations. Sufficient conditions include (i) intense LASER radiation incident on a suitably rough metallic hydride surface, (ii) high chemical potential differences across the surface due to electrolytic voltage gradients and (iii) high chemical potential differences across the surface due to pressure gradients. Under such non-equilibrium conditions, weakly coupled surface plasmon polariton oscillations and proton oscillations induce an oscillating electromagnetic field

$$F_{\mu\nu}(x) = \partial_\mu A_\nu(x) - \partial_\nu A_\mu(x) \quad (21)$$

felt by surface electrons. From a classical viewpoint, the electrons obey the Lorentz force equation

$$\frac{d^2 x^\mu}{d\tau^2} = \frac{e}{c} F_{\mu\nu}(x) \frac{dx^\nu}{d\tau}. \quad (22)$$

From the quantum mechanical viewpoint, the electron wave function obeys the Dirac equation

$$\left\{ \gamma^\mu \left( -i\hbar\partial_\mu - \frac{e}{c}A_\mu(x) \right) + mc \right\} \psi(x) = 0. \quad (23)$$

The quantum motions are intimately related to the classical motions as can be seen by formulating the problem in terms of the Hamilton-Jacobi action  $S(x)$ . To describe the classical orbits according to Eq.(22), one seeks a classical velocity field  $v^\mu(x)$  obeying the Hamilton-Jacobi equations[11]

$$\begin{aligned} mv_\mu(x) &= \partial_\mu S(x) - \frac{e}{c}A_\mu(x), \\ v^\mu(x)v_\mu(x) &= -c^2. \end{aligned} \quad (24)$$

The orbits implicit in the second order Eqs.(22) may now be obtained by solving the first order equations of motion

$$\frac{dx^\mu}{d\tau} = v^\mu(x). \quad (25)$$

From the quantum mechanical viewpoint, one seeks a solution to the Dirac Eq.(24) having the form

$$\psi(x) = u(x)e^{iS(x)/\hbar}. \quad (26)$$

The classical velocity field  $v^\mu(x)$  makes its appearance in the equation of motion for the spinor  $u(x)$ ; it is exactly

$$\left\{ \gamma^\mu \left( -i\hbar\partial_\mu + mv^\mu(x) \right) + mc \right\} u(x) = 0. \quad (27)$$

Eqs.(24), (26) and (27) constitute the ‘‘unperturbed’’ electron states in the classical electromagnetic field  $F_{\mu\nu}$  describing *soft* radiation from a non-perturbation theory viewpoint. The *hard* gamma photons may *thereafter* be treated employing low order perturbation theory. Two specific examples should suffice to illustrate the point.

#### A. Free Electrons in the Vacuum

A classical free electron has a Hamilton-Jacobi action which obeys

$$\begin{aligned} \partial_\mu S(x)\partial^\mu S(x) + m^2c^2 &= 0, \\ S(x) &= p_\mu x^\mu, \\ p_\mu p^\mu &= -m^2c^2. \end{aligned} \quad (28)$$

For a classical free electron, the velocity field is uniform in space and time; i.e.

$$\begin{aligned} \frac{dx^\mu}{d\tau} &= v^\mu = \frac{p^\mu}{m}, \\ x^\mu &= \left( \frac{p^\mu}{m} \right) \tau. \end{aligned} \quad (29)$$

The free particle quantum theory solutions follow from Eqs.(26), (27), (28) and (29) according to

$$\begin{aligned} \psi(x) &= u(p)e^{ip \cdot x/\hbar}, \\ (\gamma^\mu p_\mu + mc)u(p) &= 0. \end{aligned} \quad (30)$$

Eq.(30) serves as the starting point for the computation of a single hard photon absorption (with wave vector  $k$  and polarization  $\epsilon$ ) by an electron in the vacuum. The *vanishing* amplitude is computed as

$$\begin{aligned} \mathcal{F}(e_i^- + \gamma \rightarrow e_f^-) &= \frac{i}{\hbar c^2} \int J_{fi}^\mu(x) A_\mu(x) d^4x, \\ \mathcal{F}(e_i^- + \gamma \rightarrow e_f^-) &= \frac{ie}{\hbar c} \int \bar{\psi}_f(x) \gamma^\mu \psi_i(x) A_\mu(x) d^4x, \\ \mathcal{F}(e_i^- + \gamma \rightarrow e_f^-) &= \left( \frac{ieA_\gamma}{\hbar c} \right) \epsilon_\mu \bar{u}(p_f) \gamma^\mu u(p_i) \times \\ &\quad \int e^{i(p_i + \hbar k - p_f) \cdot x/\hbar} d^4x, \\ \mathcal{F}(e_i^- + \gamma \rightarrow e_f^-) &= \left( \frac{ieA_\gamma}{\hbar c} \right) \epsilon_\mu \bar{u}(p_f) \gamma^\mu u(p_i) \times \\ &\quad (2\pi\hbar)^4 \delta(p_i + \hbar k - p_f), \\ \mathcal{F}(e_i^- + \gamma \rightarrow e_f^-) &= 0. \end{aligned} \quad (31)$$

Of central importance is the impossibility of satisfying the four momentum conservation law  $p_i + \hbar k = p_f$  for fixed electron mass  $p_i^2 = p_f^2 = -m^2c^2$  and zero photon mass,

$$k^\mu k_\mu = 0. \quad (32)$$

Thus, hard photon absorption by a single electron in the vacuum is not possible.

#### B. Electrons and Electromagnetic Oscillations

Suppose that the electron is in the field of *soft* radiation. For example, the electron may be within a plane wave laser radiation beam. Further suppose an additional *hard* gamma photon is incident upon the electron. In this case (unlike the vacuum case) the hard photon can indeed be absorbed. For a plane wave electromagnetic oscillation of the form

$$\begin{aligned} A_{soft}^\mu(x) &= a^\mu(\phi), \\ \phi &= q_\mu x^\mu \quad \text{where } q^\mu q_\mu = 0, \\ \partial_\mu A_{soft}^\mu(x) &= q_\mu \frac{da^\mu(\phi)}{d\phi} = 0, \end{aligned} \quad (33)$$

the action function is[12]

$$S(x) = p_\mu x^\mu + W_p(\phi). \quad (34)$$

To find the function  $W_p(\phi)$ , one may compute the velocity field

$$mv^\mu(x) = p^\mu - \frac{e}{c}a^\mu(\phi) + q^\mu W_p'(\phi), \quad (35)$$

and impose the Hamilton-Jacobi condition  $v^\mu v_\mu = -c^2$ . Solving this condition for  $W_p(\phi)$  taking Eq.(33) into account yields

$$2(p \cdot q)W_p'(\phi) = \frac{2ep \cdot a(\phi)}{c} - \left\{ m^2c^2 + p^2 + \frac{e^2 a^2(\phi)}{c^2} \right\},$$

$$W_p(\phi) = \int_0^\phi W'_p(\tilde{\phi}) d\tilde{\phi}. \quad (36)$$

If  $W'_p(\phi)$  remains finite during a oscillation period, then on phase averaging  $\overline{W'_p} = \tilde{p} - p$ . This leads to mass renormalization  $m \rightarrow \tilde{m}$  of the electron in the laser field

$$\begin{aligned} \tilde{p}^2 + (\tilde{m}c)^2 &= 0, \\ (\tilde{m}c)^2 &= (mc)^2 + \left(\frac{e}{c}\right) \overline{a^2(\phi)}. \end{aligned} \quad (37)$$

Importantly, the same electromagnetic oscillations which increase the electron mass, also allow for the absorption of hard gamma photons by the surface heavy electron. The gamma ray absorption amplitude for a heavy electron has the form[13]

$$\begin{aligned} \mathcal{F}(\tilde{e}_i^- + \gamma \rightarrow \tilde{e}_f^-) &= \frac{i}{\hbar c^2} \int J_{fi}^\mu(x) A_\mu(x) d^4x, \\ \mathcal{F}(\tilde{e}_i^- + \gamma \rightarrow \tilde{e}_f^-) &= \left(\frac{ieA\gamma}{\hbar c}\right) \epsilon_\mu \times \\ &\quad \int \bar{u}_f \gamma u_i e^{i(\tilde{p}_i + \hbar k - \tilde{p}_f) \cdot x / \hbar} \times \\ &\quad e^{i(\tilde{W}_i(\phi) - \tilde{W}_f(\phi)) / \hbar} d^4x, \\ \mathcal{F}(\tilde{e}_i^- + \gamma \rightarrow \tilde{e}_f^-) &= \sum_n \epsilon_\mu \mathcal{F}_{i \rightarrow f}^\mu(n) \times \\ &\quad \delta(\tilde{p}_i + \hbar k - \tilde{p}_f - \hbar n q). \end{aligned} \quad (38)$$

The conservation of four momentum for heavy electrons  $\tilde{p}_i + \hbar k = \tilde{p}_f + n\hbar q$  as in Eq.(38) differs the conservation of four momentum  $p_i + \hbar k = p_f$  for the vacuum case in Eq.(31). Only the heavy electrons can absorb a hard photon with four momentum  $\hbar k$  emitting  $n$  photons each with four momentum  $\hbar q$ . The transition rate per unit time per unit volume for the reaction

$$\tilde{e}_i^- + \gamma \rightarrow \tilde{e}_f^- + n\gamma_{soft} \quad (39)$$

is given by

$$\begin{aligned} \nu_{i \rightarrow f}(n) &= \frac{(2\pi)^4}{c} \left| \epsilon_\mu \mathcal{F}_{i \rightarrow f}^\mu(n) \right|^2 \times \\ &\quad \delta\left(\frac{\tilde{p}_f - \tilde{p}_i}{\hbar} + nq - k\right), \\ \tilde{p}_i^2 &= \tilde{p}_f^2 = -(\tilde{m}c)^2, \\ \nu_{i \rightarrow f} &= \sum_n \nu_{i \rightarrow f}(n). \end{aligned} \quad (40)$$

with a renormalized electron mass given in Eq.(37). Thus, for the exactly soluble plane wave low frequency oscillation, we have shown how a high frequency hard photon can scatter off a heavy electron producing many low frequency soft photons.

## V. HARD PHOTON ABSORPTION

Let us now return to the heavy electron oscillations on the surface of metallic hydrides. The same heavy electrons required to produce neutrons for catalyzed LENR

are also capable of absorbing prompt gamma radiation via the electrical conductivity which now extends to frequencies as high as about  $\hbar\omega_{max} \sim 10$  MeV. Just as for the optical photon case of Sec. III, we may proceed via Maxwell's equations for the hard photon field

$$\begin{aligned} \delta F_{\mu\nu} &= \partial_\mu \delta A_\nu - \partial_\nu \delta A_\mu, \\ \partial_\mu \delta A^\nu &= 0, \\ \partial_\mu \delta F^{\mu\nu} &= -R_{vac} \delta J^\nu. \end{aligned} \quad (41)$$

The heavy electron current response to the prompt hard photon may be written as

$$R_{vac} \delta J^\mu(x) = \int \Pi^{\mu\nu}(x, y; A) \delta A_\nu(y) d^4y. \quad (42)$$

Especially note that the heavy electron current response function  $\Pi$  depends on the soft radiation field which renormalized the electron mass in the first place. To lowest order in the quantum electrodynamic coupling in Eq.(6), we have the independent electron model relativistic Kubo formula in the one loop insertion form[14]

$$\begin{aligned} \left\{ -i\gamma^\mu \left( \partial_\mu - i\frac{eA_\mu(x)}{\hbar c} \right) + \frac{mc}{\hbar} \right\} \mathcal{G}(x, y; A) &= \delta(x - y), \\ \Pi^{\mu\nu}(x, y; A) &= 4\pi i \alpha \text{tr} \{ \gamma^\mu \mathcal{G}(x, y; A) \gamma^\nu \mathcal{G}(y, x; A) \}. \end{aligned} \quad (43)$$

The equation of motion for the hard prompt gamma photon is thereby

$$-(\partial_\lambda \partial^\lambda) \delta A^\nu(x) - \int \Pi^{\mu\nu}(x, y; A) \delta A_\mu(y) d^4y = 0, \quad (44)$$

wherein the damping is contained in  $\Pi$  which in turn depends on background electromagnetic field oscillations.

The *physical kinetics* estimate[15] of the hard prompt gamma photon absorption is as follows: (i) In the energy regime of the heavy electron mass renormalization, the conductivity obeys

$$\sigma_\gamma \approx \frac{1}{(3\pi^2)^{1/3}} \left(\frac{e^2}{\hbar}\right) (\tilde{n}^{2/3} \tilde{l}),$$

$$\text{for energies } 0.5 \text{ MeV} \lesssim \hbar\omega_\gamma \lesssim 10 \text{ MeV}, \quad (45)$$

where the heavy electrons have a density per unit volume of  $\tilde{n}$  and an electronic mean free path of  $\tilde{l}$ . (ii) We estimate for typical metallic hydride LENR, the values

$$\tilde{n}^{2/3} \sim 10^{15} / \text{cm}^2 \quad \text{and} \quad \tilde{l} \sim 10^{-6} \text{ cm}. \quad (46)$$

(iii) The hard prompt photon mean free path is then

$$\frac{1}{L_\gamma} = R_{vac} \sigma_\gamma \approx 4\alpha \left(\frac{\pi}{3}\right)^{1/3} (\tilde{n}^{2/3} \tilde{l}) \quad (47)$$

in agreement with Eqs.(5) and (6). (iv) The final estimate for the mean free path of a hard prompt gamma photon follows from Eqs.(46) and (47) to be

$$L_\gamma \sim 3.4 \times 10^{-8} \text{ cm}. \quad (48)$$

Thus, the hard photon is absorbed at a distance of less than a nanometer away from where it was first created. This constitutes the central result of this work.

## VI. CONCLUSION

Our picture of LENR in non-equilibrium situations near the surface of metallic hydrides may be described in the following manner: from the weakly coupled proton and electronic surface plasmon polariton oscillations, the electrons have their mass substantially renormalized upward. This allows for the production of ultra low momentum neutrons and neutrinos from heavy electrons interacting with protons or deuterons

$$\begin{aligned}\bar{e}^- + p^+ &\rightarrow n + \nu_e, \\ \bar{e}^- + d^+ &\rightarrow n + n + \nu_e.\end{aligned}\quad (49)$$

The resulting ultra low momentum neutrons catalyze a variety of different nuclear reactions, creating complex nuclear reaction networks and related transmutations over time. The prompt hard gamma radiation which accompanies the neutron absorption is absorbed by the

heavy electrons which drastically lowers the radiation frequencies of the finally produced photons via

$$\bar{e}_i^- + \gamma_{hard} \rightarrow \bar{e}_f^- + \sum \gamma_{soft}. \quad (50)$$

In the range of energies  $\hbar\omega_\gamma$  less than the renormalized energy of the heavy electrons, the prompt photon in Eq.(50) implies a prompt hard gamma mean free path of less than a nanometer. The metallic hydride surface is thus opaque to hard photons but not to softer X-ray radiation in the KeV regime. In certain non-equilibrium metallic hydride systems, surface heavy electrons play a dual role in allowing both Eqs.(49) for catalyzing LENR and Eq.(50) for absorbing the resulting hard prompt photons. Thus, the heavy surface electrons can act as a gamma ray shield. Once the non-equilibrium conditions creating heavy electrons cease, ultra low momentum neutron production and gamma absorption both stop very rapidly.

- 
- [1] Y. Iwamura, M.Sakano and T. Itoh, *Jap. J. Appl. Phys.* **41**, 4642 (2002).
- [2] S. Focardi, V. Gabbani, V. Montalbano, F. Piantelli and S. Veronesi, *Il Nuovo Cimento* **111A**, 1233 (1998).
- [3] R.E. Marshak, Riazuddin and C.P. Ryan, *Theory of Weak Interaction of Elementary Particles*, Interscience, New York (1969).
- [4] A. Widom and L. Larsen, cond-mat/0505026 (2005).
- [5] W. Heitler, *The Quantum Theory of Radiation*, Chapt. VII, Oxford University Press, Oxford (1953).
- [6] J. Bartels, D. Haidt and A. Zichichi, *Eur. J. Phys.* **C 16**, 168-170, (2000).
- [7] P.A.M. Dirac, *Rapport du 7<sup>e</sup> Conseil Solvay de Physique, Structure et Propriétés des Noyaux Atomiques*, p. 203 (1934).
- [8] V.B. Berestetskii. E.M. Lifshitz and L.P. Pitaevskii, *Quantum Electrodynamics*, Butterworth Heinmann, Sec. 41, Oxford (1997).
- [9] E.M. Lifshitz and L.P. Pitaevskii, *Physical Kinetics*, Butterworth Heinmann, Chapt. IX, Oxford (1995).
- [10] R. Kubo, *J. Phys. Soc. Japan* **12**, 570 (1957).
- [11] L.D. Landau and E.M. Lifshitz, *The Classical Theory of Fields*, Sec.17, Pergamon Press, Oxford (1975).
- [12] L.D. Landau and E.M. Lifshitz, *op. cit.*, Sec.42 Prob. 2.
- [13] V.B. Berestetskii. E.M. Lifshitz and L.P. Pitaevskii, *op. cit.*, Sec.101.
- [14] J. Schwinger, *Proceedings of the National Academy of Sciences* **37**, 452 (1951).
- [15] J.M. Ziman, *Theory of Solids*, Sec. 7.2, Cambridge University Press, Cambridge, (1995).



- 40 -

Claims

1. A neutron production method in a condensed matter system at moderate temperatures and pressures comprising:
  - providing collectively oscillating protons;
  - providing collectively oscillating heavy electrons; and
  - providing a local electric field greater than approximately  $10^{11}$  volts/meter.
2. The method of claim 1 wherein said providing collectively oscillating protons comprises providing a metallic substrate and fully loading at least the upper portion thereof with hydrogen or deuterium.
3. The method of claim 1 wherein the Born-Oppenheimer approximation breaks down on a working surface of a substrate.
4. A method of producing neutrons comprising the steps of:
  - providing a hydride or deuteride on a metallic surface;
  - developing a surface layer of protons or deuterons on said hydride or deuteride;
  - developing patches of collectively oscillating protons or deuterons near or at said surface layer; and
  - exciting surface plasmons on said metallic surface.
5. The method of claim 4 further comprising providing target materials on said metallic surface.
6. The method of claim 5 wherein the target materials are nanoparticles.
7. The method of claim 6 wherein the target materials are alloys.
8. The method of claim 7 wherein the target materials are Palladium-Lithium alloy.
9. The method of claim 4 and further comprising directing a flux of protons or

deuterons toward said metallic surface.

10. The method of claim 4 and including loading hydrogen or deuterium via one or more of an enforced chemical potential difference, an electrical current, and a pressure gradient.

11. The method of claim 4 further comprising directing laser light toward said metallic surface.

12. The method of claim 4 wherein the neutrons are produced with intrinsically very low energies.

13. A method of producing ultra low momentum neutrons ("ULMNs") comprising:

providing a plurality of protons or deuterons on a working surface of hydride/deuteride-forming materials;

breaking down the Born-Oppenheimer approximation in patches on said working surface;

producing heavy electrons in the immediate vicinity of coherently oscillating patches of protons and/or deuterons; and

producing said ULMNs from said heavy electrons and said protons or deuterons.

14. The method of claim 13 including forming surface plasmon polaritons.

15. A nuclear process using weak interactions comprising:

forming ultra low momentum neutrons (ULMNs) from electrons and protons/deuterons using weak interactions; and

locally absorbing said ULMNs to form isotopes which undergo beta-decay after said absorbing.

16. A method of generating energy comprising the steps of:

- 42 -

at first sites, producing neutrons intrinsically having, upon their creation, ultra low momentum (ULMNs);

disposing a lithium target at a second site near said first sites in a position to intercept said ULMNs;

said ULMNs reacting with said Lithium target to produce Li-7 and Li-8 isotopes;

said lithium isotopes decaying by emitting electrons and neutrinos to form Be-8;

said Be-8 decaying to He-4;

said reaction producing a net heat of reaction.

17. The method of claim 16 further comprising:

producing helium isotopes by reacting helium with ULMNs emitted from said first sites to form He-5 and He-6;

said He-6 decaying to Li-6 by emitting an electron and neutrino;

said helium to lithium reactions yielding a heat of reaction and forming a nuclear reaction cycle.

18. A method of producing heavy electrons comprising:

providing a metallic working surface capable of supporting surface plasmons and of forming a hydride or deuteride;

fully loading said metallic surface with H or D thereby to provide a surface layer of protons or deuterons capable of forming coherently oscillating patches; and

developing at least one patch of coherently or collectively oscillating protons or deuterons on said surface layer.

19. The method of claim 18 including breaking down the Born-Oppenheimer approximation on said upper working surface.

20. The method of claim 18 wherein said metallic surface comprises a surface of

- 43 -

palladium or a similar metal and/or alloy capable of forming a hydride or deuteride; and providing a plurality of target nanoparticles on said metallic working surface.

21. The method of claim 20 wherein said target nanoparticles comprise a palladium-lithium alloy.

22. The method of claim 18 further comprising directing laser radiation to said working surface to stimulate and transfer energy into said surface plasmons.

23. The method of claim 18 wherein said H or D surface layer is fully loaded by one or more of an enforced chemical potential difference, an electrical current, or a pressure gradient.

24. Apparatus for a nuclear reaction comprising:

- a supporting material;
- a thermally conductive layer;
- an electrically conductive layer in contact with at least a portion of said thermally conductive layer;
- a cavity within said supporting material and thermally conductive layer;
- a source of hydrogen or deuterium associated with said cavity;
- first and second metallic hydride-forming layers within said cavity;
- an interface between a surface of said first hydride-forming layer, said interface being exposed to hydrogen or deuterium from said source;
- a first region of said cavity being located on one side of said interface and having a first pressure of said hydrogen or deuterium;
- a second region of said cavity being located on one side of said second hydride-forming layer and having a second pressure of said hydrogen or deuterium;
- said first pressure being greater than said second pressure;

- 44 -

said apparatus forming a sea of surface plasmon polaritons and patches of collectively oscillating protons or deuterons, and ultra low momentum neutrons in a region both above and below said interface.

25. The apparatus of claim 24 wherein a Fermi-level difference between said first and second layers is greater than or equal to about 0.5eV.

26. The apparatus of claim 24 further comprising a laser positioned to irradiate said sea and said interface.

27. The apparatus of claim 24 further comprising an electrically conductive layer forming a portion of an inside wall of said cavity.

28. A neutron generator for producing ultra low momentum neutrons ("ULMNs") comprising:

a metallic substrate having a working surface capable of supporting surface plasmons and of forming a hydride or deuteride, located above said substrate;

said metallic substrate being fully loaded with hydrogen or deuterium;

a surface layer of protons or deuterons;

at least one region of collectively oscillating protons or deuterons on said surface layer;

surface plasmons located above the surface layer and said region; and

a flux of protons or deuterons incident on said surface plasmons, surface layer, and working surface.

29. The ULMN generator of claim 28 further comprising a plurality of target nanoparticles on said working surface.

30. The ULMN generator of claim 28 wherein the Born-Oppenheimer approximation breaks down on said upper working surface.

- 45 -

31. The ULMN generator of claim 28 wherein said substrate comprises palladium or a similar metal and/or alloy capable of forming a hydride or deuteride.

32. The ULMN generator of claim 28 further comprising laser radiation incident on said working surface to stimulate and transfer energy into said surface plasmons.

33. The ULMN generator of claim 29 wherein said target nanoparticles comprise a palladium-lithium alloy.

34. The ULMN generator of claim 28 wherein said H or D surface layer is fully loaded by one or more of an enforced chemical potential difference, an electrical current, or a pressure gradient.

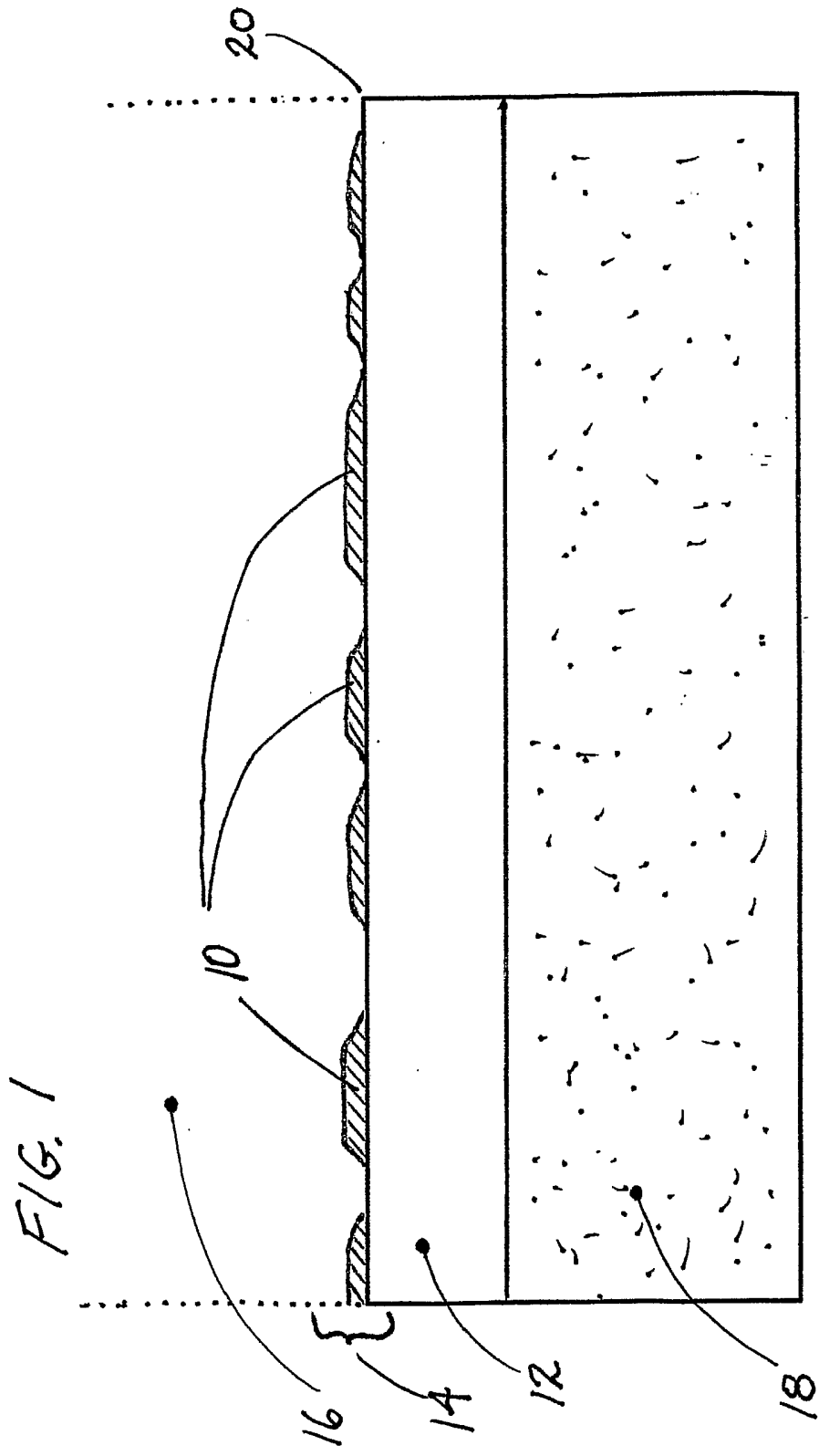
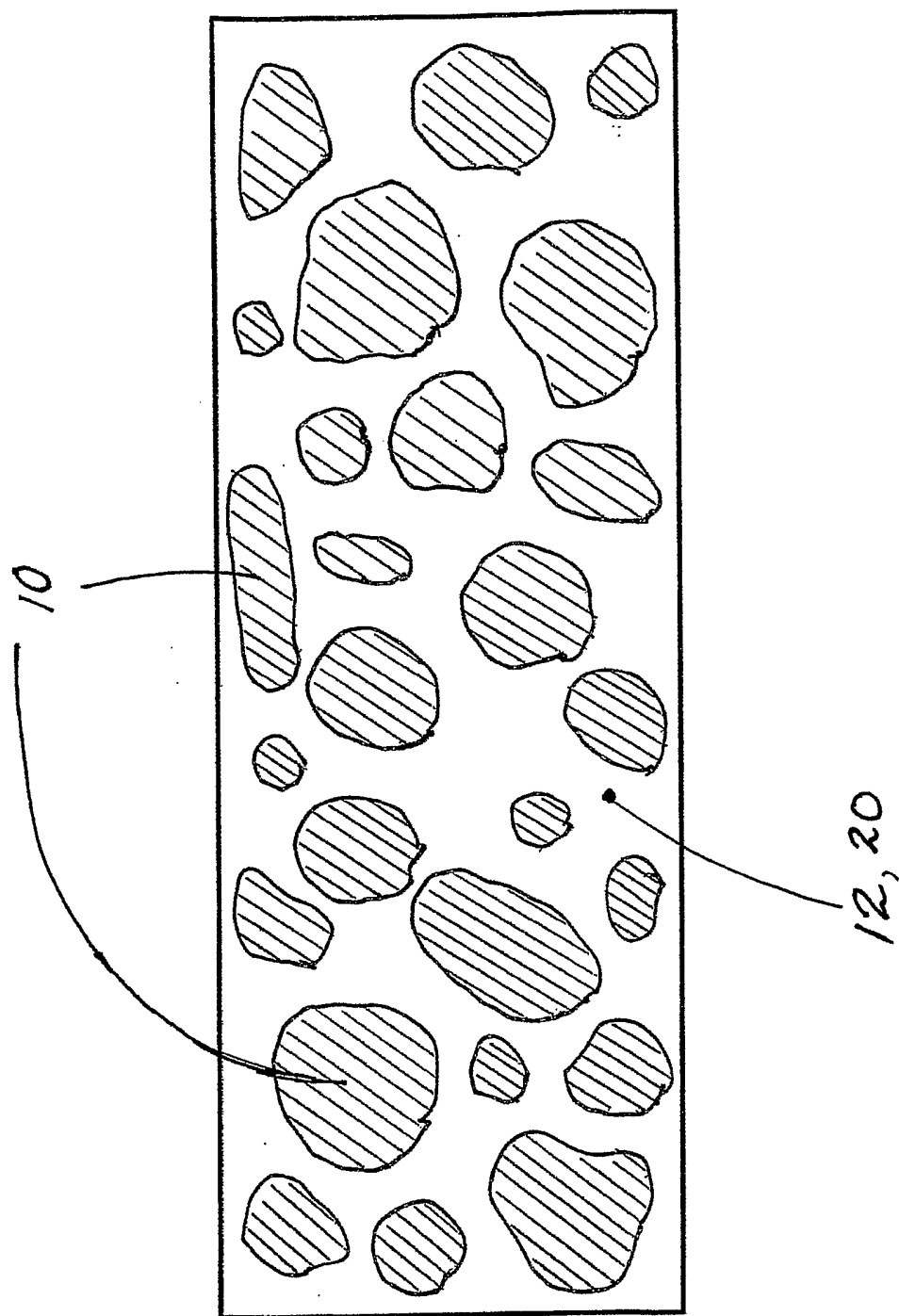


FIG. 2





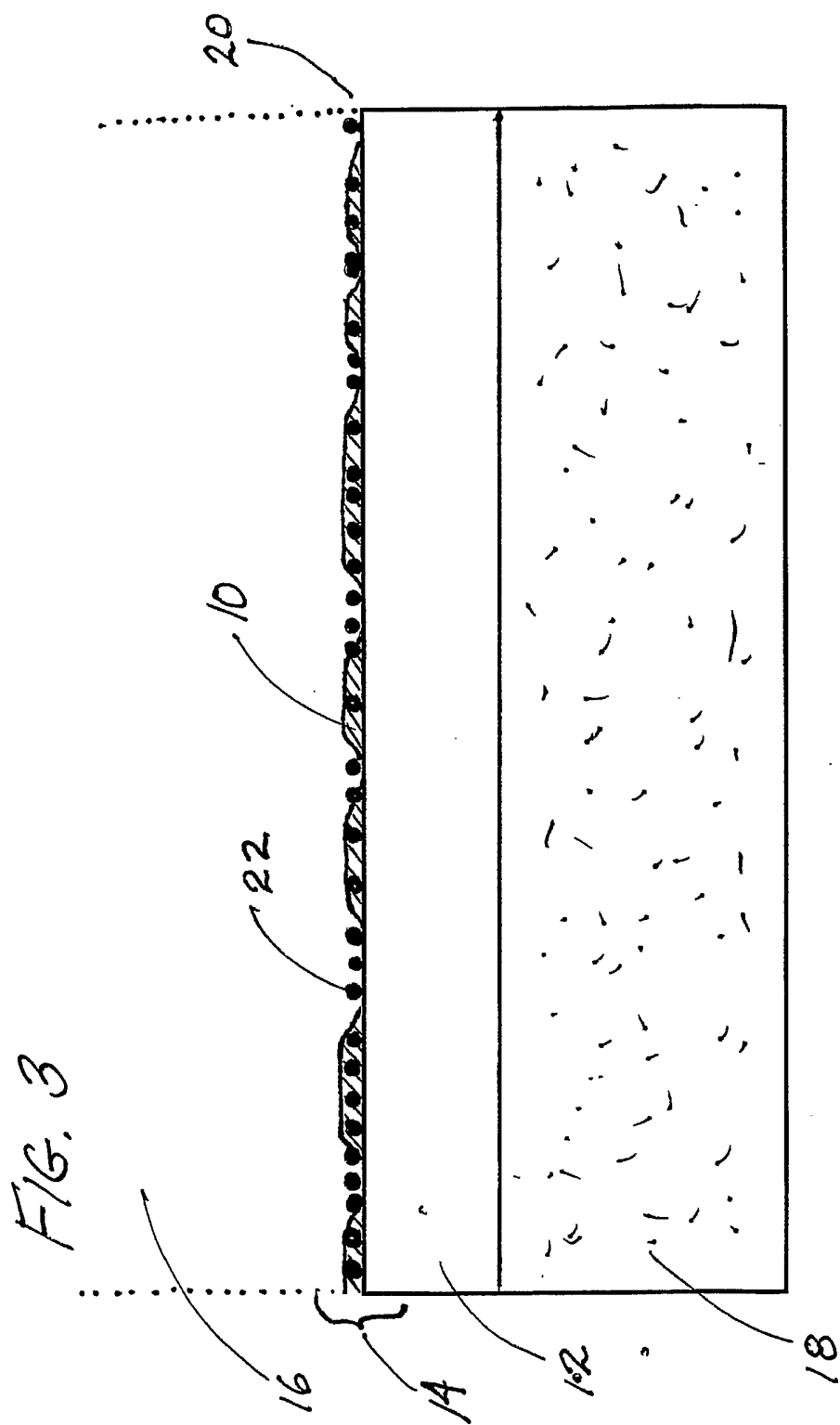


FIG. 4

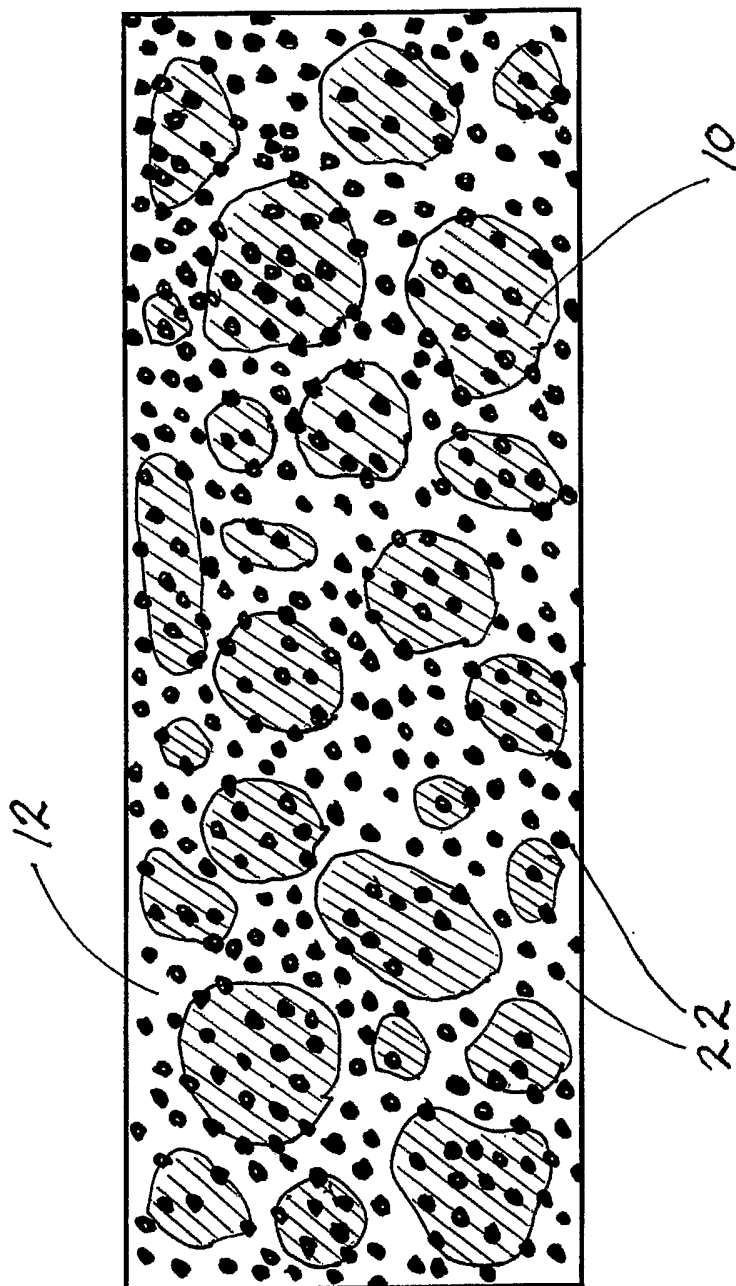
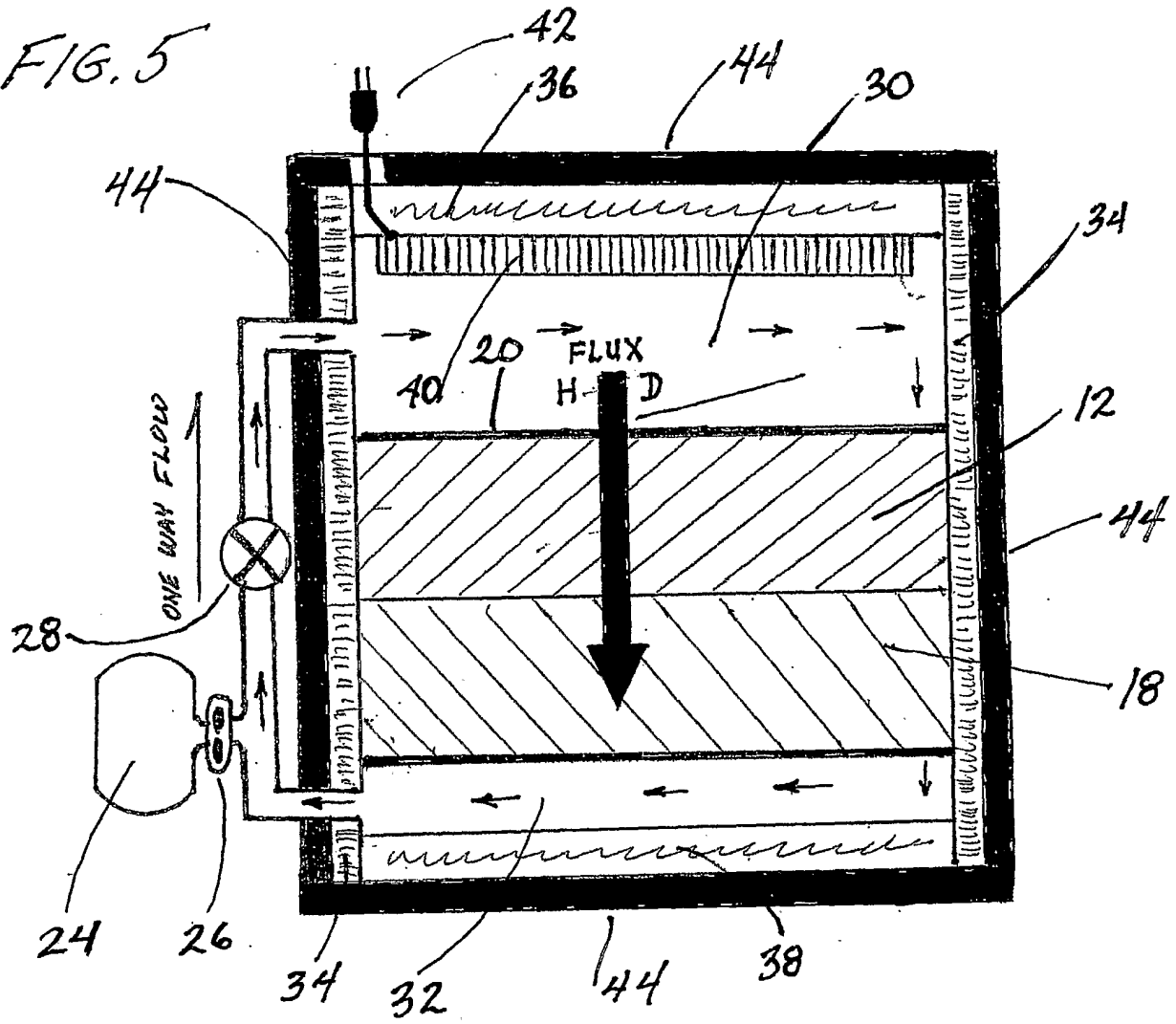


FIG. 5



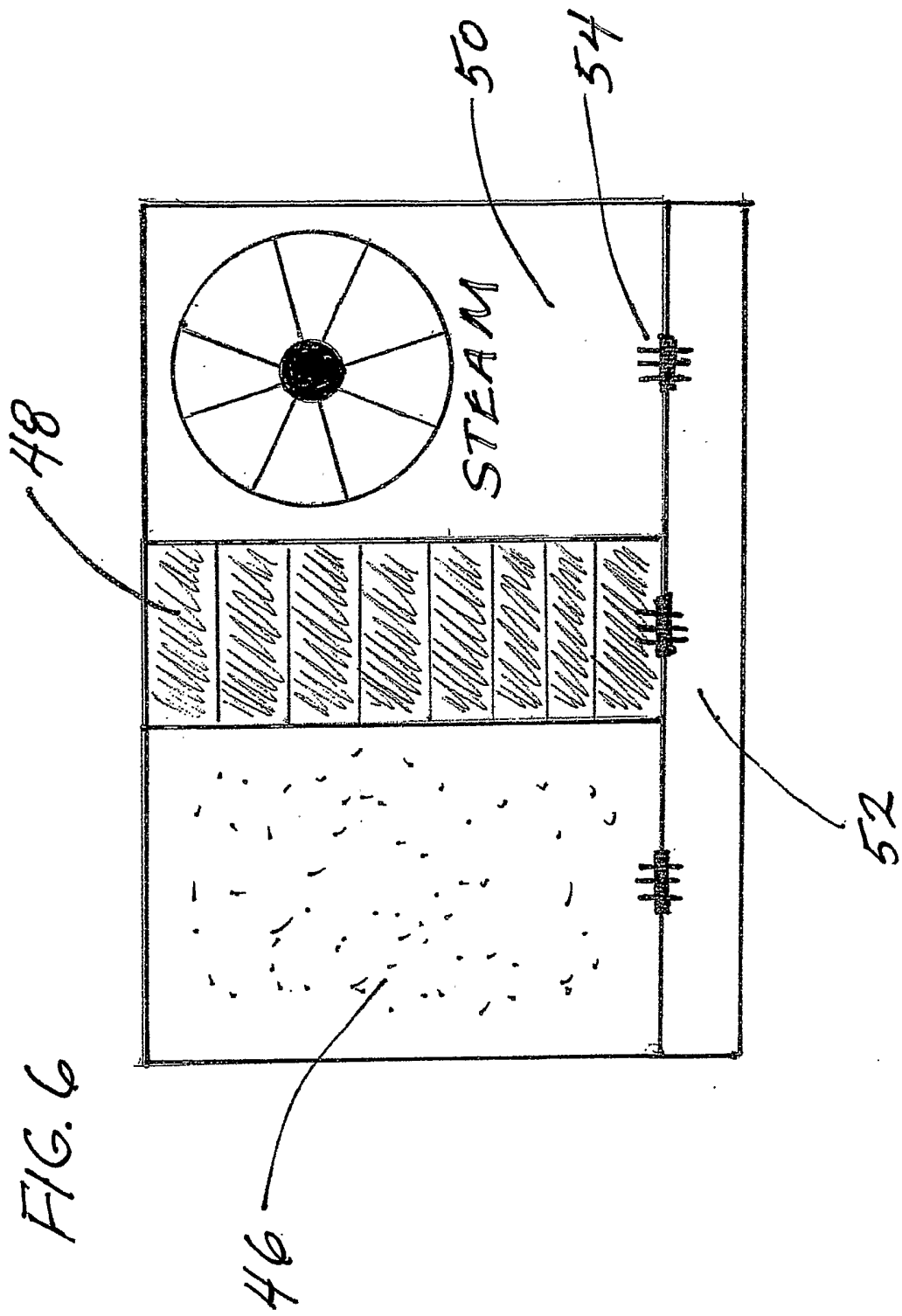
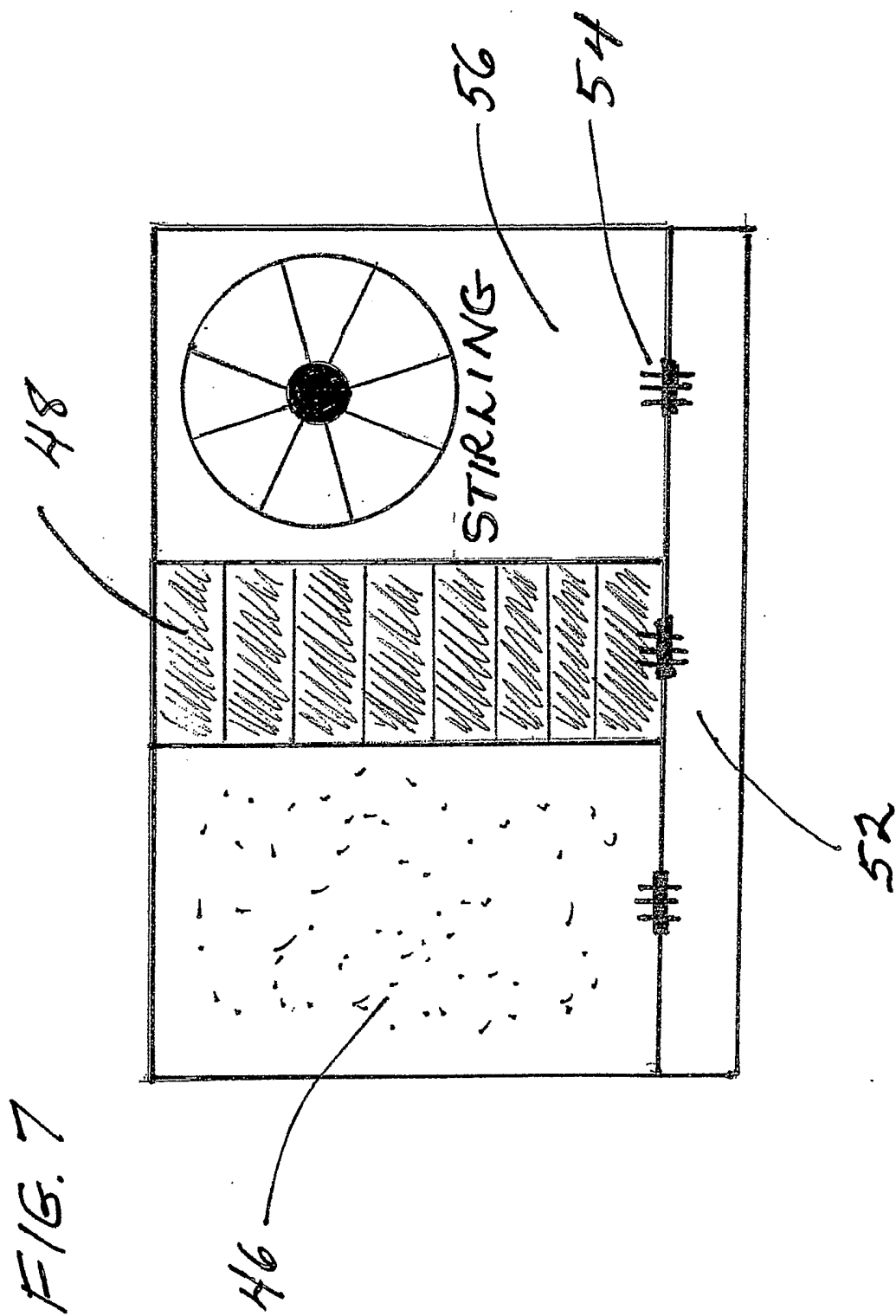


FIG. 6



The surface of the material at the "patches" of coherently oscillating hydrogenous atoms comprises the interface region between the nuclear (orange) and chemical (blue) realms

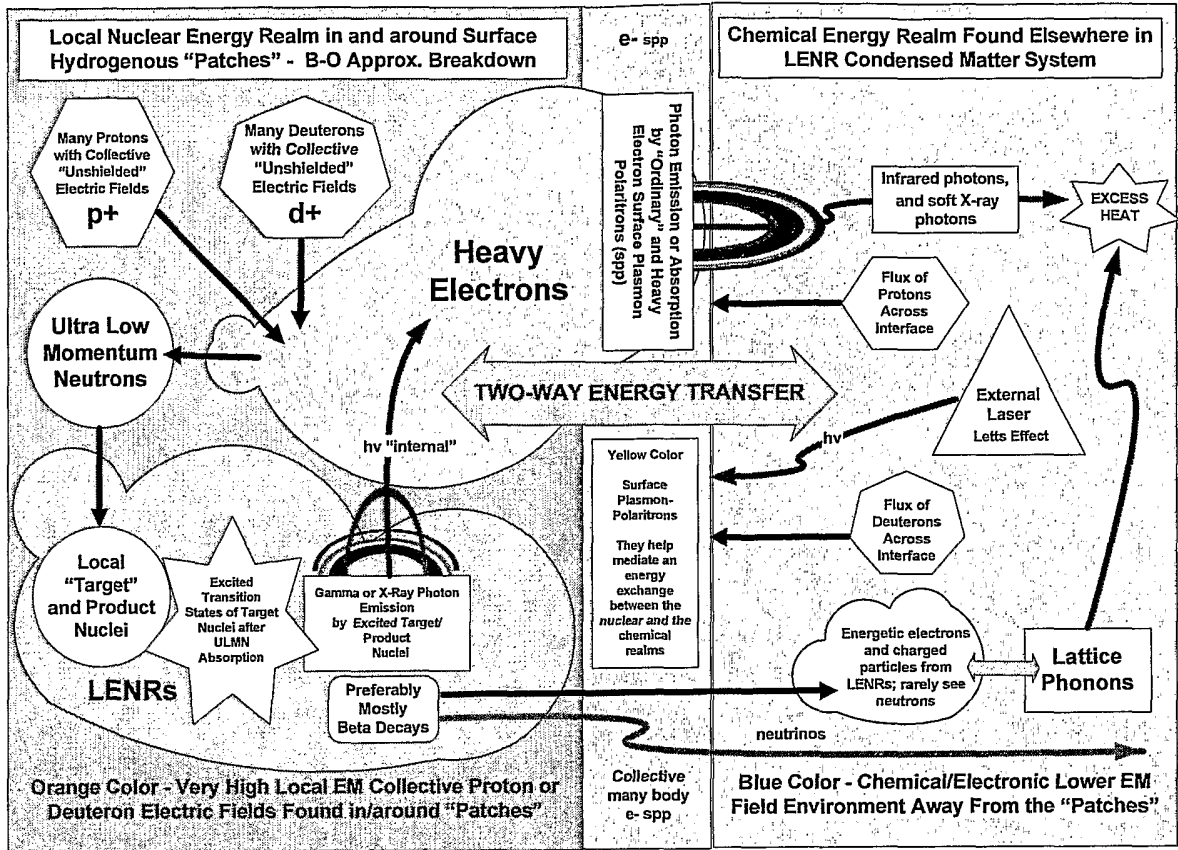


FIGURE 8