A new experimental demonstration for the occurrence of low energy nuclear reactions

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Abstract

This article discusses the recent findings of the Tohoku group related to low energy nuclear fusion (LENR) or "cold fusion" as it was called earlier. The experiment involves heating and heat production which can be almost 20 per cent of the incoming power. The reports the initial and final state concentrations of Ni^-, Cu^-, C^-, O^-, and H^- in the target demonstrating that melting has very probably occurred. The emergence of ions should be understood. O^- ions are detected only in the final situation. The mystery is how the oxygen present in the H_2 pressurized chamber manages to get to the target.

The TGD based model is a refinement of the earlier model. The reaction $H_2+O_2 \rightarrow 2H_2O$ transforms the situation to that appearing in electrolysis and Pollack effect would be also now the basic mechanism producing dark nuclei as dark proton sequences transform spontaneously to ordinary nuclei. Whether this mechanism is involved should be tested.

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1 Introduction

I learned of highly interesting new experimental results related to low energy nuclear reactions (LENR) from a popular article published in New energy times (see this) giving a rather detailed view of the findings of the Tohoku group. There is also a research article by Iwamura et al with the title "Anomalous heat generation that cannot be explained by known chemical reactions produced by nano-structured multilayer metal composites and hydrogen gas" published in Japanese Journal of Applied Physics [**?**]

Note that LENR replaces the earlier term "cold fusion", which became a synonym for pseudo-science since standard nuclear physics does not allow these effects. In practice, the effects studied are however the same. LENR often involves Widom-Larsen theory (see https://newenergytimes.com/v2/sr/WL/WLTheory.shtmlthis) based on the assumption that the fundamental step in the process not strong interaction but weak interaction producing of electron with a large effective mass in condensed matter sense with a proton producing a neutron which is very nearly at rest and is able to get near the target nucleus. The assumption that an electron has a large effective mass and is very nearly at rest can be challenged. The understanding of detailed mechanisms producing the observed nuclear transmutations is not understood in the model.

1.1 Experiments of the Tohoku group

Consider first the experimental arrangement and results.

1. The target consists of alternating layers consisting of 6 Cu layers of thickness 2 nm and 6 Ni layers of thickness 14 nm. The thickness of this part is 100 nm. Below this layer structure is a bulk consisting of Ni. The thickness of the Ni bulk is 10^5 nm. The temperature of the hydrogen gas is varied during the experiment in the range 610 - 925 degrees Celsius. This temperature range is below the melting temperatures of Cu (1085 C) and Ni (1455 C).

2. The target is in a chamber, pressurized by feeding hydrogen gas, which is slowly adsorbed by the target. Typically this takes 16 hours. In the second phase, when the hydrogen is fully adsorbed, air is evacuated from the chamber and heaters are switched on. During this phase excess heat is produced. For instance, in the first cycle the heating power was 19 W and the excess heat was 3.2 W and lasted for about 11 hours. At the end of the second cycle heat is turned off and the cycle is restarted.

   The experiment ran for a total of 166 hours, the input electric energy was 4.8 MJ and the net thermal energy output was .76 MJ.

3. The figure of the popular article (see this) summarizes the temporal progress of the experiment and pressures and temperatures involved. Pressures are below 250 Pa: note that one atmosphere corresponds to 101325 Pa.

   The energy production is about 10^9 Joule per gram of hydrogen fuel. A rough estimate gives thermal energy production of about 10 keV per hydrogen atom. Note that the thermal energy associated with the highest temperature used (roughly 1000 K) is about .1 eV. In hot nuclear fusion the power gain is roughly 300 times higher and about 3 MeV per nucleon. The fraction of power gain to the input power is below 16 per cent typically in a given phase of the experiment.

The Tohoku group has looked for changes in the abundances of elements and for unusual isotopic ratios after the experiments. Iwamura reports that they have seen many unusual accumulations.

1. Second figure (see this) represents the the depth profiles in the range 0-250 nm for the abundances of Ni^-, Cu^-, C^-, Si^- and H^- ions for the initial and final situations for an experiment in which excess heat of 9 W was generated. The original layered structure has smoothed out, which suggests that melting has occurred. This cannot be due to the feed of the heat energy. The melting of Ni requires a temperature above 1455 C.

   Earlier experiments were carried out in the absorption phase. The recent experiments were performed in the desorption phase and the heat production was higher. The proposal is that the fact that the desorption is a faster process than the absorption could somehow explain this.

2. The most prevalent is an unusually high percentage of the element oxygen showing up below the surface of the multilayer composite, within the outer areas of the bulk.

   Pre-experiment analysis for the presence of oxygen concentration, after fabrication of the multilayer composite, has indicated a concentration of 0.5 to a few percent down to 1,000 nm from the top surface. The Tohoku group has observed many accumulations of oxygen in post-experimental analyses exceeding 50 % in specific areas.

Iwamura says that once the multilayer is fabricated, there is no way for atmospheric oxygen to leak below the top surface, at least beyond the first few nanometers. As a cross-check, researchers looked for nitrogen (which would suggest contamination from the atmosphere) but they detected no nitrogen in the samples.

3. Coulomb wall makes the low energy reactions of protons with the nuclei of the target extremely slow. If one assumes that the Widom-Larsen model is a correct way to overcome the Coulobm wall, it is natural to look what kinds of stable end products the reactions p + Ni and p + Cu, made possible by the Widom-Larsen mechanism, could yield.The most abundant isotope of Ni has charge and mass number $(Z, A = Z + N) = (28, 59)$ (see this). Ni has other stable isotopes with $A \in \{58, 60, 61, 62, 64\}$. The reaction Ni+p could lead from stable Ni isotope (28,62)*resp.* (28,64) to stable Cu isotope (29,63) *resp.* (29,65).

   Cu has $(Z, A) = (29, 63)$ (see this) and stable isotopes with $A \in \{63, 65\}$. The reaction Cu+p $\rightarrow$ ... could lead from $(Z, A) \in (29, \{63, 65\})$ to $(Z, A) \in (30, \{64, 66\})$). This could be followed by alpha decay to $(Z, A) \in (28, \{60, 62\})$. Iron has 4 stable isotopes with $A \in \{54, 56, 57, 58\}$. ^{60}Fe is a radionuclide with half life of 2.6 million years decaying to ^{60}Ni.

1.2 Theoretical models

Krivit has written a 3-part book "Hacking the atom: Explorations in Nuclear Research " about LENR [C4, C3, C5]. I have written an article [L5] about LENR in the TGD framework inspired by this book.

The basic idea of Widom-Larsen theory (see this) is as follows. First, a heavy surface electron is created by electromagnetic radiation in the LENR cells. This heavy electron binds with a proton to form an ultra-low momentum (ULM) neutron and neutrino. A weak reaction would be basically in question. The heaviness of the surface electron implies that the kinetic tunnelling barrier due Uncertainty Principle is very low and allows electron and proton get very near to each other so that the weak transition p+e $\rightarrow$ n+ν can occur. Neutron has no Coulomb barrier and has very low momentum so that it can be absorbed by a target nucleus at a high rate.

The difference of proton and neutron masses is $m_n - m_p = 2.5m_e$. The final state neutron produced in p+e $\rightarrow$ n+ν is almost at rest. One can argue that at the fundamental level ordinary kinematics should be used. The straight forward conclusion would be that the energy of an electron must be $2.5m_e$ so it would be relativistic.

Second criticism relates to the heaviness of the surface electron. I did not find from the web any support for heavy electrons in Cu and Ni. Wikipedia article (see this) and web search suggest that they quite generally involve f electrons and they are absent in Cu and Ni.

I also found a second model involving heavy electrons but no weak interactions (see this). Heavy electrons would catalyze nuclear transmutations. There would be three systems involved: electron, proton and nucleus. There would be no formation of an ultralow energy neutron. An electron would form a bound state with a proton with nuclear size. Although Coulomb attraction is present, the Uncertainty Principle would prevent the tunnelling of ordinary electrons to a nuclear distance. It is argued that a heavy electron has a much smaller quantum size and can tunnel to this distance. After this, the electron is kicked out of the system and by energy conservation its energy is compensated by a generation of binding energy between proton and nucleus so that heavier nucleus is formed. The same objection applies to both the Widom-Larsen model and this model.

What about the TGD based model derived to exlain the electrolysis based "cold fusion" [K1]. The findings indeed allow to sharpen the TGD based model for "cold fusion" based on generation of dark nuclei as dark proton sequences with binding energies in keV range instead of MeV range. One can understand what happens by starting from 3 mysteries.

1. The final state contains negatively charged Ni^-, Cu^-, C^-, S^-i, O^-, and H^- ions. What causes their negative charge? In particular, the final state target contains O^- ions although there is no oxygen present in the target in the initial state!

2. A further mystery is that the Pollack effect requires water. Where could the water come from?

Could O_2 and 2 H_2 molecules present in the chamber in the initial state give rise to oxygen ions in the final state? Could the spontaneously occurring reaction $2H_2+O_2 \rightarrow 2H_2O$ in the H_2 pressurized chamber liberating energy of about 4 eV generate the water in the target volume so that the Pollack effect, induced by heating could take place for the water. Note that the reverse of this reaction occurs in photosynthesis. It would transform ordinary protons to dark protons and generate a negatively charged exclusion zone involving Ni^-, Cu^-, C^-, S^-i, O^-, and H^- ions in the final state. The situation would effectively reduce to that in systems involving electrolyte studied in the original "cold fusion" experiments.

The spontaneous transformation of dark nuclei to ordinary ones would liberate essentially all the ordinary nuclear binding energy. It is of course not obvious whether the transformation to ordinary nuclei is needed to explain the heat production: it is however necessary to explain the nuclear transmutations, which are not discussed in the article of Tohoku group. The resulting dark nuclei could be rather stable and the X-ray counterpart for the emission of gamma rays could explain the heating. That gamma rays of ordinary nuclear physics have not been observed in "cold fusion" is the killer objection against "cold fusion" based on standard nuclear physics. In TGD gamma rays would be replaced by X rays in keV range, which is also the average thermal energy produced per hydrogen atom.

2 TGD inspired models of "cold fusion"/LENR or whatever it is

TGD suggests dark fusion [L5, L8] as the mechanism of "cold fusion". One can consider two models explaining these phenomena in the TGD Universe. Both models rely on the hierarchy of Planck constants $h_{eff} = n \times h$ [K2, K3, K4, K5, K6] explaining dark matter as ordinary matter in $h_{eff} = n \times h$ phases emerging at quantum criticality. h_{eff} implies scaled up Compton lengths and other quantal lengths making possible quantum coherence at longer scales than usual.

The hierarchy of Planck constants $h_{eff} = n \times h$ has now a rather strong theoretical basis and reduces to number theory [L6, L7]. Quantum criticality would be essential for the phenomenon and could explain the critical doping fraction for cathode by D nuclei. Quantum criticality could help to explain the difficulties to replicate the effect.

2.1 Simple modification of WL does not work

The first model is a modification of WL and relies on dark variants of weak interactions. In this case LENR would be an appropriate term.

1. Concerning the rate of the weak process $e + p \rightarrow n + \nu$ the situation changes if h_{eff} is large enough and rather large values are indeed predicted. h_{eff} could be large also for weak gauge bosons in the situation considered. Below their Compton length weak bosons are effectively massless and this scale would scale up by factor $n = h_{eff}/h$ to almost atomic scale. This would make weak interactions as strong as electromagnetic interactions and long ranged below the Compton length and the transformation of proton to neutron would be a fast process. After that a nuclear reaction sequence initiated by neutrons would take place as in WL. There is no need to assume that neutrons are ultraslow but electron mass remains the problem. Note that also proton mass could be higher than normal perhaps due to Coulomb interactions.

2. As such this model does not solve the problem related to the too small electron mass. Nor does it solve the problem posed by gamma ray production.

2.2 Dark nucleosynthesis

Also the second TGD inspired model involves the h_{eff} hierarchy. Now LENR is not an appropriate term: the most interesting things would occur at the level of dark nuclear physics, which is now a key part of TGD inspired quantum biology.

1. One piece of inspiration comes from the exclusion ones (EZs) of Pollack [L1] [L1], which are negatively charged regions [K1] [L2, L3]. Also the work of the group of Prof. Holmlid [C1, L4] not yet included in the book of Krivit was of great help. TGD proposal [L2, L4] is that protons causing the ionization go to magnetic flux tubes having interpretation in terms of space-time topology in the TGD Universe. At flux tubes they have $h_{eff} = n \times h$ and form dark variants of nuclear strings, which are basic structures also for ordinary nuclei.

2. The sequences of dark protons at flux tubes would give rise to dark counterparts of ordinary nuclei proposed to be also nuclear strings but with dark nuclear binding energy, whose scale is measured using as natural unit MeV/n, $n = h_{eff}/h$, rather than MeV. The most plausible interpretation is that the field body/magnetic body of the nucleus has $h_{eff} = n \times h$ and is scaled up in size. $n = 2^{11}$ is favoured by the fact that from Holmlid's experiments the distance between dark protons should be about electron Compton length.

   Besides protons also deuterons and even heavier nuclei can end up in the magnetic flux tubes. They would however preserve their size and only the distances between them would be scaled to about electron Compton length on the basis of the data provided by Holmlid's experiments [C1, L4].

   The reduced binding energy scale could solve the problems caused by the absence of gamma rays: instead of gamma rays one would have much less energetic photons, say X rays assignable to $n = 2^{11} \simeq m_p/m_e$. For infrared radiation the energy of photons would be about 1 eV and nuclear energy scale would be reduced by a factor about $10^{-6} - 10^{-7}$: one cannot exclude this option either. In fact, several options can be imagined since the entire spectrum of h_{eff} is predicted. This prediction is testable.

   Large h_{eff} would also induce quantum coherence as a scale between electron Compton length and atomic size scale.

3. The simplest possibility is that the protons are just added to the growing nuclear string. In each addition one has $(A, Z) \to (A + 1, Z + 1)$. This is exactly what happens in the mechanism proposed by Widom and Larsen for the simplest reaction sequences already explaining reasonably well the spectrum of end products.

   In WL the addition of a proton is a four-step process. First $e + p \to n + \nu$ occurs at the surface of the cathode. This requires large electron mass renormalization and fine tuning of the electron mass to be very nearly equal but higher than the $n - p$ mass difference.

   There is no need for these questionable assumptions of WL in TGD. Even the assumption that weak bosons correspond to large h_{eff} phase might not be needed but cannot be excluded with further data. The implication would be that the dark proton sequences decay rather rapidly to beta stable nuclei if a dark variant of $p \to n$ is possible.

4. EZs and accompanying flux tubes could be created also in electrolyte: perhaps in the region near the cathode, where bubbles are formed. For the flux tubes leading from the system to the external world most of the fusion products as well as the liberated nuclear energy would be lost. This could partially explain the poor replicability for the claims about energy production. Some flux tubes could however end at the surface of the catalyst under some conditions. Flux tubes could end at the catalyst surface. Even in this case the particles emitted in the transformation to ordinary nuclei could be such that they leak out of the system and Holmlid's findings indeed support this possibility.

   If there are negatively charged surfaces present, the flux tubes can end to them since the positively charged dark nuclei at flux tubes and therefore the flux tubes themselves would be attracted by these surfaces. The most obvious candidate is catalyst surface, to which electronic charge waves were assigned by WL. One can wonder whether Tesla observed in his experiments the leakage of dark matter to various surfaces of the laboratory building. In the collision with the catalyst surface dark nuclei would transform to ordinary nuclei releasing all the ordinary nuclear binding energy. This could create the reported craters at the surface of the target and cause heating. One cannot of course exclude that nuclear reactions take place between the reaction products and target nuclei. It is quite possible that most dark nuclei leave the system.

It was in fact Larsen, who realized that there are electronic charge waves propagating along the surface of some catalysts, and for good catalysts such as Gold, they are especially strong. This would suggest that electronic charge waves play a key role in the process. The proposal of WL is that due to the positive electromagnetic interaction energy the dark protons of dark nuclei could have rest mass higher than that of neutron (just as in the ordinary nuclei) and the reaction $e + p \rightarrow n + \nu$ would become possible.

5. Spontaneous beta decays of protons could take place inside dark nuclei just as they occur inside ordinary nuclei. If the weak interactions are as strong as electromagnetic interactions, dark nuclei could rapidly transform to beta stable nuclei containing neutrons: this is also a testable prediction. Also dark strong interactions would proceed rather fast and the dark nuclei at magnetic flux tubes could be stable in the final state. If dark stability means the same as the ordinary stability then also the isotope shifted nuclei would be stable. There is evidence that this is the case.

Neither "CF" nor "LENR" is an appropriate term for the TGD inspired option. One would not have ordinary nuclear reactions: nuclei would be created as dark proton sequences and the nuclear physics involved is on a considerably smaller energy scale than usual. This mechanism could allow at least the generation of nuclei heavier than Fe not possible inside stars and supernova explosions would not be needed to achieve this. The observation that transmuted nuclei are observed in four bands for nuclear charge Z irrespective of the catalyst used suggest that the catalyst itself does not determine the outcome.

One can of course wonder whether even "transmutation" is an appropriate term now. Dark nucleosynthesis, which could in fact be the mechanism of ordinary nucleosynthesis outside stellar interiors to explain how elements heavier than iron are produced, might be a more appropriate term.

2.3 The TGD based model and the findings of Iwamura et al

The presence of ions Ni^-, Cu^-, C^-, Si^- and H^- ions in the target is an important guideline. LENR involves negatively charged surfaces at which the presence of electrons is thought to catalyze transmutations: the WL model relies on this idea. The question concerns the ionization mechanism.

1. The appearance of Si^- in the entire target volume could be understood in terms of melting. It is difficult to understand its appearance as being due to nuclear transmutations.

2. What is remarkable is the appearance of O^-. The Coulomb wall makes it very implausible that the absorption of an ordinary alpha particle in LENR could induce the transmutation of C to O.

   Could the oxygen be produced by dark fusion? It is difficult to see why oxygen should have such a preferred role as a reaction product in dark fusion favouring light nuclei?

   Could the oxygen enter the target during the first phase when the pressurized hydrogen gas is present together with air, as the statement that air was evacuated after the first stage, suggests. Iwamura has also stated that nitrogen N, also present in air, is not detected in the target so that the leakage of O to the target looks implausible. Could the leakage of oxygen rely on a less direct mechanism?

3. Oxygen *resp.* hydrogen appears as O_2 *resp.* H_2 molecules. O_2 *resp.* H_2 has a binding energy of 5.912 eV and *resp.* 4.51 eV. Therefore the reaction $2H_2+O_2 \rightarrow 2H_2O$ could occur during the pressurization phase. The energy liberated in this reaction is estimated to be about 4.88 eV (see ¡A HREF="http://umdberg.pbworks.com/w/page/89327588/Chemical

4. What is remarkable is that water plays a key role in the Pollack effect interpreted as a formation of dark proton sequences. Pollack effect generates negatively exclusion zones as negatively charged regions and Ni^-, Cu^-, C^-, Si^- and H^- ions would serve as a signature of these regions. In the "cold fusion" based on electrolysis, the water would be present from the beginning but now it would be generated by the proposed mechanism.

The difference of the bonding energy of OH and binding energy of O$^-$ is about .33 eV in absence of electric fields and corresponds to the thermal energy at temperature of 630 C. This would suggest that the heating replaces IR photons in ordinary Pollack effect as energy source inducing the formation of dark protons and exclusion zones consisting of negative ions.

5. In fact, Pollack effect suggests a deep connection between computers, quantum computers and living matter based on the notion of OH-O$^-$ + dark proton qubit and its generalizations [L11].

6. The earlier TGD based model for "cold fusion" as dark fusion suggests that the value of h_{eff} for dark protons is such that the Compton length is of order electron Compton length. Dark proton sequences as dark nuclei would spontaneously decay to ordinary nuclei and produce the heat. In TGD, ordinary nuclei also form nuclear strings as monopole flux tubes [K7].

   TGD assigns a large value of h_{eff} to systems having long range strong enough classical gravitational and electric fields [L9, L10]. For gravitational fields the gravitational Planck constant is very large and the gravitational Compton length is one half of the Schwartschild radius of the system with large mass (Sun or Earth). In biology, charged systems such as DNA, cells and Earth itself involve large negative charge and therefore large electric Planck constant proportional to the total charge of the system. Pollack effect generates negatively charged exclusion zones, which could be characterized by gravitational or electric Planck constant. In the recent case, the electric Compton length of dark protons should be of the order of electron Compton length so that $h_{eff}/h \sim m_p/m_E \sim 2^{11}$ is suggestive.

2.4 Summmary

In the TGD based model, the reaction $H_2+O_2 \rightarrow 2H_2O$ transforms the situation to that appearing in electrolysis and Pollack effect would be also now the basic mechanism producing dark nuclei as dark proton sequences transforming spontaneously to ordinary nuclei. Whether this mechanism is involved should be tested.

The TGD based model predicts much more than is reported in the article of Iwamura et al. A spectrum of light nuclei produced in the process and containing at least alpha particles but there is no information about this spectrum in the article.

1. The article reports only the initial and final state concentrations of Ni$^-$, Cu$^-$, C$^-$, O$^-$, and H$^-$ but does not provide information about all nuclei produced by transmutations. Melting has very probably occurred for Ni and Cu.

2. The heat production rate is higher during the desorption phase than during the adsorption phase. The TGD explanation would be that the dark proton sequences have reached a full length during desorption and can produce more nuclei as they decay.

3. The finding that the maximum of the energy production per hydrogen atom is roughly 1/100 times smaller than the binding energy scale of nuclei of nuclei, forces to challenge dark fusion as a reaction mechanism. The explanation could be that the creation of dark nuclei from hydrogen atoms is the rate limiting step. If roughly 1 percent of hydrogen atoms generates dark protons, the rate of heat production could be understood.

4. The basic prediction of Widom-Larsen model about $(A, Z) \rightarrow (A + 1, Z + 1) \rightarrow ...$ follows trivially from TGD inspired model in which dark nuclei with binding energy scale much lower than for ordinary nuclei and Compton length of order electron Compton length are formed as sequences consisting of dark protons, deuterons or even heavier nuclei, which then transform to ordinary nuclei and liberate nuclear binding energy. This occurs at negatively charged surfaces (that of cathode for instance) since they attract positively charged flux tubes. On the other hand, the negative surface charge could be generated in the Pollack effect for the water molecules generating exclusion zone and dark protons at the monopole flux tubes.

   The energy scale of dark variants of gamma rays liberated in dark nuclear reactions is considerably smaller than that of gamma rays since it is scaled down from few MeV to few keV which indeed corresponds to the thermal energy liberated per hydrogen atom. This could explain why gamma rays are not observed. The questionable assumptions of the Widom-Larsen model are not needed.

It should be noted however that the spontaneous decay of dark nuclei to ordinary nuclei might not be needed at all to explain the heat production so that the dark nuclei could be rather long-lived. The decay is however needed to explain the nuclear transmutations, not discussed in the article by Tohoku group.

5. The maximum length of dark nucleon sequences determines how heavy nuclei can emerge. The minimum length corresponds to a single alpha nucleus and it could induce nuclear transformation such as the transmutation of C to O. Part of the dark nuclei could escape from the target volume and remain undetected. Dark nuclei could also directly interact with the target nuclei, in particular Ni and Cu.

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