LOW ENERGY NUCLEAR REACTIONS?

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PART I: INTRODUCTION AND THEORETICAL CONSIDERATIONS

See S. Ciuchi, L. Maiani, ADP, V. Riquer, G. Ruocco, M. Vignati, EPJC (2012) 72:2193
L. Maiani, ADP in preparation (on Sommerfeld enhancement)
Acknowledged discussions with F. Guerra and M. Testa

PART II: DESCRIPTION OF THE PLASMA DISCHARGE EXPERIMENT AT ENEA

Work done with **ENEA** staff: M. Angelone, E. Castagna, S. Lecci, A. Pietropaolo, M. Pillon, M. Sansovini, F. Sarto, V. Violante
INFN-Frascati Staff: R. Bedogni, A. Esposito
and **Sapienza**: R. Faccini, A. Pilloni, ADP

See arXiv:1310.4749

1ST EXAMPLE: NEUTRONS IN LIGHTENINGS

PRL **111,** 115003 (2013) PHYSICAL REVIEW LETTERS week ending 13 SEPTEMBER 2013

Observation of Neutron Bursts Produced by Laboratory High-Voltage Atmospheric Discharge

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For the first time the emission of neutron bursts in the process of high-voltage discharge in air was observed. Experiments were carried out at an average electric field strength of $\sim 1\ \mathrm{MV \cdot m^{-1}}$ and discharge current of ~ 10 kA. Two independent methods (CR-39 track detectors and plastic scintillation detectors) registered neutrons within the range from thermal energies up to energies above 10 MeV and with an average flux density of $\gtrsim 10^6\ \mathrm{cm^{-2}}$ per shot inside the discharge zone. Neutron generation occurs at the initial phase of the discharge and correlates with x-ray generation. The data obtained allow us to assume that during the discharge fast neutrons are mainly produced.

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10 MEV!! NEUTRONS IN LIGHTENINGS

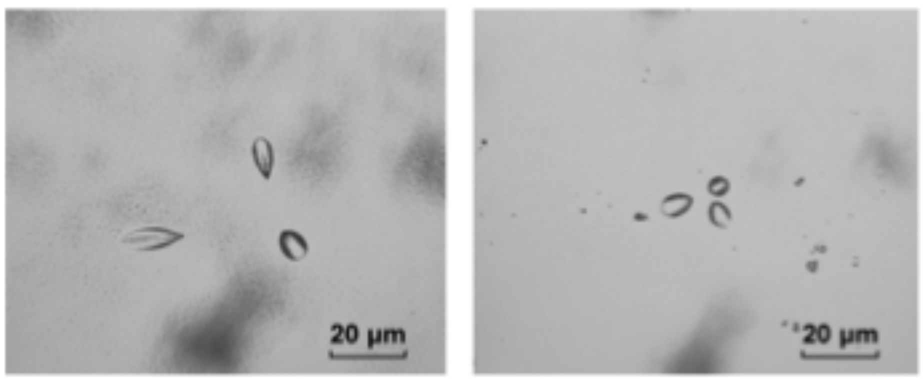


FIG. 4. Typical photomicrographs of the events of ^{12}C nucleus desintegration into three α particles (the size of the image is $130 \times 100\ \mu m^2$).

Conclusion.—For the first time in a laboratory experiment during high-voltage atmospheric discharge neutron emission was observed. The energies of neutrons within the range from thermal up to fast are detected; the contribution of fast neutrons in the total flux is a significant part. It should be emphasized that neutron emission occurs at the very beginning of the discharge and is strongly correlated with x-ray radiation. No neutron pulses were observed out of the x-ray pulse. The fast neutron flux drops exponentially and more slowly than $1/r^2$ with distance from the first CR-39 detector. The observed deviation may be explained as a case of a nonlocal neutron source distributed inside the anode-cathode gap.

To clarify the source of the observed neutrons and the spatial domain of its emission requires further experimental investigation. In order to carry out the needed neutron energy spectrum measurements, a search for the locus or loci of the neutron emission should be done. These observation require a precision time-of-flight technique using additional neutron detectors based on ^3He and ZnS counters, and partial shielding of discharge area, and the application of different moderators and converters for increasing the neutron flux sensitivity in the different energy ranges. It is also important to perform measurements of possible neutron emission anisotropy. On the other hand, any influence of average and local electric fields and atmospheric parameters must be shown.

Currently, there is no reasonable model or mechanism to explain the generation of neutron bursts during atmospheric discharge in air. A special mystery is the origin of the neutrons with energies above 10 MeV.

LENR are never mentioned in this paper, but neutrons in lightenings are very much mentioned in LENR people talks.

2ND EXAMPLE: TI FRACTURES & PIEZONUCLEAR REACTIONS

Titanium fracture yields neutrons?

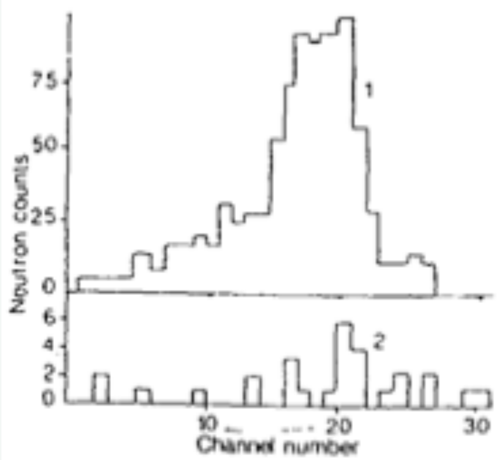
SIR—In recent experiments[1,2], we showed that violent mechanical action on heavy ice and lithium deuteride lead to neutron emission at levels substantially above the background, indicating the occurrence of d–d nuclear reactions. Because of current interest in the possibility of d–d reactions as a result of saturating titanium and palladium with deuterium[3,4], we felt that a test of mechanical agitation of titanium in the presence of deuterium was warranted.

Titanium chips of technical purity were tested in conjunction with heavy water, deuterated polypropilenium (PP) and lithium deuteride. Ti chips were put in a vibromill, operated at 50 Hz and with an amplitude of 5 mm (the power applied was ~ 10 W g^{-1}). Two-thirds of the volume of the vibromill drum was filled with steel balls 6 mm in diameter[5,6], the remaining one-third comprising Ti chips and deuterated material. In control experiments, finely crushed Ti chips were used separately, as well as D_2O and $PP(D_4)$.

Our neutron detector was a block of seven proportional counters, immersed in a tank of oil and covered with cadmium sheet, placed 15 cm from the vibromill drum. Detector counts were brought out to an AI-256-6 analyser. Detector efficiency was measured using a source of 200 neutrons s^{-1} intensity placed in the vibromill drum (curve 1 in the figure), and at regular intervals the neutron background was measured by removing the operating drum to a large distance.

In our experiments, neither Ti chips nor deuterium containing compounds showed a neutron signal above background (0.05 counts s^{-1}) when put separately in the drum, but when Ti chips were combined with 10% heavy water or 4–5% $PP(D_4)$, or with both, a neutron flux 6–7 times background (0.31 ± 0.13 counts s^{-1}, taking detector efficiency into account) was measured, as indicated in curve 2 in the figure, which shows the results from Ti + 10% D_2O + 4 % $PP(D_4)$. A constant excess over background was measured for 10 minutes, with a subsequent attenuation after crushing of the chips was stopped. The greatest effect (0.41 ± 0.14 counts s^{-1}) was measured using 10% D_2O and 4% $PP(D_4)$ when the vibromill drum was cooled in liquid nitrogen after mechanical action was stopped. After three or four cycles of vibration, each lasting 3 minutes, neutron emission fell to the background level. Smaller effects (0.14 ± 0.02 counts s^{-1}) were found using LiD with $PP(D_4)$.

We conclude that d–d reactions occur when Ti particles in the drum are saturated with deuterium, perhaps as a result of deuterium diffusion through freshly created Ti surfaces produced by the fracturing[6]. At least 2 atoms of D per atom of Ti can be absorbed, and the lattice of Ti particles deforms by as much as 25% during this absorption[7]. So it is conceivable that absorbed deuterons can approach each other closely enough for fusion to occur. In addition, electric fields of up to 10^7 V cm^{-1} can be created by destruction of the crystal lattice, perhaps making d–d reactions more probable[8]. The increase of neutron counts with cooling in liquid nitrogen may indicate increased absorption of D, as it is known that cooling decreases the partial pressure of absorbed hydrogen or deuterium[7].



Histogram of neutron counts *versus* analyser channel for a calibrated neutron source (curve 1) and for Ti chips agitated with 10% D_2O and 4% $PP(D_6)$ (curve 2).

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1. Derjaguin, B. V., Kluev, V. A., Lipson, A. G. & Toporov, Yu. P. *Colloid J.* **48**, 12–14 (1986).
2. Kluev, V. A. *et al.* *J. tech. Phys. Lett.* **12**, 1333 (1986).
3. Jones, S. E. *et al.* *Nature* **338**, 737–740 (1989).
4. Fleischmann, M. *et al.* *J. electroanalyt. Chem.* **261**, 301–308 (1989), and erratum, **263**, 187–188 (1989).
5. Kuznetsov, V. A. *et al.* *Sov. Phys. Doklady* **299**, 1170–1174 (1988).
6. Heinicke, G. *Tribochemistry* (Akademie, Berlin, 1984).
7. *Transition Metal Hydrides* (ed. Muetterties, E. L.) (Dekker, New York, 1971).
8. Artsimovich, L. A. *Controlled Thermonuclear Reactions* (Phizmatgiz, Moscow, 1961).

Nature 1989

GOOGLING 'LENR'

The Politics delaying LENR

Cold Fusion LENR

E-Cat

The fusion revolution

Evidence that LENR is real

LENR Cars

LENR Cities

Is commercial LENR the real deal?

LENR Technology

Reactors for energy generation though LENR

LENR NASA

LENR Widom-Larsen Theory Portal: New Energy Times

ITALIAN POLITICIANS GOT INTERESTED…

Mostra rif. normativi

Legislatura 17 Atto di Sindacato Ispettivo n° 3-00406

Atto n. 3-00406

Pubblicato il 3 ottobre 2013, nella seduta n. 118

GIROTTO , SERRA , BOCCHINO , DE PIETRO - Al Ministro dell'istruzione, dell'università e della ricerca. -

Premesso che:

da circa 25 anni si conducono esperimenti con la cella elettrolitica di Fleischmann e Pons o con reattori basati su metalli di transizione (ad esempio in Italia il reattore al titanio-deuterio di Scaramuzzi, il reattore al nichel-idrogeno di Piantelli-Focardi; il reattore al costantana, lega nichel-rame, di Celani) nei quali è stata rilevata una produzione di eccesso di calore con densità di potenza elevatissime, superiori per ordini di grandezza a quelle delle ordinarie reazioni chimiche, esplosive incluse, quindi di grande potenzialità per le applicazioni energetiche;

l'elevata densità di potenza faceva annunciare, ai primi scopritori, di aver identificato ciò che avveniva nella cella: reazioni di fusione a temperatura ambiente, la "fusione fredda" (FF). Si tratta di un'affermazione in totale contrasto con le conoscenze acquisite e condivise nel mondo scientifico: l'American Physical Society (nel suo congresso di Baltimora del 1° maggio 1989), dopo solo venti giorni dalla pubblicazione dell'articolo di Fleischmann, Pons e Hawkins sul Journal of electroanalytical chemistry, dichiarava la scoperta di Fleischman e Pons una mera pretesa e, nel giro di due anni, la "fusione fredda" veniva bollata come "scienza patologica" dal mondo accademico;

alla condanna aveva attivamente contribuito il mondo accademico stesso e con la reiezione da parte delle riviste scientifiche degli articoli sulla FF, come lamentava già nel 1990 il premio Nobel Julian l'elevata densità di potenza faceva annunciare, ai primi scopritori, di aver identificato ciò che avveniva nella cella: reazioni di fusione a temperatura ambiente, la "fusione fredda" (FF). Si tratta di un'affermazione in totale contrasto con le conoscenze acquisite e condivise nel mondo scientifico: l'American Physical Society (nel suo congresso di Baltimora del 1° maggio 1989), dopo solo venti giorni dalla pubblicazione dell'articolo di Fleischmann, Pons e Hawkins sul Journal of electroanalytical chemistry, dichiarava la scoperta di Fleischman e Pons una mera pretesa e, nel giro di due anni, la "fusione fredda" veniva bollata come "scienza patologica" dal mondo accademico;

alla condanna aveva attivamente contribuito il mondo accademico stesso e con la reiezione da parte delle riviste scientifiche degli articoli sulla FF, come lamentava già nel 1990 il premio Nobel Julian Schwinger, e al Massachussets institute of technology (MIT) con attive campagne di denigrazione e falsificazione dei dati a favore della "fusione calda", come testimoniò in un suo libro del 1991 Eugene Mallove, caporedattore scientifico al MIT;

a parere degli interroganti l'ostilità nei confronti della FF, oltre che per la sua inspiegabilità nell'ambito delle teorie condivise, è perdurata negli anni principalmente per i seguenti motivi: le difficoltà nella riproducibilità degli esperimenti; la consolidata tendenza nel mondo della fisica a voler legittimare ciò che si debba ritenere scienza, atteggiamento indubitabilmente pre-galileiano ma funzionale, e con successo, ad orientare cospicui investimenti pubblici sui canali designati (un solo esempio tra i tanti: risulta agli interroganti che ammonta ad oltre 7 miliardi di euro il costo dell'esperimento sul bosone di Higgs); una tendenza dei militari a velare gli esperimenti di FF con la segretezza per motivi connessi all'innovazione nelle armi nucleari (ad esempio, compare solo nel 2002 il rapporto della U.S. Navy sugli esperimenti condotti nei loro laboratori nel periodo 1989-2002, quasi tutti con produzione di rilevanti "anomalie" termiche e di elio);

considerato che:

l'esperimento più citato dai fautori della FF come prova del carattere di reazione di fusione a temperatura ambiente - la replica nel 1998 presso lo Stanford research institute (SRI) dell'esperimento noto come "M4", realizzato da M. McKubre e altri nel 1994 sempre presso lo SRI - mentre conferma l'eccesso di energia ad alta densità nella forma di calore e la simultanea produzione di elio, è, paradossalmente, una prova sperimentale che la reazione nella cella elettrolitica non può essere una reazione di fusione a temperatura ambiente, con ciò postulando la necessità di una diversa teoria;

la nuova teoria avanzata negli ultimi anni da A. Widom, L. Larsen e Y. Srivastava (WLS) per interpretare vari fenomeni, tra i quali l'eccesso di potenza termica rilevato nella cella di Fleischmann e

OTHER SOURCES: DOD, NASA ...

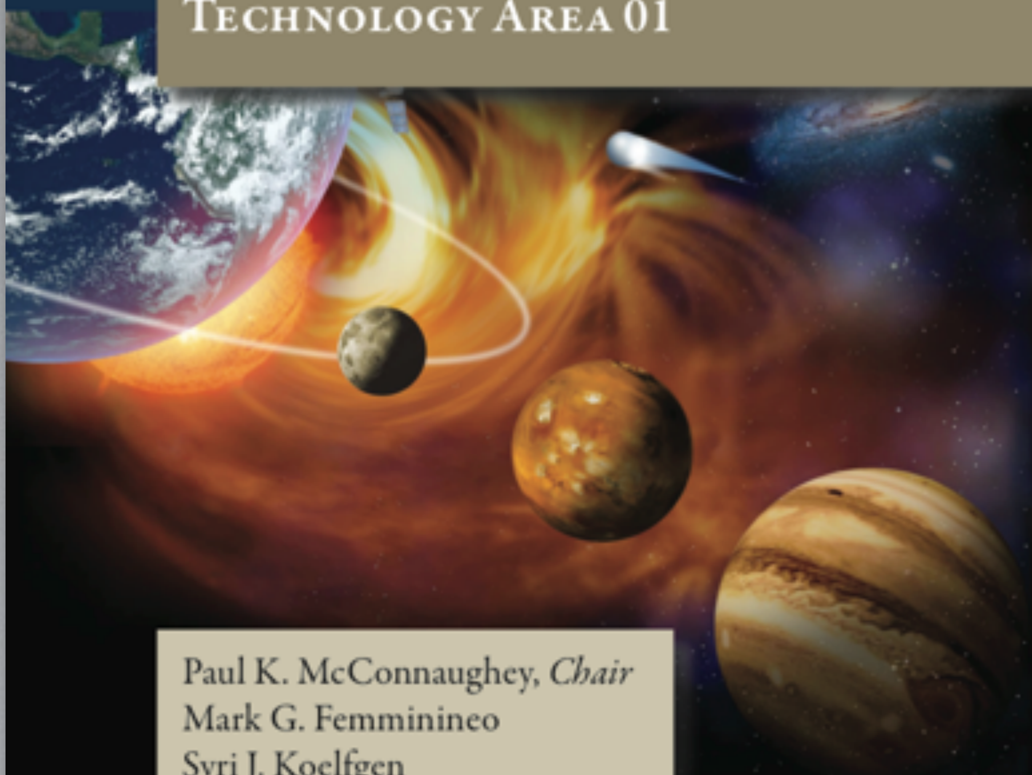
Department of Defense FY 2012 Budget Estimates (DARPA) Includes Budget for LENR

http://www.scribd.com/doc/100046879/Department-of-Defense-FY-2012-Budget-Estimates-DARPA-Includes-Budget-for-LENR

National Aeronautics and Space Administration

Launch Propulsion Systems Roadmap

Technology Area 01



Paul K. McConnaughey, *Chair*
Mark G. Femminineo
Syri J. Koelfgen
Roger A. Lepsch
Richard M. Ryan
Steven A. Taylor

April • 2012

Technology Investment	Description	TRL	Major Challenges	Path to TRL6
1.5.5 Nuclear - Using nuclear fission or fusion reactions for high propulsive performance.				
Advanced Solid Core Fission NTR	A nuclear thermal rocket (NTR) that uses an advanced solid-core nuclear fission reactor. The reactor employs fine alloy fibers arranged in a lattice for greatly improved heat transfer to the propellant and increased Isp (>1,000 sec) with reduced mass.	2	Lightweight, robust, high-temperature core with low pressure drop and high surface area. Radiation shielding. Accident hazard containment.	Core material and manufacturing R&D, rad shielding R&D, component tests, ground engine tests
Liquid & Gaseous Core Fission NTR	Thermal rockets that use liquid- or gaseous-core nuclear fission reactors. These would operate at very high temperatures, potentially enabling Isp of 3,000–5,000 sec.	2	Nuclear criticality, radiant heat transfer, and fuel containment. Radiation shielding. Accident hazard containment.	Analysis and lab testing, rad shielding R&D, component design and testing, sys grnd demo
Fusion NTR	A thermal rocket that uses a fusion reactor. Concepts for achieving clean aneutronic fusion include Inertial Electrostatic Confinement, Inertial Electrodynamic Fusion, and Dense Plasma Focus. Performance is generally similar to fission NTR.	2	Device size to achieve power break-even. Control of ion and electron feeds. Structure and cooling. Drive current/ voltage. Magnetic field drive (for IEF).	Scaled-up reactor tests, continuous reactor operations demo, component design and testing, sys grnd demo
External Pulsed Plasma	External pulses generated by successive detonations of nuclear material are used to generate propulsion by the action of plasma expanding against a pusher plate at the rear of the vehicle. (Isp of 5,000–10,000 sec).	2	Type of pulse unit, its degree of collimation, detonation position and fissile burn-up fraction. Pulse unit safety and loading. Pusher plate-plasma interaction.	Pulse unit R&D, detonation testing, plasma interaction tests, subscale flight demo
Low-Energy Nuclear Reactions NTR	A thermal rocket that uses a reactor that operates on Low Energy Nuclear Reactions (LENR), a form of "cold fusion." Performance would be similar to other NTR approaches, but without the radiation hazards.	1	Development and validation of underlying LENR predictive theory. Demonstration of controlled reactions.	LENR process research, experimentally initiate and control LENR, component design and testing, sys grnd demo
Nuclear-based Combined Cycle	The energy from nuclear reactions is applied in a combined cycle propulsion system with both air-breathing and rocket modes of operation. Specific impulse values in air-breathing mode are essentially infinite.	2	Challenges are similar to those of conventional TBCC and RBCC systems and advanced NTR, but include integration of a nuclear reactor into an air-breathing flow path.	Analysis and lab testing (including wind tunnel tests), rad shielding R&D, component design and testing, sys grnd demo, flight demo
1.5.6 High Energy Density Materials/Propellants – Propellants or materials that contain considerably higher stored energy per mass than conventional chemical propellants				
Polynitrogen	New liquid or solid compounds of nitrogen, such as N_x or N_y, which release very high energy upon decomposition into N_2 molecules, potentially enabling I_{sp} of 350–500 sec.	2	Stability/shock sensitivity, production, and storage.	Formulation R&D, production R&D, stability tests, propulsion demos
Nanopropellants	Propellants with embedded nanoscale particles of combustible material (e.g. aluminum powder), providing greater reactive surface area and energy.	2	Controlled energy release. Consistently reproducible properties.	Production R&D, combustion/ stability tests, propulsion demos
Atomic and Metastable	Very high-energy propellants that contain atomic free-radicals or metastable forms of molecules, such as atomic hydrogen, metastable helium, and metallic hydrogen. Potential for I_{sp} > 2,000 sec.	2	Stability/shock sensitivity, production, and storage.	Production R&D, energy release and stability tests, propulsion demos

3. INTERDEPENDENCY WITH OTHER TECHNOLOGY AREAS

The launch vehicle propulsion technology area has many interdependencies and synergies with many of the other technology areas. (If a TA is not listed, no significant interdependency was identified.) Among them are:

In-Space Propulsion – Most of the fundamental tools, rocket propulsion, and nonrocket (tether) propulsion systems have direct synergy with the in-space propulsion area. This is particularly true for launches from planetary surfaces, including bodies with atmospheres, both for robotic sample return and for safe and assured return of humans. Many of the technology challenges facing launch vehicle propulsion systems are common to the ones facing this TA.

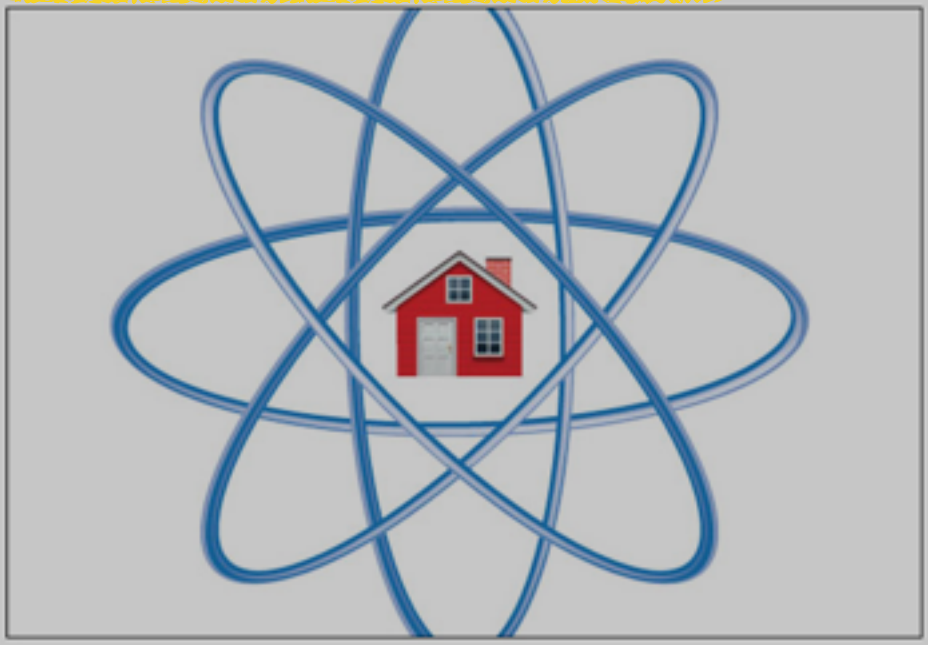
Space Power and Energy Storage Systems – There are several propulsion systems like beamed energy that use high-power electrical storage and distribution systems, which are synergistic with this TA. Nuclear propulsion systems are also considered synergistic with this TA in the area of power generation.

GLOBAL CLIMATE CHANGE

Vital Signs of the Planet

ENERGY INNOVATIONS

The nuclear reactor in your basement



February 12, 2013

By Bob Silberg,
NASA Jet Propulsion Laboratory

How would you like to replace your water heater with a nuclear reactor? That's what Joseph Zawodny, a senior scientist at NASA's Langley Research Center, hopes to help bring about. It would tap the enormous power of the atom to provide hot water for your bath, warm air for your furnace system, and more than enough electricity to run your house and, of course, your electric car.

If your thoughts have raced to Fukushima or Three Mile Island or Chernobyl, let me reassure you. Zawodny is not suggesting that you put that kind of reactor in your house. What he has in mind is a generator that employs a process called Low-Energy Nuclear Reactions. (The same process is sometimes called Lattice Energy Nuclear Reactions. We'll just call it LENR.)

So what is LENR and how might it one day fill all your energy needs without risk of blowing up, melting down, or irradiating the neighbors?

Nuclear energy in a nutshell

A few nuclear nuggets

To understand what this is all about, let's review a few nuggets about the atom that you'll want to keep in mind:

1. An atom consists of a nucleus (one or more protons and, usually, one or more neutrons) around which one or more electrons orbit.

2. Protons have a positive charge, while neutrons have no charge. All nuclei therefore have a positive charge, so they tend to repel each other.

3. The number of protons in a nucleus determines which element it is.

4. Isotopes are versions of an element which differ by the number of neutrons in their nuclei. A group of atoms which all have the same number of protons but different numbers of neutrons is a group of isotopes of the same element.

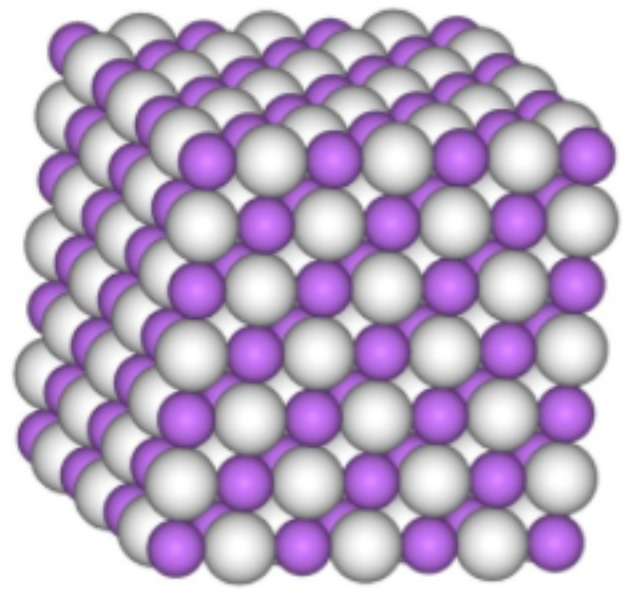
5. Different isotopes have different levels of stability. Some last for billions of years, others decay into more stable isotopes in a tiny fraction of a second.

Related resources

Dennis Bushnell's article, "Low Energy Nuclear Reactions, the Realism and

The epiphany

"For NASA Langley," according to Bushnell's article, "the epiphany moment on LENR was the publication of the Widom-Larsen Weak Interaction LENR Theory," which was published in 2006. According to Zawodny and Bushnell, this theory provides a better explanation than "cold fusion" for the results which researchers have obtained over the last couple of decades. And it might explain much more than that. At a meeting of the American Nuclear Society in November 2012, the theory's co-developer, Lewis Larsen, speculated that LENR may occur naturally in lightning—not only on present-day Earth, but also in the primordial cloud of gas and dust that became our solar system. If true, LENR might solve a mystery uncovered by NASA's Genesis mission, that the pattern of oxygen isotopes on the sun differs greatly from that of Earth.



In theory, a metal (gray) holding hydrogen ions (purple) as a sponge holds water (called a metal hydride) can provide one potential fuel for LENR.

The theoretical underpinnings of LENR are complex, but the basics are pretty easy to understand. Instead of splitting an atomic nucleus apart or ramming two mutually repelling nuclei together, Widom-Larsen's LENR simply offers a very slow-moving neutron to a nucleus. According to Zawodny, nuclei presented with sluggish neutrons slurp them up like a hungry Texan with a bowl of firehouse chili. But like many a chili consumer, the nuclei can find that their indulgence makes them, shall we say, unstable. And while I am too polite to continue the chili metaphor past this point, the nuclei do find that emissions relieve their distress.

With rare exception, Zawodny said, a nucleus which has lapped up one too many neutrons spits out an electron, which it gets by breaking up one of its neutrons into an electron and proton (and an anti-neutrino, but we can ignore that). So where it once had an extra neutron, making it an unstable isotope of whatever element it was, it now has an extra proton instead, which makes it a more stable isotope of a different element. This process releases energy which, hypothetically, can be used to generate electricity.

THE BASICS OF WIDOM-LARSEN THEORY

- Surface electron masses are shifted upwards by localized condensed matter electromagnetic fields (effective mass). In particular '*the collective motions of the surface (metallic hydride) protons produce the oscillating fields that renormalize the electron mass*' [...] '*highly loaded palladium hydrides present a full proton layer on the hydride surface oscillating with some frequency* $\boldsymbol{\Omega}$'.

- $\mathbf{e}^- + (A,Z) \longrightarrow (A,Z-1) + \nu_e$ (where $m(\mathbf{e}^-) > m(e^-)$)

  A process of this kind is known to occur when muons are mixed into hydrogen systems, otherwise we need $m(\mathbf{e}^-) > m(n) - m(p) \simeq 1.29$ MeV $\simeq 2.5\, m(e)$

SOME IMMEDIATE QUESTIONS

- Do we need an external source to stimulate oscillations? For example a LASER source. (If not, the material should eventually loose its capacity to dress the electrons masses).
- Should we expect an output neutron flux? Sometimes one reads that the ultracold neutron flux are just trapped in the material. Sometimes they are supposed to be able to escape, as in 'plasma discharge experiments'.
- Never seen a discussion on the expected neutron spectra. Theory should give some indication on neutron spectra to guide experimental searches for neutron detection depending on the energy spectrum.
- Emissions of gamma and/or X? The authors claim NO. They are expected to be captured (??) by (heavy) plasma electrons which radiate back in the IR.

HOW TO EXTRACT SOME ENERGY

Suppose that an initial concentration of lithium-6 is employed (near a suitable metallic hydride surface). The existence of weak interaction produced neutrons allows the following chain [from their papers]

$$n + {}^{6}_{3}\mathrm{Li} \rightarrow {}^{7}_{3}\mathrm{Li}$$

$$n + {}^{7}_{3}\mathrm{Li} \rightarrow {}^{8}_{3}\mathrm{Li}$$

$${}^{8}_{3}\mathrm{Li} \rightarrow {}^{8}_{4}\mathrm{Be} + e^{-} + \bar{\nu}_e$$ contributes ~16 MeV

$${}^{8}_{4}\mathrm{Be} \rightarrow 2\,{}^{4}_{2}\mathrm{He}$$

$$Q(2n + {}^{6}_{3}\mathrm{Li} \rightarrow 2\,{}^{4}_{2}\mathrm{He} + e^{-} + \bar{\nu}) \approx 27 \text{ MeV}$$

A nuclear reaction cycle is obtained considering the chain

$$n + {}^{4}_{2}\mathrm{He} \rightarrow {}^{5}_{2}\mathrm{He}$$

$$n + {}^{5}_{2}\mathrm{He} \rightarrow {}^{6}_{2}\mathrm{He}$$

$${}^{6}_{2}\mathrm{He} \rightarrow {}^{6}_{3}\mathrm{Li} + e^{-} + \bar{\nu}_e$$

$$Q(2n + {}^{4}_{2}\mathrm{He} \rightarrow {}^{6}_{3}\mathrm{Li} + e^{-} + \bar{\nu}_e) \approx 3 \text{ MeV}$$

What about the energy needed to produce all these neutrons?

SOME COMMENTS ON THE EFFECTIVE MASS
(*SEMI-QUALITATIVE* CONSIDERATIONS)

ELECTRON IN A PLANE WAVE AND M*

$$\left(\partial_\mu S + \frac{e}{c} A_\mu\right)\left(\partial^\mu S + \frac{e}{c} A^\mu\right) = m^2 c^2$$

Canonical Momentum $$P_\mu = -\partial_\mu S = p_\mu + \frac{e}{c} A_\mu(\xi)$$

Find the integral in the form $$S = -f_\mu x^\mu + F(\xi)$$ in such a way that $f^0>0$

$$\xi = k \cdot x$$

$$f^2 = m^2 c^2$$

A solution for F can be found as a function of xi. Differentiating *S* w/ respect to *x* one obtains the Canonical Momentum P, and, subtracting A, the Kinetic momentum ($\gamma = k.f$)

$$p_\mu = f_\mu - \frac{e}{c} A_\mu + \frac{e}{c\gamma}(f \cdot A) k_\mu - \frac{e^2}{2c^2\gamma} A^2 k_\mu$$

If we square this quantity (a *sanity check*) we simply get the standard dispersion relation $p^2=m^2c^2$

$$E^2 - \boldsymbol{p}^2 c^2 = m^2 c^4$$

Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces

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Published online: 9 March 2006 –

Abstract. 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 that 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. 24.60.-k; 23.20.Nx

1 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]

$$l^- + p^+ \to n + \nu_l . \qquad (1)$$

A common form of nuclear transmutation in condensed matter is understood in terms of (1). An electron e^- that wanders into a nucleus with Z protons and $N = A - Z$ neutrons can be captured, producing an electron neutrino ν_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]

$$e^- + (A, Z) \to (A, Z-1) + \nu_e . \qquad (2)$$

Note the absence of a Coulomb barrier to such a weak interaction nuclear process. It is this feature that makes the neutron induced nuclear transmutations more likely than other nuclear reactions that are impeded by Coulomb bar-

protons at virtual rest. For (1) to spontaneously occur it is required that the lepton mass obey a threshold condition,

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

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]

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

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 $M_e \to \tilde{M}_e$ according to a previously established rule [7, 8]

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

THE WL EFFECTIVE MASS

In other words the **WL recipe** is: start from

$$p_\mu = f_\mu - \frac{e}{c} A_\mu + \frac{e}{c\gamma}(f \cdot A) k_\mu - \frac{e^2}{2c^2\gamma} A^2 k_\mu$$

Average over fields fluctuations setting <*A*>=*0* in such a way to be left with

$$\overline{p}_\mu = f_\mu - \frac{e^2 \overline{A^2}}{2c^2 (f \cdot k)} k_\mu$$

Defining

$$\overline{p}_\mu \overline{p}^\mu = m^{*2} c^2$$

WL obtain (set c=1)

$$m^* = m \sqrt{1 - \frac{e^2}{m^2 c^4} \overline{A^2}}$$

…a *non-gauge invariant quantity*. In such a way WL deduce that the effective mass can be as large as $20m_e$ by working on the <A^2> value

$m^* = \beta m$ with β as large as 20!

BUT, on the timescales over which the actual weak interaction process occurr should we really use <p> instead of the instantaneous p?

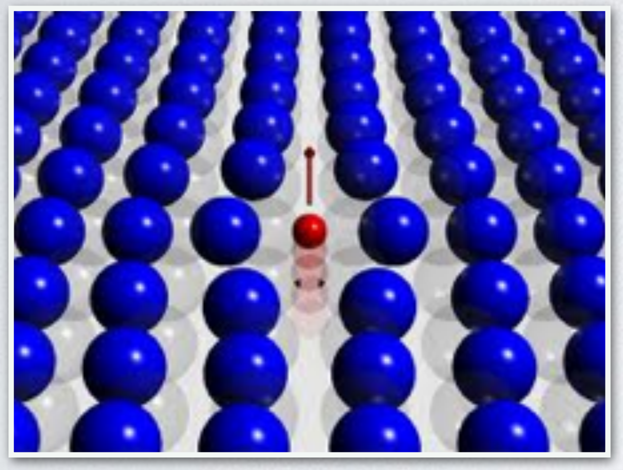
ANOTHER EXAMPLE: THE POLARON

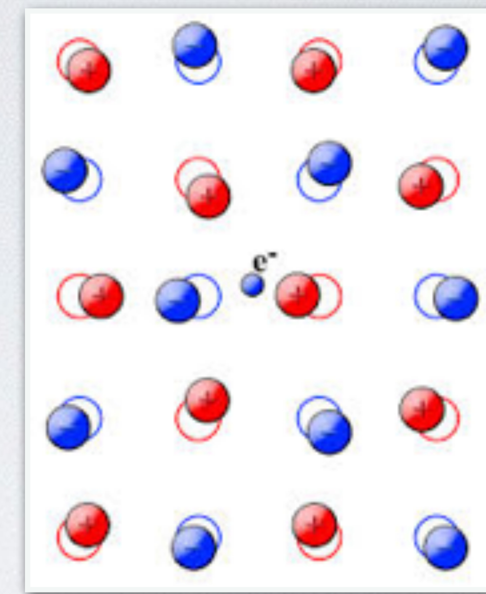
$$H = \frac{\boldsymbol{p}^2}{2} + \sum_{\boldsymbol{k}} a^\dagger_{\boldsymbol{k}} a_{\boldsymbol{k}} + i\alpha \sum_{\boldsymbol{k}} \frac{1}{k}\left(a^\dagger_{\boldsymbol{k}} e^{-i\boldsymbol{k}\cdot\boldsymbol{x}} - a_{\boldsymbol{k}} e^{i\boldsymbol{k}\cdot\boldsymbol{x}}\right)$$

e- potential energy due to lattice vibrations

$\boldsymbol{x}$ electron position

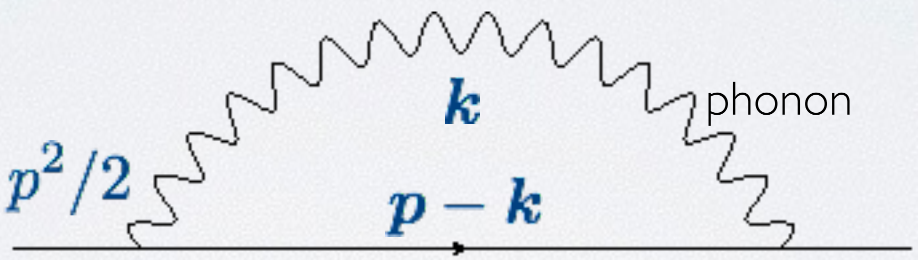
$\boldsymbol{k}$ phonon momentum





$$\Delta E_0 = H'_{00} + \sum_n \frac{H'_{0n} H'_{n0}}{E^0_0 - E^0_n} + \ldots$$

$$E^0_0 = p^2/2$$



$$E^0_n = (\boldsymbol{p} - \boldsymbol{k})^2/2 + 1$$

$m = 1$ and $\omega = 1$

$$E = \frac{\boldsymbol{p}^2}{2} + \Delta E_0 \approx \frac{\boldsymbol{p}^2}{2} - \beta - \beta\,\frac{\boldsymbol{p}^2}{12} + \ldots = \frac{\boldsymbol{p}^2}{2(1+\beta/6)} - \beta + \ldots$$

For small values of p

Read the effective mass from here

$$\beta = \frac{\alpha}{\pi\sqrt{2}}$$

Depends on static and h.f. dielectric constants of the crystal
(and $\omega=\omega(k\to 0)$ assumed independent of k)

COMMENTS ON THE NEUTRON PRODUCTION RATE (*QUANTITATIVE* CONSIDERATIONS)

HOWEVER, LET US ALLOW AN EFFECTIVE MASS

An order of magnitude estimate can already be derived from a four fermion weak interaction model presuming a previously discussed [12] electron mass renormalization $m \to \tilde{m} = \beta m$ due to strong local radiation fields. Surface electromagnetic modes excited by large cathode currents can add energy to a bare electron state e^- yielding a mass renormalized heavy electron state $\tilde{e}^-$, with

$$\tilde{m} = \beta m. \quad (7)$$

The threshold value for the renormalized electron mass which allows for the reaction Eqs.(1) and (2) is

$$\beta > \beta_0 \approx 2.531. \quad (8)$$

For a given heavy electron-proton pair $(\tilde{e}^- p^+)$, the transition rate into a neutron-neutrino pair may be estimated in the Fermi theory by

$$\Gamma_{(\tilde{e}^- p^+)\to n+\nu_e} \sim \left(\frac{G_F m^2}{\hbar c}\right)^2 \left(\frac{mc^2}{\hbar}\right) (\beta - \beta_0)^2,$$

$$\Gamma_{(\tilde{e}^- p^+)\to n+\nu_e} \sim 9 \times 10^{-24} \left(\frac{mc^2}{\hbar}\right) (\beta - \beta_0)^2,$$

$$\Gamma_{(\tilde{e}^- p^+)\to n+\nu_e} \sim 7 \times 10^{-4}\ \mathrm{Hz} \times (\beta - \beta_0)^2, \quad (9)$$

If there are $n_2 \sim 10^{16}/\mathrm{cm}^2$ such $(\tilde{e}^- p^+)$ pairs per unit surface area within several atomic layers below the cathode surface, then the neutron production rate per unit

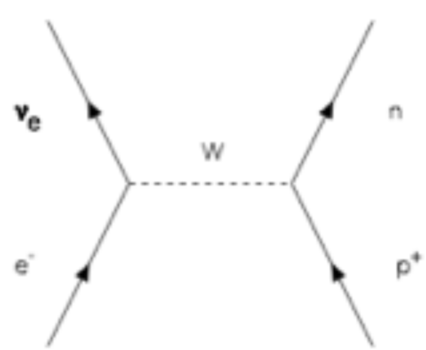


FIG. 1: A low order diagram for $e^- + p^+ \to n + \nu_e$ in the vacuum is exhibited. In condensed matter metallic hydrides, the amplitude must include radiative corrections to very high order in α.

Widom & Larsen nucl-th/0608059

Putting the constants at their place

$$\Gamma_{WL}(ep \to n\nu_e) = \frac{(G_F m^2)^2}{2\pi^2}(1+3\lambda^2) m (\beta - \beta_0)^2$$

PHSP

$$\lambda = g_A/g_V \approx 1.25 \text{ and } \cos\theta_C \approx 1$$

Something was missing here: *the probability weight of finding the e- and p at the same point!* A mandatory consequence of the Fermi Lagrangian

$$\Gamma(ep \to n\nu_e) = |\psi(0)|^2 \times v\sigma =$$

$$= |\psi(0)|^2 \times \frac{(G_F m)^2}{2\pi}(1+3\lambda^2)(\beta - \beta_0)^2$$

Fermi NP VIII 9'

Similar formula for the annihilation of e^-e^+ into photons

Recall: if $\beta < \beta_0$ the process is forbidden.

S. Ciuchi et al. EPJC (2012) 72:2193

RATE OF NEUTRON PRODUCTION

We can rewrite (Ciuchi, Maiani, Polosa, Riquer, Ruocco, Vignati, EPJ**C**2012, 72:2193)

$$\Gamma(\boldsymbol{ep} \to n\nu_e) = \alpha^3 \frac{(G_F m^2)^2}{2\pi^2}(1+3\lambda^2)m\, \beta^3\, (\beta-\beta_0)^2$$

where we used
$$|\psi(0)|^2 = \frac{1}{\pi(a^*)^3} = \frac{\beta^3}{\pi a^3}$$
and $a = 1/(\alpha m) = 0.54$ Å

The β^3 cubic factor is an enhancement with respect to WL but it has to be confronted with $\boldsymbol{\alpha}^3$!

Consider that
$$\Gamma_{WL}(\boldsymbol{ep} \to n\nu_e|\beta = 20) = 0.56 \text{ Hz}$$

whereas
$$\Gamma(\boldsymbol{ep} \to n\nu_e|\beta = 20) = 1.8 \times 10^{-3} \text{ Hz}$$
$$\Gamma(\boldsymbol{ep} \to n\nu_e|\beta = 2\beta_0 = 5.2) = 6.9 \times 10^{-7} \text{ Hz}$$
$$\ldots$$

A beta of 61 is needed to recover the numerical value of WL; this means an electron with 30 MeV !

FREE ELECTRONS??

The reason for considering the potentially *active* electrons (dressed) as those bound in atoms was that of enhancing the WL effect at its highest possible values. Otherwise what is the flux of incident (dressed) electrons? Recall that we have to confront with weak interactions xsects:

$$\sigma(\boldsymbol{e}^- + p \to \nu + n) \simeq 10^{-41}\ \mathrm{cm}^2$$

Consider 10 MeV electrons (??) with v~0.1 (to use a WLS number) the rate is

$$\Gamma = \rho\, v \times \sigma$$

e^- flux on a single proton

Suppose the material is as thick as L, then

$$\rho(1/\mathrm{cm}^3) \times L(\mathrm{cm}) = 10^{16}/\mathrm{cm}^2$$

assumed in WL

and we would get

$$\Gamma(L = 10\mu\mathrm{m}) = 10^{-13}\ \mathrm{Hz}$$

$$\Gamma(L = 1\text{Å}) = 10^{-8}\ \mathrm{Hz}$$

$$\ldots$$

to be compared with $\boldsymbol{\Gamma}$~0.5 Hz

Weak Interaction Neutron Production Rates in Fully Ionized Plasmas

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Employing the weak interaction reaction wherein a heavy electron is captured by a proton to produce a neutron and a neutrino, the neutron production rate for neutral hydrogen gases and for fully ionized plasmas is computed. Using the Coulomb atomic bound state wave functions of a neutral hydrogen gas, our production rate results are in agreement with recent estimates by Maiani *et al.* Using Coulomb scattering state wave functions for the fully ionized plasma, we find a substantially enhanced neutron production rate. The scattering wave function should replace the bound state wave function for estimates of the enhanced neutron production rate on water plasma drenched cathodes of chemical cells.

PACS numbers: 24.60.-k, 23.20.Nx

I. INTRODUCTION

In years past we have been working on weak interaction inverse beta decay[1-3] including electromagnetic interactions with collective plasma modes of motion. Our considerations have been recently criticized[4]. Our neutron production rate[1, 2] is a factor of ~ 300 larger than that of Maiani[4]. Our purpose is to point out the source of this difference so that the physical principles may be resolved.

In Sec II, the calculation of neutron production for a neutral plasma of Ciuchi *et al*[4] is briefly reviewed. Since the surface plasmas of hot cathodes within which neutron production is observed[3] are fully ionized, the neutral atomic gas case is not relevant. The irrelevant two body wave function[4] employed for the neutral gas case should be replaced by the two body Coulomb wave function relevant to the fully ionized plasma. This is the usual fully ionized plasma situation, for example, in the study of the weak interaction electron capture reactions

$$\text{(general)} \quad e^- + {}^A_Z X \to {}^{\ \ A}_{(Z-1)}X + \nu_e \ ,$$
$$\text{(special case)} \quad e^- + p^+ \to n + \nu_e \ , \qquad (1)$$

in solar[5] physics. Scattering Coulomb wave functions also enter laboratory high energy[6] physics. The case of the fully ionized plasma is discussed in Sec III. In Sec IV our previous neutron production estimates[1-3] are verified employing the scattering Coulomb wave function.

In the concluding Sec V we briefly indicate how collective many body interactions may modify the situation.

II. NEUTRAL GAS OF ATOMS

For a gas of neutral objects which consist of a heavy electron bound to a proton, the Coulomb wave function in the zero total momentum frame

$$\psi(\mathbf{r}) = \frac{e^{-r/a}}{\ldots} \ \ldots \ \frac{\hbar^2}{\ldots} \qquad (2)$$

wherein $\mathbf{r} = \mathbf{r}_{e^-} - \mathbf{r}_{p^+}$ and m is the reduced mass of the heavy electron. With the lowest order Fermi cross section for a heavy electron to scatter from a proton producing a neutron and a neutrino,

$$\bar{\nu} = v\sigma = \frac{c}{2\pi}\left(\frac{G_F m^2}{\hbar c}\right)^2 (g_V^2 + 3g_A^2) \times \left(\frac{\hbar}{mc}\right)^2 (\gamma^2 - \gamma^2_{Threshold}). \qquad (3)$$

If n denotes the number of bound neutral objects per unit volume, then the transition rate per unit time per unit volume to produce neutrons from the decay of the neutral objects

$$\varpi_0((e^- p^+) \to n + \nu_e) = n v\sigma |\psi_{e^- p^+}(0)|^2 \ ,$$
$$\varpi_0 = \left(\frac{n}{\pi a^3}\right) v\sigma = \left(\frac{n\bar{\nu}}{\pi a^3}\right). \qquad (4)$$

Up to this point we are in agreement with the comment of Ciuchi *et al*[4]. Our disagreement involves the more physical regime wherein the plasma is fully ionized. The particles are charged and not neutral and the wave function Eq.(2) chosen by Ciuchi *et al*[4] is thereby incorrect. The correct wave function is written below.

III. FULLY IONIZED PLASMA MODES

For a fully ionized plasma, the constituents of the plasma are the charged heavy electron and the proton. We seek the scattering state production of neutrons

$$e^- + p^+ \to n + \nu_e. \qquad (5)$$

The wave function factor $|\psi(0)|^2$ needed to include Coulomb attraction into the scattering is changed from the neutral plasma value $1/(\pi a^3)$. The positive energy $E = mv^2/2 = \hbar^2 k^2/2m$ scattering Coulomb wave

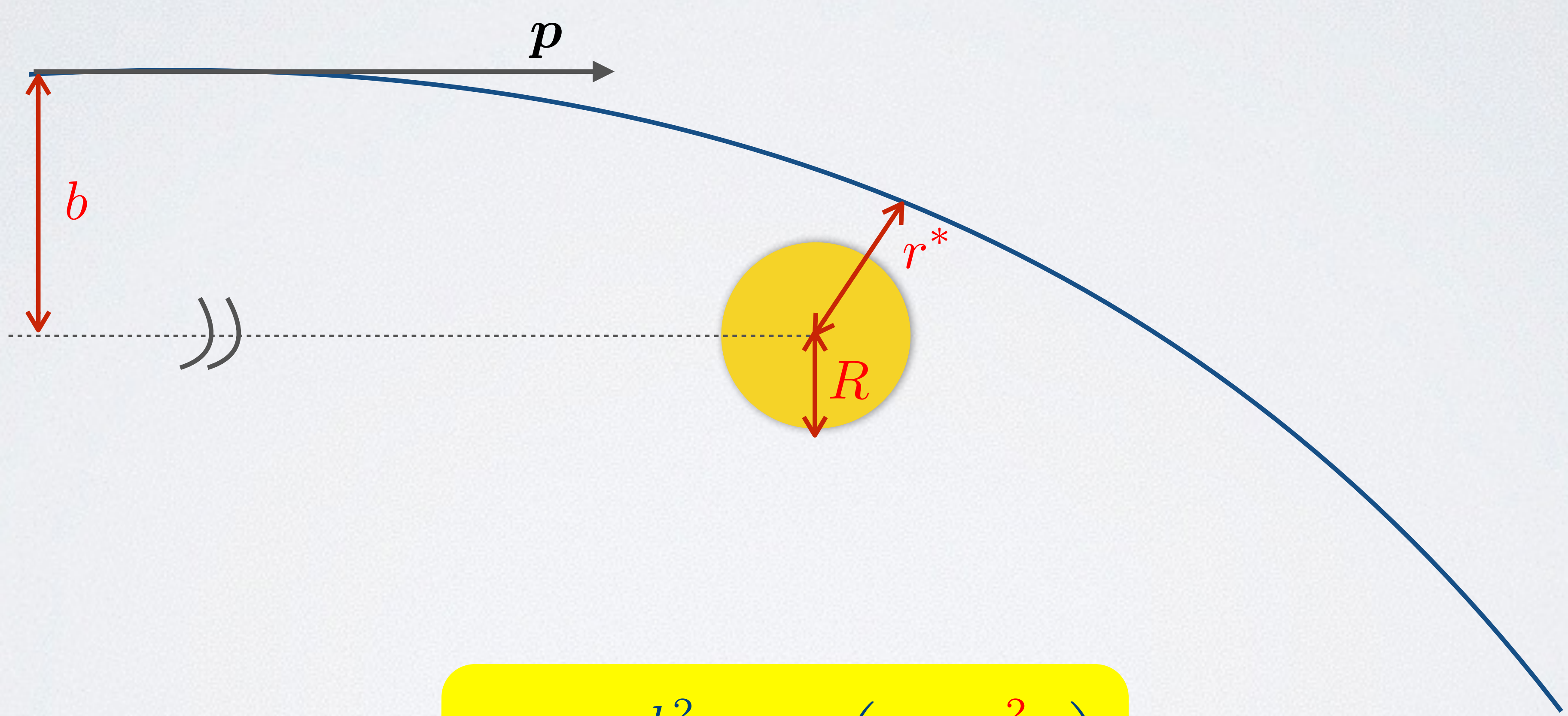
Plasma Regime

CLASSICAL SOMMERFELD ENHANCEMENT

$$E \equiv \frac{1}{2}mv^2 = \frac{L^2}{2mr^{*2}} - \frac{\alpha}{r^*} = \frac{mv^2b^2}{2r^{*2}} - \frac{\alpha}{r^*}$$

When $r^* = R$ then $b = b_{\text{max}}$

Recall $v_{\text{esc}} = \sqrt{2gR}$



$$\frac{\sigma}{\sigma_0} = \frac{\pi b_{\text{max}}^2}{\pi R^2} = \left(1 + \frac{v_{\text{esc}}^2}{v^2}\right)$$

QUANTUM SOMMERFELD E.: EXTRA 1 / V

Gamma function $\Gamma(z)$ and the confluent hypergeometric function ${}_1F_1(\xi;\zeta;z)$

$$\psi(\mathbf{r}) = e^{i\mathbf{k}\cdot\mathbf{r}}\left[e^{\pi/(2ka)}\Gamma\left(1-\frac{i}{ka}\right)\times {}_1F_1\left(\frac{i}{ka};1;\frac{kr-\mathbf{k}\cdot\mathbf{r}}{ka}\right)\right]. \quad (6)$$

If $r \to 0$, then

$$|\psi(0)|^2 = \frac{(2\pi e^2/\hbar v)}{1-exp(-(2\pi e^2/\hbar v))}. \quad (7)$$

The neutron production rate per unit time per unit volume is then

$$\varpi(e^- + p^+ \to n + \nu_e) = n^2 v\sigma|\psi(0)|^2 = n^2\bar{\nu}|\psi(0)|^2 ,$$
$$\varpi = \frac{2\pi\alpha c n^2\sigma}{1-exp(-2\pi c\alpha/v)} , \quad (8)$$

wherein $\alpha = e^2/\hbar c$.

IV. THE NEUTRON PRODUCTION RATIO

The ratio ϖ/ϖ_0 of the neutron production rates per unit time per unit volume can be deduced from Eqs.(4) and (8). Thermal averaging at a temperature small on the scale of the heavy electron mass $k_BT \ll mc^2$ yields[5] the transition rate per unit time per unit volume for producing neutrons

$$\eta = \frac{\varpi}{\varpi_0} = 2\pi^2\alpha n a^3\left\langle\frac{c}{v}\right\rangle,$$

$$\eta \approx 2\pi^2\alpha n a^3\sqrt{\frac{2mc^2}{\pi k_BT}} , \quad (9)$$

where n is the number of electrons per unit volume.

Previously[2] estimated temperatures of hydride cathodes $T \sim 5\times10^3\ {}^oK$ are in agreement with the observed hot color of their brightly light emitting surfaces[3]. The resulting neutron production as described by Eq.(9) is given by $\eta \sim 5\times10^2$ in rough agreement with our previous estimates[1-3]. The factor of ~ 300 discrepancy is thereby resolved.

V. CONCLUSION

Many body plasma effects on neutron production may be described by the correlations between the electron coordinates $(\mathbf{r}_1,\cdots,\mathbf{r}_N)$ and proton coordinates $(\mathbf{s}_1,\cdots,\mathbf{s}_N)$ as given by the correlation function

$$C = \frac{1}{N}\left\langle\sum_{i=1}^{N}\sum_{j=1}^{N}\delta(\mathbf{r}_i-\mathbf{s}_j)\right\rangle = n\xi \quad (10)$$

wherein $\xi = |\psi(0)|^2$ only if there are merely two body collisions in the plasma. Collective oscillations and many body collisions would tend to raise the value of ξ but require a many body Greens function analysis to include such effects in detail. However, previous discrepancies are now understandable.

We reiterate that at the level of dilute plasma two-body correlations dealt with in previous work[4], the order of magnitude of the discrepancy has herein been resolved.

[1] A. Widom and L. Larsen, *Eur. Phys. J.* **C 46**, 107 (2006).
[2] A. Widom and L. Larsen, arXiv:0608059v2 [nucl-th] 25 Sep 2007.
[3] D. Cirillo, R. Germano, V. Tontodonato, A. Widom, Y.N. Srivastava, E. Del Giudice, and G. Vitiello *Key Engineering Materials* **495**, 104 (2012); *ibid* 124 (2012).
[4] S. Ciuchi, L. Maiani, A. D. Polosa, V. Riquer, G. Ruocco and M Vignati *Eur. Phys. J.* **C72** , 2193 (2012).
[5] J.H. Bahcall, *Phys. Rev.* **128**, 1297 (1962).
[6] G. Bardina et. al., *Nuc. Phys.* **B411**, 3 (1994).
[7] S. Flüge, "*Practical Quantum Mechanics*", pp 290-293, Springer-Verlag, Berlin (1970).

> **1/v** additional enhancement (if v small)

BUT we are in a plasma, thus the field is not Coulomb but rather Yukawa type

$$V = -\frac{\alpha}{r} \to -\frac{\alpha}{r}e^{-m_D r}$$

COULOMB SCATTERING (IN VACUUM)

The Coulomb scattering Schrödinger equation can be solved analitically

$$\psi^+_{\boldsymbol{k}}(\boldsymbol{r}) = e^{\pi/2k}\Gamma(1-i/k)e^{i\boldsymbol{k}\cdot\boldsymbol{r}}F(i/k,1,ikr-i\boldsymbol{k}\cdot\boldsymbol{r})$$

which gives the low velocity enhancement (here Coulomb+natural units are used)

$$S \sim |\psi^+_{\boldsymbol{k}}(0)|^2 = \frac{2\pi}{k(1-e^{-2\pi/k})} \simeq \frac{2\pi}{k} = \frac{2\pi\alpha}{v}$$

and, since electrons are *not paired* to a single proton, a factor of n^2 appears

$$\Gamma_c(e^- + p \to n + \nu_e) = n^2|\psi(0)|^2 v\sigma \simeq 2\pi n^2\alpha\sigma$$

to be compared with the one of a bound electron (the wave function has different dimensions in the bound problem)

$$\Gamma_b(e^- + p \to n + \nu_e) = n|\psi(0)|^2 v\sigma = nv\frac{1}{\pi(a^*_B)^3}\sigma = nv\frac{1}{\pi a_B^3}\sigma\beta^3$$

giving

$$\frac{\Gamma_c}{\Gamma_b} \simeq 2\pi^2\alpha n a_B^3\ \frac{1}{\beta^3}\ \frac{1}{v}$$

WSS miss the beta factor

But do we really have the `vacuum` Sommerfeld enhancement in a plasma?

IN A PLASMA: DEBYE SCREENING

In a plasma

$$V = -\frac{\alpha}{r} \to -\frac{\alpha}{r} e^{-m_D r}$$

the maximum attainable Sommerfeld enhancement saturates to (in WKB approximation)

$$S_0 \sim \frac{1}{\varepsilon} = \frac{a}{a_B^*} = \frac{a}{a_B}\beta$$

Using densities like those quoted in Widom, Swain & Srivastava $n \sim 10^{20}$ cm^{-3} and

$$a = 3.7 \times 10^7 \left(\frac{T}{n}\right)^{1/2} \mathrm{eV}^{-1}$$

where T ~ 5 10^3 K we get

$$\frac{a}{a_B} \approx 9$$

thus obtaining

$$\frac{\Gamma_c}{\Gamma_b} \simeq \pi n a_B^3 \frac{1}{\beta^3} S_0 = \pi n a_B^3 \frac{1}{\beta^3} \frac{a}{a_B^*} = \pi (n a_B^3) \frac{a}{a_B} \frac{1}{\beta^2}$$

where we expect at maximum ($n a_B^3 \sim 1$): thus 10/400=**0.025** for beta=20! Very far from the claimed factor of **500**…

BUT EVEN WITH NO SCREENING...

Incidentally we note that the ratio computed by WSS does not contain beta

$$\frac{\Gamma_c}{\Gamma_b} \approx 2\pi^2 \alpha n a_B^3 \frac{1}{\beta^3} \sqrt{\frac{2m_e}{\pi T}} \approx 10^{-7}$$

does not yield 500! Even dropping beta, we are left with 10^{-3}

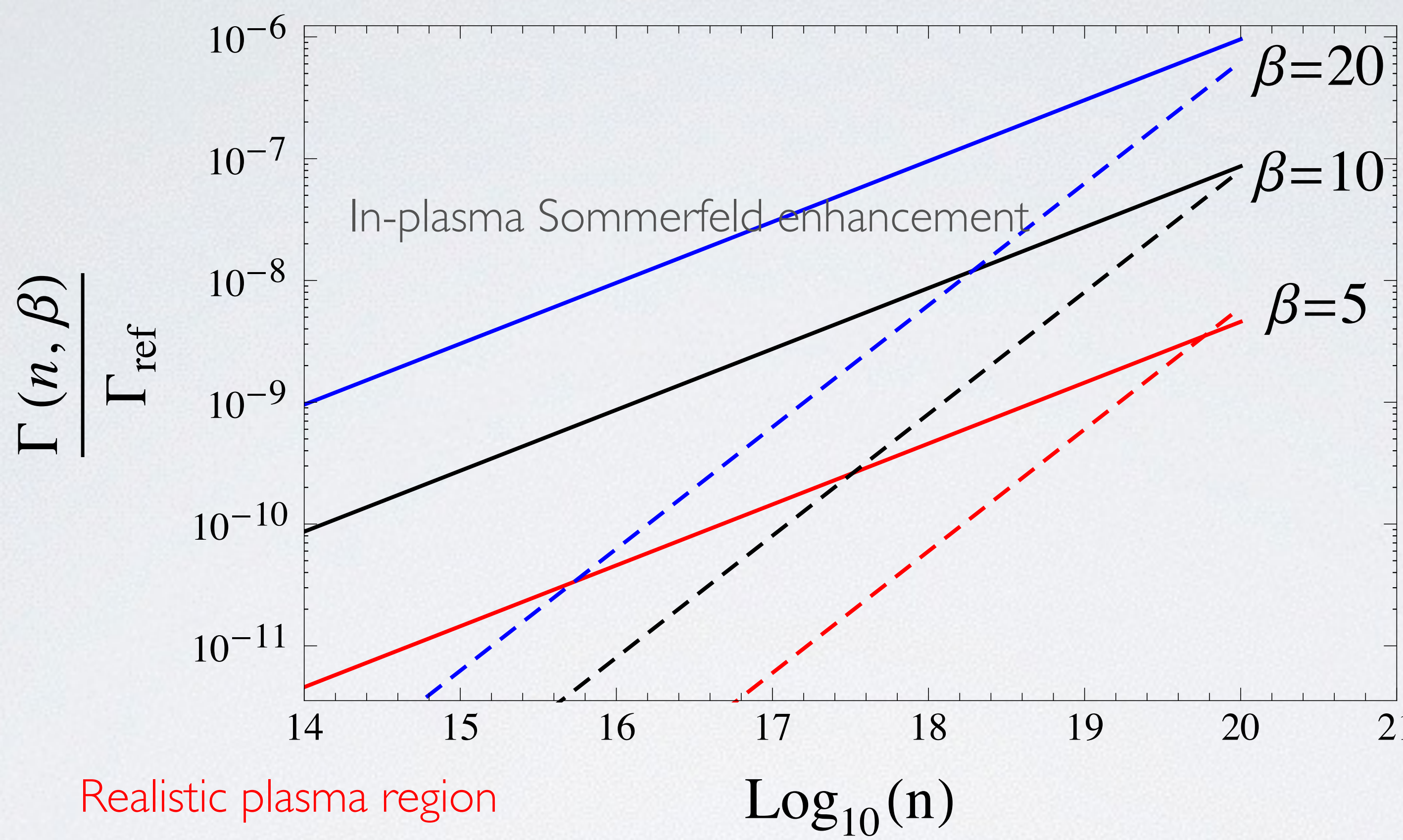
N.B. We notice that the WKB approximation *breaks down* for velocities

$$v \lesssim \alpha \, (a_B^*/a) = \alpha \, (a_B/a\beta)$$

Using $n \sim 10^{20}$ cm^{-3} we have $a/a_B \sim 10$ and beta=20, this means $v \sim 4 * 10^{-5}$ to be compared with the thermal velocity

$$v \simeq \sqrt{kT/m^*} = 3 \times 10^{-4}$$

MORE PRECISELY



Realistic plasma region

We indicate the points (arrows) where the rate is the WL claimed one, namely 0.56 Hz @ β=20. The density n is in cm^{-3} higher values are not realistic.

NEED AN EXPERIMENT

Erroneous Wave Functions of Ciuchi *et al* for Collective Modes in Neutron Production on Metallic Hydride Cathodes

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There is a recent comment [1] concerning the theory of collective many body effects on the neutron production rates in a chemical battery cathode. Ciuchi *et al* employ an inverse beta decay expression [illegible] are no metallic hydrides, there are no cathodes and there are no chemical batteries. Employing a wave function with only one electron and one proton is inadequate for describing collective metallic hydride surface quantum plasma physics in cathodes accurately.

PACS numbers: 24.60.-k, 23.20.Nx

I. INITIAL COMMENTS

In years past we have been working on weak interaction inverse beta decay while interacting with various collective modes of motion in condensed matter systems. Our considerations have been recently criticized [1]. The difference of opinion on the rate of neutron production in hydride battery cathodes has a brief history starting from a talk at Roma La Sapienza by Y. Srivastava cited by Ciuchi *et al* [1].

At this talk, a discussion arose where some of the authors of [1] mentioned disagreements with the results presented by YS by factors of 10^{40}, later reduced to a factor of 10^{20}. We pointed out that our estimates were based on an actual calculation of the collective process and di- [illegible] erse beta decay [illegible] tivate neutron [illegible] of that group [illegible] an internal re- [illegible] gh in our esti- [illegible] wards the goal [illegible] that they work [illegible] cess. As a re- [illegible] on production [illegible] *way down from*

[illegible] public the last [illegible] del that would [illegible] with theoreti- [illegible] is subject [2, 3] [illegible]. A complete discussion of the issues involved is under preparation and will be presented shortly.

II. DANGER IN THE NUMBERS

The Ciuchi *et al* team asserts that the factor of two or three orders of magnitude would render the inverse beta decay unobservable. Fortunately they *are completely incorrect* in this regard. There are experiments carried out by those in D. Cirillo *et al* [5] that reside in Naples. They have actually observed both nuclear transmutations and actual neutrons in hydride metallic battery cathodes. Even if our theoretical neutron counting rates were high by a factor of 300, then Cirillo *et al* could still and indeed did experimentally observe nuclear transmutations.

Ciuchi et. al. use our numbers from papers dealing with other applications but *not batteries*. For example, they start from neutron production rate with the time honored formula

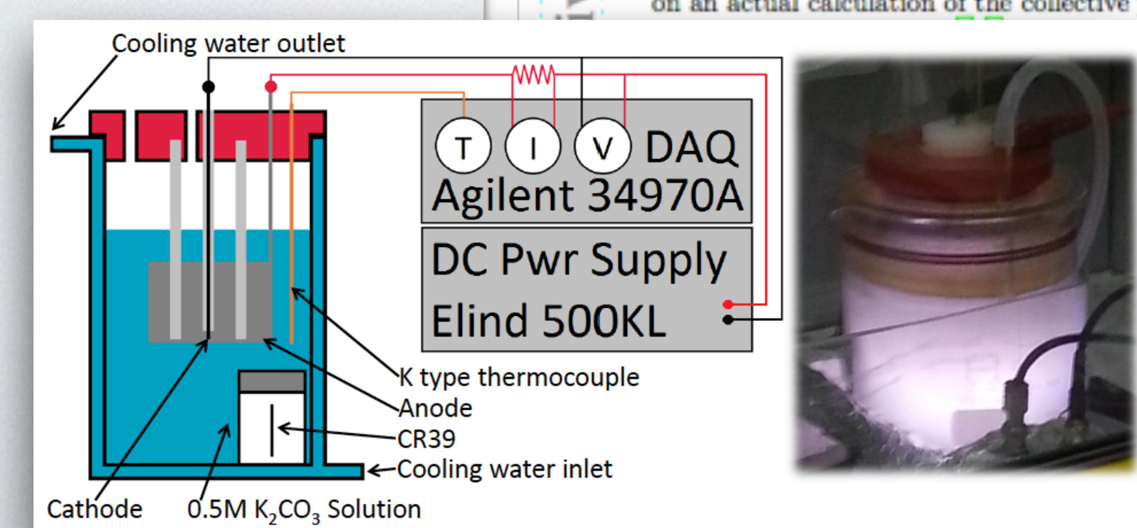
$$\Gamma(e^- p^+ \to n + \nu_e) = |\psi(0)|^2 v\sigma \quad (1)$$

wherein the amplitude for finding one electron at position $\mathbf{r}$ and one proton at position $\mathbf{R}$ is

$$\psi = \psi(\mathbf{r} - \mathbf{R}), \quad (2)$$

v is the relative velocity and σ is the $e^- p^+$ cross section.

The relative velocity value employed by Ciuchi *et al* is copied from our paper on exploding wires thus arriving at a theory of exploding batteries [6]. Absurdities would also arise from Ciuchi *et al* taking our numbers from a paper describing neutron rates in lightening bolts. All these papers of ours are cited and numbers copied from them even though they are clearly irrelevant for describing neutron production on metal hydride cathodes.



SOME BACKUP SLIDES

OSCILLATION CENTRE FRAME

It the effective mass connected to the instantaneus kinetic momentum or to its time average?

Assume that ***A*** lies in the yz plane and **ϕ**=0. Define **κ** as the components of ***f*** in the transverse ***yz*** plane, and compute the kinetic momenta (differentiating *S* w/ resp to coordinates)

$$p_y = \kappa_y - \frac{e}{c} A_y$$

$$p_z = \kappa_z - \frac{e}{c} A_z$$

$$p_x = -\frac{\gamma}{2} + \frac{m^2c^2 + \boldsymbol{\kappa}^2}{2\gamma} - \frac{e}{c\gamma}\boldsymbol{\kappa}\cdot\boldsymbol{A} + \frac{e^2}{2\gamma c^2}\boldsymbol{A}^2$$

Now we can **average over time** and compute <*p_i*>.

We can choose a **reference frame** in which all spatial components <*p_i*>=0 i.e. **the particle is at rest in it** on average. This is known as **oscillation center frame**.

The following two conditions on **κ** and **γ** are found (to allow <*p_i*>=0)

$$\boldsymbol{\kappa} = 0 \text{ and } \gamma^2 = m^2c^2 + \frac{e^2}{c^2}\overline{\boldsymbol{A}^2} \qquad \text{(OCF)}$$

Does fact that there is a relation between **γ** and **<*A*²>** implies that the effective mass formula in the previous slide is arbitrary? $m^* = (f\cdot k)/c$

OSCILLATION CENTRE FRAME

Then, writing the instantaneous kinetic momentum using the conditions on ***f*** and the relation between (*f.k*) and **<A²>** one (obviously) obtains the the expected squared value of the four-momentum

$$p_x = \frac{e^2}{2\gamma c^2}(\boldsymbol{A}^2 - \overline{\boldsymbol{A}^2})$$

$$p_y = -\frac{e}{c}A_y$$

$$p_z = -\frac{e}{c}A_z$$

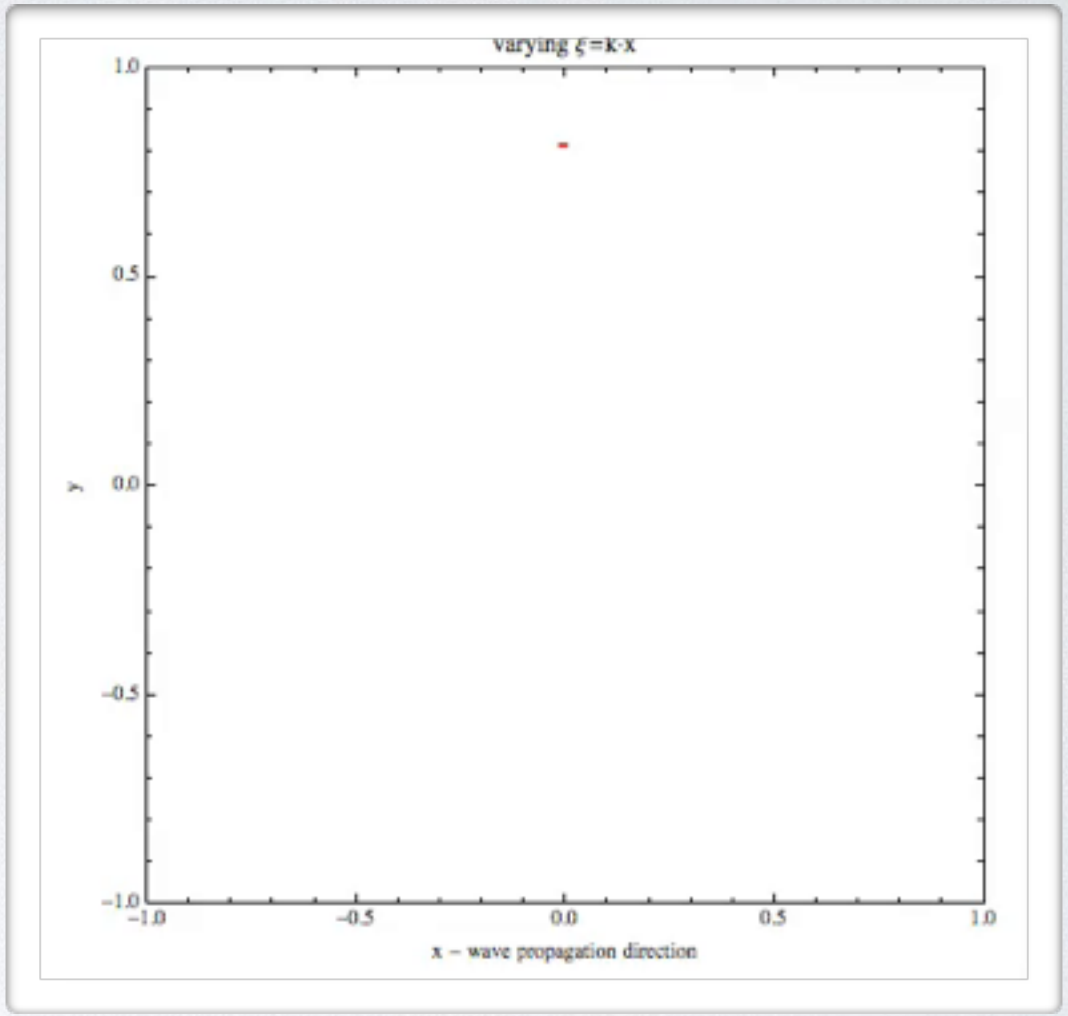
$$E = c\gamma + cp_x, \quad \gamma^2 = m^2c^2 + \frac{e^2}{c^2}\overline{\boldsymbol{A}^2}$$

Comes from requiring $<p_i>=0$.
Oscillation Center reference system:
the particle is at reast in it on average.

$k^\mu = (k, k, 0, 0)$ and $A^\mu = (0, 0, \sin\xi, 0)$

Again one obtains:

$$E^2 - \boldsymbol{p}^2c^2 = m^2c^4$$



$$k^\mu = (k, k, 0, 0), \quad A^\mu = (0, 0, \sin\xi, 0), \quad \xi = k \cdot x$$

$$x = -\frac{a^2}{8(1 + a^2/2)}\sin 2\xi$$

$$y = \frac{a}{(1 + a^2/2)^{1/2}}\cos\xi$$

(EP) BOUND STATE

$$[\bar{\nu}(x)\gamma_\mu(1-\gamma_5)e(x)][\bar{n}(x)\gamma^\mu(1-\lambda\gamma_5)p(x)] =$$

$$= -[\bar{e}_c(x)\gamma_\mu(1+\gamma_5)\nu_c(x)][\bar{n}(x)\gamma^\mu(1-\lambda\gamma_5)p(x)] =$$

$$= \frac{1+3\lambda}{2}[\bar{e}_c(x)(1-\gamma_5)p(x)][\bar{n}(x)(1+\gamma_5)\nu_c(x)] +$$

$$- \frac{1-\lambda}{2}[\bar{e}_c(x)\gamma_i(1+\gamma_5)p(x)][\bar{n}(x)\gamma^i(1+\gamma_5)\nu_c(x)]$$

and define

$$f_0\langle 0|\mathcal{O}_0|(e^-p)_0\rangle := \frac{1+3\lambda}{2}\langle 0|[\bar{e}_c(0)(1-\gamma_5)p(0)]|(e^-p)_0\rangle$$

$$f_1\langle 0|\mathcal{O}_1^i|(e^-p)_1\rangle := -\frac{1-\lambda}{2}\langle 0|[\bar{e}_c(0)\gamma^i(1+\gamma_5)p(0)]|(e^-p)_1\rangle$$

$$\mathcal{L}_{\text{phen}} = \frac{G_F}{\sqrt{2}}[f_0\bar{n}(x)(1+\gamma_5)\nu_c(x)\mathcal{O}_0 + f_1\bar{n}(x)\gamma_i(1+\gamma_5)\nu_c(x)\mathcal{O}_1^i]$$

to find

$$\frac{1}{4}[\Gamma(\mathcal{O}_0 \to n\nu) + 3\Gamma(\mathcal{O}_1 \to n\nu)] = |\psi(0)|^2\frac{(G_F m_e)^2}{2\pi}(1+3\lambda^2)(\beta-\beta_0)^2$$

where

$$|e^-p\rangle = (2\pi)^{3/2}\int d^3p\, f(\boldsymbol{p})\phi(r,s)(a_r^e)^\dagger(\boldsymbol{p})(a_s^p)^\dagger(-\boldsymbol{p})|0\rangle$$

and

$$\psi(0) = \frac{1}{(2\pi)^{3/2}}\int d^3p\, f(\boldsymbol{p})$$

DIRAC EQ. IN EM PLANE WAVE

One can even go through the Dirac equation in an external em plane wave (set c=1)

$$\psi = \left(1 + \frac{e}{2(k\cdot f)}\not{k}\not{A}\right)\frac{u}{\sqrt{2f_0}}e^{iS}$$

$$S = -f\cdot x - \int_0^{k\cdot x} d\phi\left(\frac{e}{(k\cdot f)}(f\cdot A) - \frac{e^2}{2(k\cdot f)}A^2\right)$$

where $\phi = k\cdot x$

f^μ is a constant four-vector with $f^2 = m^2$

and $\bar{u}u = 2m$

The time-averaged momentum is obtained by computing (here c=1)

$$P_\mu := \left\langle \frac{\psi^\dagger(i\overleftrightarrow{\partial_\mu})\psi}{\psi^\dagger\psi}\right\rangle = f_\mu - \frac{e^2\overline{A^2}}{2(f\cdot k)}k_\mu \quad (= -\partial_\mu S)$$

Same as in the classical case. Again we have to specify f and after that we will find the standard dispersion relation for the electron.

Notice that once the average over time is taken, the canonical and kinetic momentum are the same.

$$S = -f\cdot x - \int_0^{k\cdot x} d\xi\left(\frac{e}{c(k\cdot f)}(f\cdot A) - \frac{e^2}{2c^2(k\cdot f)}A^2\right)$$

OTHER `PIEZONUCLEAR` REFS.

G Preparata '*A new look at solid state fractures, particle emissions and cold nuclear fusion*'
N. Cim. 104, 1259 (1991)

F Cardone and R Mignani '*Piezonuclear reactions and Lorentz invariance breakdown*'
Int. J. Mod. Phys. E15, 911 (2006)

F Cardone et al. '*Piezonuclear neutrons*'
PLA373, 862 (2009)

F Cardone et al. '*Piezonuclear decay of Thorium*'
PLA373, 1956 (2009)

F Cardone, A Carpinteri and G Lacicogna '*Piezonuclear neutrons from fracturing of inert solids*'
PLA373, 4158 (2009)

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