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Research Article

Very Sizeable Increase of Gravitation at Picometer Distance: A Novel Working Hypothesis to Explain Anomalous Heat Effects and Apparent Transmutations in Certain Metal/Hydrogen Systems*

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Abstract

Since more than 15 years, unexplained heat effects have been reported in systems involving hydrogen isotopes (hydrogen and deuterium) and certain metals like palladium. The most studied system (palladium/deuterium) has given birth to the “Cold Fusion” concept: a special kind of DD fusion reaction, only occurring in a metallic lattice, which yields heat and helium-4 as the main reaction product. Other systems have also been studied (nickel hydrogen and caesium/deuterium for instance), showing shifts in isotopic ratio of the products of reaction and leading to the more generalized concept of Low Energy Nuclear Reaction (LENR). A novel conjecture (the pico-gravity conjecture) is presented here, that may explain all the anomalies observed in this so-called “Cold Fusion” field. According to this conjecture, the main part of the energy produced in Low Energy Nuclear Reaction could be the result of a very special kind of chemical reactions (pico-chemical reactions), induced by a considerable increase of gravity at pico-meter distances (pico-gravity). True nuclear signatures (α-particles emission for instance) could also occur according to the pico-gravity conjecture. But they should be many orders of magnitude lower than would be expected from the energy produced (which is observed experimentally). This conjecture will be tested by analysing the products of the reaction of hydrogen isotopes with selected metals.

Keywords: Cold fusion, Gravity, Isotopic shift, LENR, Low Energy Nuclear Reactions

1. Introduction

For more than 15 years since 1989, claims have been made of nuclear reactions occurring in metals (palladium for instance) at room temperature in the presence of hydrogen isotopes. During the course of electrolysis of D_2O with a palladium cathode, Fleischmann and Pons [1] observed an exothermal reaction, which they interpreted as being a special kind of deuterium nuclear fusion reaction. Claims have also been made of transmutations of chemical species, inducing

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isotopic composition variations. Recently, very surprising results (transmutation of cesium into praseodymium and strontium into molybdenum) have been obtained by passing a flux of deuterium through a multi-layer composite of palladium and calcium oxide [2].

Various working hypothesis have been presented to explain the occurrence of nuclear reactions in solids at energies in the order of eV [3,4]. These hypotheses address the two main problems in the field and explain by novel quantum mechanical effects in condensed matter, the overcoming of the Coulomb barrier at room temperature and the absence of the expected characteristic radiations accompanying nuclear reactions. These hypothesis are generally rejected by mainstream scientists. In that perspective, the DOE report of 1 December 2004 [4], proposes that dedicated experiments should be founded to check two types of observations: one is the anomalous character of the heat production with deuterium, the other is the particles reportedly emitted from deuterated foils, using state of the art apparatus and methods. This is an indication that the DOE report acknowledges that something unusual might occur in certain metal/hydrogen systems.

In this DOE report, observation of apparent transmutations without radiation emission [2,5] was not taken into account. Although this might be seen as a strong proof of the occurrence of nuclear reactions in condensed matter, it will be seen that these results can indeed be rationalized by the novel working hypothesis presented below.

2. The Novel Working Hypothesis

It is commonly accepted that the electromagnetic, the weak nuclear and the strong nuclear forces, have the same intensity at the quark scale (Grand unification). It is suspected that the intensity of gravity should increase when the distance decreases and that the four interactions should have the same intensity at a sufficiently small distance (Superunification). Since 1926 and the publication of the article of Kaluza [6], who proposed a model for gravitation variations with distance, the increase of gravitation has been confined to the Plank distance, but with no experimental proof. With this very restrictive concept, gravitation should increase by a factor of some 10^{40} within a distance of 10^{-33} cm (the Plank distance), which is very questionable. The attitude towards gravitation intensity variations with distance has changed during the last 20 years [7] and a great number of theoretical models embedded in string theory and with very surprising and intellectually challenging concepts await experimental results to choose those that are backed by reality. A sizeable experimental effort is carried out at tens of μm distances [8] and so far no variations have been observed down to 50 μm. This is the upper limit for experimentally allowed gravitation variations, from the known macroscopic value (6.673×10^{-11} m^3/kg s^2), towards the ultimate one expected at Plank distance (some 7×10^{29} m^3/kg s^2). Direct measurement of the Newton constant at much smaller distances seems impossible.

It is then hypothesized that the intensity of gravitation very strongly increases at distances of the order of the inner atomic distances (0 to some 100 pm). This increase is supposed to attain such a level, that the gravitational intensity attraction between a proton (or a deuteron) and a nucleus A becomes of the same order of magnitude as their Coulomb repulsion. A simplified model of the interaction between the nucleus A and the proton (deuteron) embedded in the electronic layers of A is presented. This model is purely phenomenological, no attempt being made to modelize additional dimensions of space/time. A strong increase of the gravitational constant G is indeed considered, in the ordinary four-dimensional space/time.

It will be shown that this model predicts the possibility of bound states between the proton (deuteron) and A, with binding energies of a few hundred eV. This can explain the bulk of the anomalous enthalpy of reaction observed in certain metal/hydrogen systems. This model can also explain some very faint nuclear reactions, producing only very weak typical nuclear signatures and contributing only marginally to the enthalpy of reaction.

3. The Model

The model presented below, uses the same line of reasoning as the elementary calculation of the Bohr radius and the ionisation energy of the hydrogen atom, which is described now.

3.1. Simplified Model of the Hydrogen Atom

To calculate the radius and ionisation energy of a hydrogen atom, the following simple calculation is often used: with

$$Q^2 = \frac{e^2}{4\pi\varepsilon_0},$$

m_e, v_e the electron mass and velocity and r the distance proton/electron, the potential energy of the electron is

$$E_P = -\frac{Q^2}{r}$$

and its kinetic energy is $E_C = (1/2)\, m_e v_e^2$. A bound state of the electron has a radius r that minimizes its total energy $E = E_P + E_C$. Taking into account Heisenberg uncertainty on momentum: $m_e v_e r = n\hbar$ with $n \geq 1$ (n being an integer), the total energy of the electron is

$$E = -Q^2 \frac{1}{r} + \frac{n^2\hbar^2}{2m_e}\frac{1}{r^2}. \quad (1)$$

Thus,

$$\frac{\partial E}{\partial r} = \frac{1}{r^2}\left[Q^2 - \frac{n^2\hbar^2}{m_e}\frac{1}{r}\right],$$

yielding the electron bound states:

$$r_n = n^2 \frac{\hbar^2}{Q^2 m_e} = n^2 a,$$

with

$$a = 52.92\,\text{pm (Bohr radius)}$$

and

$$E_n = -\frac{1}{n^2}\frac{Q^4 m_e}{\hbar^2} = -\frac{1}{n^2}E_I,$$

with $E_I = 13.6\,\text{eV}$ (hydrogen ionisation energy).

Simplified model of bound states of a hydrogen nucleus surrounding an atom A, embedded in its electronic system and submitted to an hypothetical strong gravitational potential:

The above approach is used in Fig. 1.

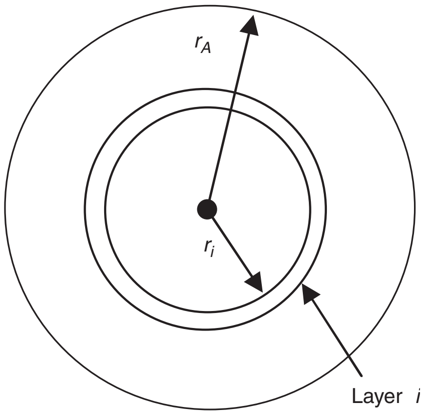

Figure 1. Simplified model of bound states of a hydrogen nucleus surrounding an atom A.

The electronic system of an atom A, having a mass number A, an atomic number Z and a radius r_{A}, is represented by a series of equidistant two-dimensional layers of electric charges, each layer having a charge equal to e, the electric charge of an electron. There are thus Z layers surrounding the nucleus of A, the innermost radius of layer i being:

$$r_i = \frac{r_{\mathrm{A}}}{Z} i \quad \text{with} \quad 0 < i \leq Z - 1.$$

A hydrogen nucleus approaching atom A from outside will be submitted to two potentials:

(1) The repulsive Coulomb potential of the nucleus of A, which will be less an less screened by the electron layers as it moves towards the nucleus of A: $E_{\mathrm{P}}^{\mathrm{E}} = (Z - i)\, Q^2 \frac{1}{r_i}$.
(2) The attractive gravitational potential of A: $E_{\mathrm{P}}^{\mathrm{G}} = -G' A m_{\mathrm{p}} m_{\mathrm{H}} 1/r_i$, G' being the increased Newtonian gravitation constant, m_{p} the mass of the proton (the mass difference between the proton and the neutron and the mass corresponding to the binding energy of the nucleus being neglected) and m_{H} the mass of the hydrogen isotope under study. The total energy of the hydrogen nucleus is thus

$$E = \left[(Z - i)\, Q^2 - G' A m_{\mathrm{p}} m_{\mathrm{H}}\right] \frac{1}{r} + \frac{n^2 \hbar^2}{2 m_{\mathrm{H}}} \frac{1}{r^2} = -k\,(Z - i)\, Q^2 \frac{1}{r} + \frac{n^2 \hbar^2}{2 m_{\mathrm{H}}} \frac{1}{r^2} \tag{2}$$

with

$$k = \frac{G' A m_{\mathrm{p}} m_{\mathrm{H}}}{(Z - i)\, Q^2} - 1 \tag{3}$$

using for (2) the same method as for (1), yields the hypothetical bounds states of the hydrogen nucleus, embedded in the electronic system of A, submitted to a combined Coulomb and gravitational potential of intensity G' and round its nucleus:

$$r_n = \frac{n^2 \hbar^2}{k\,(Z - i)\, Q^2 m_{\mathrm{H}}} = n^2 a \frac{1}{k\,(Z - i)} \frac{m_{\mathrm{e}}}{m_{\mathrm{H}}}, \tag{4}$$

$$E_n = -\frac{1}{2}\frac{k^2\,(Z-i)^2\,Q^4 m_{\mathrm{H}}}{n^2\hbar^2} = -\frac{1}{n^2}E_{\mathrm{I}}k^2\,(Z-i)^2\,\frac{m_{\mathrm{H}}}{m_{\mathrm{e}}}. \tag{5}$$

Remark: Through all this article and to distinguish the hydrogen isotopes under study, the following notations will be used for their nuclei.

Generic denomination: H for both isotopes

(1) Hydrogen (one proton) p.
(2) Deuterium (one proton, one neutron) d.

4. Discussion

For solutions to exist, k (3), must be positive. The minimum required value of the increased Newtonian gravitation constant is thus

$$G' = \frac{(Z-i)Q^2}{Am_{\mathrm{p}}m_{\mathrm{H}}},$$

obviously corresponding to a very sizeable increase of the intensity of gravitation. It can also be seen that the exact required minimum value of G' depends upon the system under study. It will be much higher for the hydrogen/hydrogen system ($A = 1, m_{\mathrm{H}} = m_{\mathrm{p}}$), than for the $^{206}_{82}$Pb/deuterium system for instance ($A = 206, m_{\mathrm{H}} = 2m_{\mathrm{p}}$).

The simpler system (in term of number of protons and neutrons involved) that has been observed experimentally to yield reactions will thus fix the value of G'. This value can then be used to study more complicated reactions. The deuterium/deuterium case seems to be a good candidate to determine G' For the sake of simplicity, we shall call "pico-gravity" the strongly enhanced gravity at picometer distances with an apparent newtonnian constant G'.

4.1. Interaction of Two Deuterium Nuclei

Although, the simple model presented is even more oversimplified in that case (the centre of mass of the system is in between the two deuterium nuclei), it is used to give an order of magnitude of G'

Equation (4) gives

$$r_1 = a\frac{1}{k_{\mathrm{d,d}}}\frac{m_{\mathrm{e}}}{m_{\mathrm{H}}} \approx a\frac{1}{k_{\mathrm{d,d}}}\frac{m_{\mathrm{e}}}{2m_{\mathrm{p}}} = 2.7\times 10^{-4}\frac{a}{k_{\mathrm{d,d}}}.$$

Thus,

$$k_{\mathrm{d,d}} = 2.7\times 10^{-4}\frac{a}{r_1}.$$

It is known that in a deuterium molecule, the distance between the two deuterium nuclei is some 74 pm. With this distance, nuclear fusion reactions between the two nuclei are extremely rare. On the contrary, in a mesic deuterium molecular ion, this distance is some 200 times smaller (0.4 pm), yielding a reaction time of a few μs. It has been observed that deuterium trapped in a palladium lattice yields very small amounts of tritium, neutron and helium 4. The amounts of helium 4 observed are much larger than would be expected from a classical "hot fusion reaction" and the helium 4 looks like the major product of the "cold fusion reaction" observed. Another plausible explanation for the apparition of sizeable amounts of helium 4 and heat in a lattice where a "cold fusion reaction" occurs will be discussed later. For the time being, it is hypothesized that a classical "hot fusion reaction" can be catalysed by pico-gravity, through the formation of a compound with a size smaller than 74 pm, but much bigger than 0.4 pm, yielding a very small but measurable rate of "hot fusion" reactions with associated heat and classical products pattern. The determination of the exact value would require more experiments to determine the exact rate of the reaction and thus the exact value of r_1. In first approximation, r_1 is set at 20 pm, finally yielding

$$k_{\mathrm{d,d}} = 7.15 \times 10^{-4}$$

and

$$G' = \left(1 + k_{\mathrm{d,d}}\right) \frac{Q^2}{4m_{\mathrm{p}}^2} \approx 2.06 \times 10^{25}\ \mathrm{m^3\ kg^{-1}\ s^{-2}}, \tag{6}$$

which is a 3×10^{35}-fold increase compared to the measured macroscopic value ($6.67 \times 10^{-11}\mathrm{m^3\ kg^{-1}\ s^{-2}}$). It will be shown below that this increase can well have been hidden in all presently known systems, because of its very weak effects in such systems.

Using this value of G' for the pico-gravity constant, the interactions of hydrogen isotopes with atoms with mass number higher than two are now examined.

5. Interaction of Hydrogen Isotopes with Atoms with Atomic Number $Z \geq 2$ and Mass Number A

To explicit Eqs. (4) and (5), the value for G' is taken equal to the value calculated from the interaction d,d and given by (6):

$$G' = \left(1 + k_{\mathrm{d,d}}\right) \frac{Q^2}{4m_{\mathrm{p}}^2}.$$

Thus,

$$k_{\mathrm{A,H}} = \frac{G' A m_{\mathrm{P}} m_{\mathrm{H}}}{(Z-i)\, Q^2} - 1 = \frac{m_{\mathrm{H}}}{4m_{\mathrm{p}}} \frac{A}{(Z-i)} \left(1 + k_{\mathrm{d,d}}\right) - 1.$$

Thus,

$$r_n = n^2 a \frac{1}{k_{\mathrm{A,H}}\,(Z-i)} \frac{m_{\mathrm{e}}}{m_{\mathrm{H}}} = n^2 a \frac{m_{\mathrm{e}}}{m_{\mathrm{H}}} \left[\frac{1}{\frac{m_{\mathrm{H}}}{4m_{\mathrm{p}}} A \left(1 + k_{\mathrm{d,d}}\right) - (Z-i)} \right] = n^2 a \frac{m_{\mathrm{e}}}{m_{\mathrm{H}}} K(i), \tag{7a}$$

with

$$K(i) = \frac{1}{\frac{m_{\mathrm{H}}}{4m_{\mathrm{p}}} A \left(1 + k_{\mathrm{d,d}}\right) - (Z-i)} \tag{7b}$$

and

$$E_n = -\frac{1}{n^2} E_{\mathrm{I}} k_{\mathrm{A,H}}^2 (Z-i)^2 \frac{m_{\mathrm{H}}}{m_{\mathrm{e}}} = -\frac{1}{n^2} E_{\mathrm{I}} \frac{m_{\mathrm{H}}}{m_{\mathrm{e}}} L(i), \tag{8a}$$

with

$$L\,(i) = \frac{m_{\mathrm{H}}^2}{16m_{\mathrm{p}}^2} A^2 \left(1 + k_{\mathrm{d,d}}\right)^2 - \frac{m_{\mathrm{H}}}{2m_{\mathrm{p}}} A \left(1 + k_{\mathrm{d,d}}\right)(Z - i) + (Z - i)^2. \tag{8b}$$

Equations (7a) and (8a), describe the possible bound states of H in the combined Coulomb + gravitational field of A. H entering the electronic layers of A from the outside, n should decrease as H approaches the nucleus of A. For the model to be coherent, n is determined as a function of i by writing:

$$r_i = \frac{r_{\mathrm{A}}}{Z} i = r_n = n^2 a \frac{m_{\mathrm{e}}}{m_{\mathrm{H}}} K\,(i)\,.$$

Thus,

$$n = \sqrt{\frac{r_{\mathrm{A}}}{a} \frac{m_{\mathrm{H}}}{m_{\mathrm{e}}} \frac{i}{ZK\,(i)}}. \tag{9}$$

In the regions of interest, n is high; r_n and E_n are thus calculated by taking the integer value of n given by (9). The discrepancy between r_i and r_n is small.

Equations (7a), (7b), (8a), (8b) and (9) shall be used to study the interaction of a proton (p) and a deuteron (d) with various atoms A and their isotopes (r_{A} is taken equal to the covalent radius of A). The values of $K(i)$ and $L(i)$ given by (7b) and (8b) are calculated for both hydrogen isotopes as will be seen below.

6. Interaction of a Proton (p) with an Atom A

In this case,

$$K\,(i) = \frac{1}{\frac{1}{4} A \left(1 + k_{\mathrm{d,d}}\right) - (Z - i)}. \tag{10a}$$

The progression of p towards the nucleus of A is limited to the layers with

$$i > Z - \frac{A}{4}\left(1 + k_{\mathrm{d,d}}\right) \approx Z - \frac{A}{4} \;\; (k_{\mathrm{d,d}} \text{ is small compared to 1})$$

and the minimum value for i is

$$i_{\min} = Z - \frac{A}{4} + 1,$$

for which $K\,(i_{\min}) = 1$. In other word, when the screening by electrons becomes insufficient ($i < Z - A/4$), the Coulomb repulsion gets higher than the pico-gravity attraction and the proton is repelled. An equilibrium can nevertheless be attained, the proton oscillating between the layers $i_{\min}$ and $i_{\min} + 1$.

Hence,

$$r_{\min} = \frac{r_{\mathrm{A}}}{a} \frac{m_{\mathrm{H}}}{m_{\mathrm{e}}} a \frac{m_{\mathrm{e}}}{m_{\mathrm{H}}} \frac{i_{\min}}{ZK\,(i_{\min})} = r_{\mathrm{A}} \frac{Z - \frac{A}{4} + 1}{Z}. \tag{10b}$$

The proton p can thus never come to the close vicinity of the nucleus of A. Compounds formed will contain proton(s) embedded in the outer electronic layers of A.

$$L(i) = \frac{m_{\mathrm{H}}^2}{16m_{\mathrm{p}}^2} A^2 \left(1 + k_{\mathrm{d,d}}\right)^2 - \frac{m_{\mathrm{H}}}{2m_{\mathrm{p}}} A \left(1 + k_{\mathrm{d,d}}\right)(Z - i) + (Z - i)^2$$
$$= \frac{A^2}{16}\left(1 + k_{\mathrm{d,d}}\right)^2 - \frac{A}{2}\left(1 + k_{\mathrm{d,d}}\right)(Z - i) + (Z - i)^2 \approx \left[\frac{A}{4} - (Z - i)\right]^2. \quad (11)$$

Thus, the energy of the proton is always negative, and at the layer $i = i_{\min} \approx Z - \frac{A}{4} + 1$, $L(i_{\min}) = 1$. The value of the energy at $i_{\min}$ is then

$$E_{i_{\min}} = -\frac{a}{r_{\mathrm{A}}} E_{\mathrm{I}} \frac{2K(i_{\min}) L(i_{\min})}{i_{\min}} = -\frac{a}{r_{\mathrm{A}}} E_{\mathrm{I}} \frac{2}{Z - \frac{A}{4} + 1}.$$

Examples of the variation of the proton energy with its distance to the nucleus of various atoms A are given below. Calculations are made using Eqs. (7a), (8a), (9), (10a) and (11).

7. Interaction of a Deuteron (*d*) with an Atom A

In this case,

$$K(i) = \frac{1}{\frac{1}{2}A\left(1 + k_{\mathrm{d,d}}\right) - (Z - i)} \quad (12)$$

is always positive (in stable isotopes $A \geq 2Z$). The deuteron could come to contact with the nucleus of A (for $n = 1$, values of r_n are of the size of a nucleus). This might happen in rare cases, and could result in a nuclear reaction (fission, α emission, ...). But in most cases it is likely that its progression is limited by Pauli exclusion principle, the electrons between the deuteron(s) and the nucleus of A having less and less energetic levels available as the deuteron d progresses towards A, in a way comparable of what is considered in the calculation of Chandrasekhar's limit for white dwarf stars. This is confirmed by the very low intensity of typical nuclear radiations experimentally observed. It is assumed that Pauli exclusion principle sets the minimum distance between the deuteron(s) and the nucleus of A. To visualize, on the graphs presented below, the possible effect of the Pauli exclusion principle, a repulsive Lennard–Jones type of potential (A/r^{12}) has been added to the combined Coulomb/gravitational potential. This potential has been set empirically, hypothesizing that the 2 s electrons are involved, which gives an order of magnitude of the distance at which the minimum total energy of the system occurs. The complex atom formed could have atomic characteristics close to but different from the product of a nuclear reaction between A and d [8]. This point will be discussed in details below.

$$L(i) = \frac{A^2}{4}\left(1 + k_{\mathrm{d,d}}\right)^2 - A\left(1 + k_{\mathrm{d,d}}\right)(Z - i) + (Z - i)^2 \approx \left[\frac{A}{2} - (Z - i)\right]^2 \quad (13)$$

is always positive. The total energy of the deuteron is thus always negative.

Examples of the variation of the deuteron energy with its distance to the nucleus of various atoms A are given below. Calculations are made using Eqs. (7a), (8a), (9), (12) and (13).

8. General Comments on the Proposed Model

Due to the simplified character of the model presented, only a rough order of magnitude can be expected when using it to describe this novel type of chemical reactions between a hydrogen isotope and an atom A. Anyhow, it will be seen that there is a general concordance between its predictions and what has been observed in the so-called LENR field (Low Energy Nuclear Reaction).

A second point must be stressed. An infinite range of the strong gravity has been considered, resulting in a sizeable attractive potential at the limit of the atom A (orders of hundred eV). Such a potential should already have been seen. In fact the range of strong gravity should be limited, probably at values lower than 100 pm, that is lower than typical atom size. This point will be discussed below in details. In the graphs that are presented in the following paragraph, this limitation has not been taken into account. Some of the reactions described in these graphs could not occur, if the range of pico-gravity is too small.

A third point is worth being noted: the proton and the deuteron behave differently. The mass of the latter is sufficient to insure an attractive combined Coulomb gravitational potential, even at very short distance from the nucleus of A. An equilibrium position can be found between this attractive combined potential and the repulsive potential created by the Pauli exclusion principle.

On the contrary, the progression of the proton towards the nucleus of A is limited to a minimum distance [Eq. (10b)]. Anyhow, an equilibrium could be reached, the proton oscillating round its minimum distance from the nucleus of A given by Eq. (10b), but it is likely that reactions with hydrogen should be less frequent and with a lower rate than those observed with deuterium. In other words, the pico-gravity conjecture explains heat production with deuterium. In certain favourable cases (nickel and compact atoms for instance) hydrogen could also react. This will be exemplified below.

9. Examples of Bound States of Hydrogen Isotopes with Selected Atoms A

The case of four atoms A will be examined: nickel, palladium, caesium and strontium.

9.1. Case of Nickel

The calculation has been made for the most abundant nickel isotope ($^{58}_{28}$Ni, 68%). Results are displayed in Fig. 2, giving the total energy of the hydrogen isotope as a function of the distance to the nucleus of Ni.

For deuterium, a bound state could occur with binding energy of some 200 eV. For hydrogen, as explicited above, the proton could oscillate at a distance $r_{\min}$ of some 55 pm from the nickel nucleus with a binding energy round 350 eV.

The type of radiation expected is a copious emission of very low energy X-rays, more likely to be detected as heat in the calorimeter. Heat generation has indeed been observed in the system Nickel/Hydrogen [10].

The rate of reaction should vary with the various isotopes of nickel (influence of A), giving rise to an apparent isotopic change in the remaining unreacted nickel.

As regards the products formed, they could mimic (depending upon the analytical method used) atoms A′ resulting from the addition of proton(s) or deuteron(s) to the nucleus of A. This point will be discussed in detail below in the case of caesium and strontium.

9.2. Case of Palladium

The calculation has been made for the most abundant palladium isotope ($^{106}_{46}$Pd, 28%). Results are displayed in Fig. 3, giving the total energy of the hydrogen isotope as a function of the distance to the nucleus of Pd.

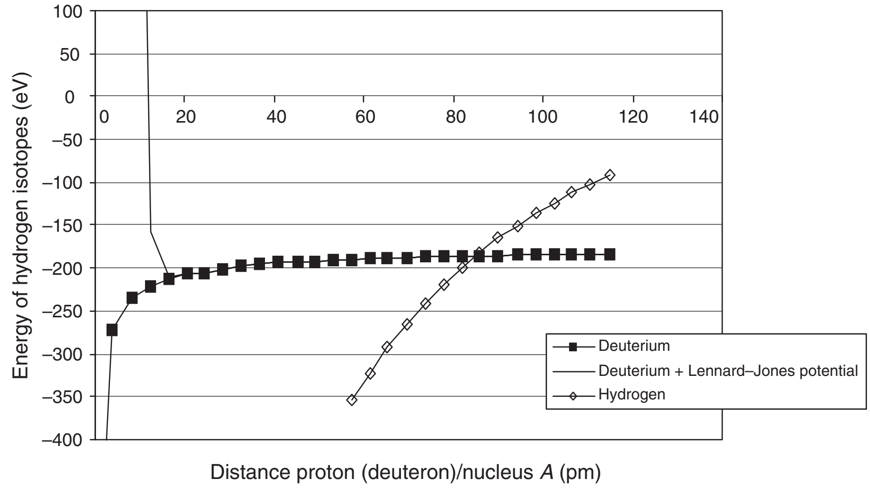

Figure 2. Bound states of hydrogen isotopes with Nickel (58).

For deuterium, a bound state could occur with binding energy of some 800 eV. For hydrogen, the binding energy should be less, round 650 eV corresponding (as for nickel) to the layer $i_{\min}$. Same considerations as for nickel, apply for the other characteristics of this reaction.

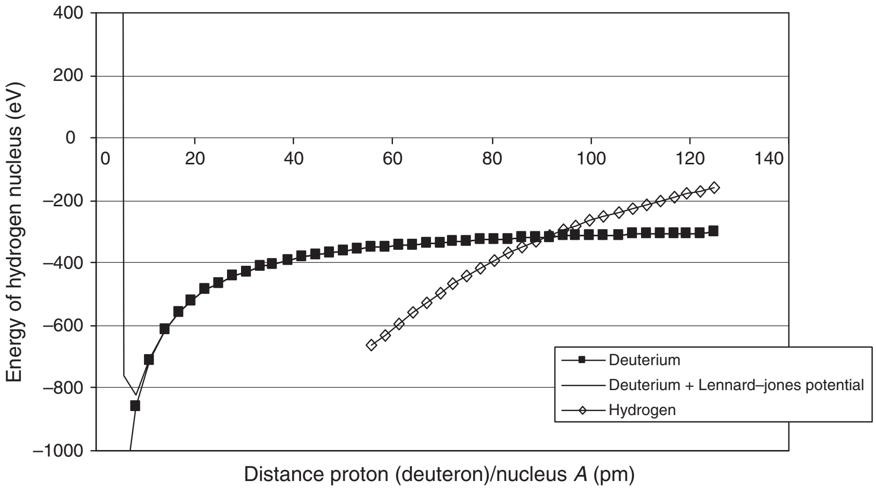

Figure 3. Bound states of hydrogen isotopes with palladium (106).

9.3. Case of Caesium

The calculation has been made for the sole stable caesium isotope ($^{133}_{55}$Cs, 100%). Results are displayed in Fig. 4, giving the total energy of the hydrogen isotope as a function of the distance to the nucleus of Cs.

For deuterium, a bound state could occur with binding energy of some 1200 eV. For hydrogen, the binding energy should be very low: 50–100 eV and decreases when the distance proton nucleus decreases.

In that case, the energy for $i_{\min}$ is very low and it is very unlikely that the proton could oscillate round $r_{\min}$ as for Nickel and hydrogen. Caesium could even not react with hydrogen, the distance at which the combined Coulomb gravitational potential becomes repulsive being some 70 pm, which might be to close to the maximum range of pico-gravity.

The case of caesium has been the object of extensive experimental studies [2,5]. By permeating deuterium through a complex layered structure of palladium and calcium oxide, containing minute amounts of caesium, the apparent following nuclear reaction has been observed (with various experimental techniques):

$$^{133}_{55}\mathrm{Cs} + 4^{2}_{1}\mathrm{H} \rightarrow {}^{141}_{59}\,\mathrm{Pr}, \;\; Q = 50.5\,\mathrm{MeV}. \tag{14}$$

The Q-value was calculated from the mass defect of Eq. (14).

Should reaction (14) occur, copious fast neutrons would be generated (they where not observed). It is unlikely that the majority of the energy could be passed to fission fragments (because of the Coulomb barrier) or to gamma rays (because of the slow electro-magnetic transition).

Following analytical techniques were used to characterize the apparently formed praseodymium:

(1) In situ X-ray Photoelectron Spectroscopy (XPS) for most of the experiments.
(2) X-ray Absorption Near Edge Structure (XANES) for some experiments.
(3) TOF SIMS for a few experiments.

Results of in situ *XPS*: they show the clear disappearance of the caesium LM lines and the concomitant appearance of the praseodymium LM lines.

Results of XANES: they confirm the results of in situ XPS.

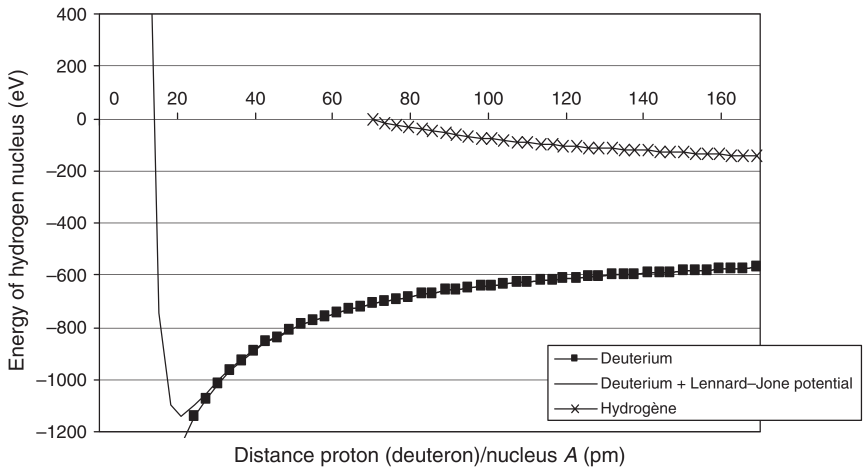

Figure 4. Bound states of hydrogen isotopes with caesium (133).

Results of TOF SIMS: they clearly show the appearance of an atom with mass 140.90 very close to the mass of praseodymium (140.908). No standard deviation of this result is given: TOF SIMS has a very high resolution, but it cannot be excluded that the absolute value found is not exactly 140.90: it could be closed to, but different from this value. This point will be discussed below.

9.4. Case of Strontium

The calculation has been made for the most abundant strontium isotope ($^{88}_{38}$Sr, 82.6%). Results are displayed in Fig. 5, giving the total energy of the hydrogen isotope as a function of the distance to the nucleus of Sr.

For deuterium, a bound state could occur with binding energy of some 800 eV. For hydrogen, the binding energy should be in the order of 50–100 eV. As for caesium, the existence of a minimum of the total energy for the proton, will depend upon the exact range of the increased gravity, which, as stated before, has not been taken into account in Fig. 5. As for caesium, strontium could even not react with hydrogen.

As for caesium, the case of strontium has been the object of extensive experimental studies [2,5]. By permeating deuterium through a complex layered structure of palladium and calcium oxide, containing minute amounts of strontium, the apparent following nuclear reaction has been observed (with various experimental techniques):

$$^{88}_{38}\mathrm{Sr} + 4\,^{2}_{1}\mathrm{H} \rightarrow \,^{96}_{42}\mathrm{Mo}, \quad Q = 53.5\,\mathrm{MeV}. \tag{15}$$

The Q-value was calculated from the mass defect of Eq. (15).

Following analytical techniques were used to characterize the apparently formed molybdenum:

(1) In situ XPS for most of the experiments.
(2) Secondary Ion Mass Spectroscopy (SIMS) for many experiments.

Results of in situ XPS: they show the clear disappearance of the strontium lines and the concomitant appearance of the molybdenum lines.

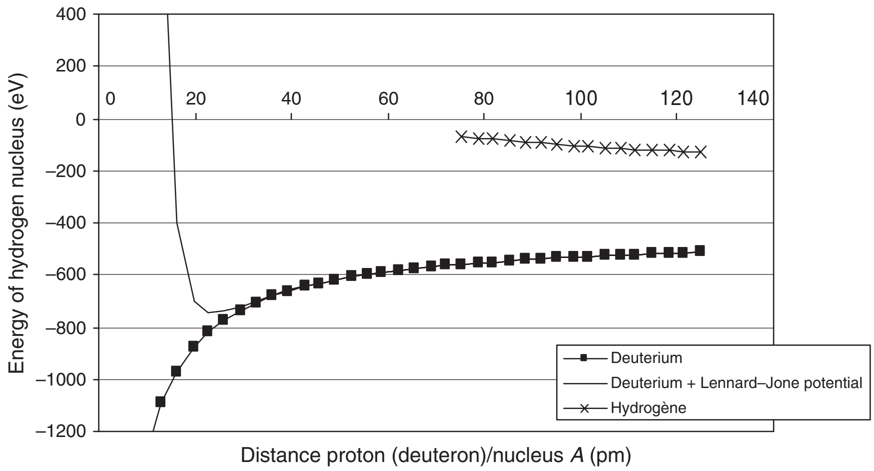

Figure 5. Bound states of hydrogen isotopes with strontium (88).

Results of SIMS: the product of strontium transformation has an isotopic composition very different from that of natural molybdenum. The major "molybdenum" peak is ${}^{96}_{42}$Mo. The major isotope of strontium is ${}^{88}_{38}$Sr. It is thus tempting to attribute the formation of Mo to reaction (15) and the similar ones for the other strontium isotopes

9.5. General Comments for the Case of Caesium and Strontium

All experimental observations described above, together with the absence of reaction with hydrogen, have been presented as strong evidence for nuclear reactions (14) and (15) to occur in solids.

The model presented here gives a simple and semi-quantitative description of another possible mechanism:

Four deuterons bind to the nucleus as described above (the proposed model is too simple to confirm or refute the assumption made that four deuterons could bind) and form a complex compound that can be written: $\left[{}^{88}_{38}\mathrm{Sr},4{}^{2}_{1}\mathrm{H}\right]or\left[{}^{133}_{55}\mathrm{Cs},4{}^{2}_{1}\mathrm{H}\right]$.

As these deuterons are close to the nucleus of strontium or caesium, the external electronic layers of the compound formed, see in fact a molybdenum or praseodymium nucleus and this is what XPS or XANES describe. The isotopic variation observed for the case of strontium is also a straightforward consequence of the model.

Remains the case of the mass of the "praseodymium" formed: the mass of ${}^{141}_{59}$ Pr is 140.9076.

The mass of $\left[{}^{133}_{55}\mathrm{Cs},4{}^{2}_{1}\mathrm{H}\right]$would be very close to 140.9614, a 380 ppm difference with the mass of Pr, that can be distinguished by TOF SIMS. What is questionable is the absolute calibration of the apparatus and this point would be worth being studied in details. A measure of the standard deviation is a must, together with an absolute calibration of the system.

10. Pico-gravity Conjecture and Other Observations in the Field of So-called Cold Fusion

10.1. Helium-4 Production

It has been observed experimentally (as mentioned in Section 4.1) that excess heat frequently occurs with the production of helium 4 in quantities many orders of magnitude higher than would be expected from a "hot fusion" reaction. This helium production has been ascribed to a special kind of dd fusion reaction where helium 4 is the main product. Another plausible scenario to explain this (apparent) helium 4 production is the following:

(1) Case of deuterium and palladium: the expected energy per pico-chemistry reaction in that case, is some 800 eV. It is likely that any helium 4 in the surroundings of the reacting palladium atom would get sufficient energy to be expelled from the lattice and measured as "reaction product". In these circumstances, any correlation between the energy produced and the helium measured would only reflect the initial helium 4 content of the lattice. It is interesting to note that there is a great dispersion in the measured values of the energy per atom helium 4 produced in the case of palladium (the most studied system).

(2) Case of hydrogen: as mentioned above, the reaction with hydrogen according to the pico-gravity conjecture is less probable, with a lower rate than with deuterium and likely to be limited to compact atoms like nickel. Data are lacking on a possible (apparent) production of helium 4 in that case.

10.2. "True" nuclear reactions

Nuclear signatures at very low level, as alphas or fast charged particles, have been observed in certain experiments. These can be accounted for by the pico-gravity conjecture. Consider the case of deuterium and palladium. As mentioned above, in very rare occasions the deuteron could reach the nucleus of the atom A and react with it. As an example, the following reaction could be observed:

$$^{105}_{46}\mathrm{Pd} + ^{2}_{1}\mathrm{H} = ^{103}_{45}\mathrm{Rh} + +^{4}_{2}\mathrm{He}, \quad Q = 10.8\ \mathrm{MeV}$$

yielding fast alphas and lower mass isotopes (transmutation in lighter isotopes).

11. Range of the Increased Pico-gravity and Possible Effects on Known Systems

In the modern concept of gravitation increase, additional space dimensions open at a given range.

Modelling such concept is far beyond the scope of this note. One requirement is that this opening does not conflict with known physic and chemistry. So the range of these new dimensions should be well within atom size. A range between some 50 and 100 pm seems realistic. Known chemistry would not have seen them. Inside the atom and due to the very small mass of an electron, the electronic layers would not be altered in a measurable way. There remains the case of the Lamb shift which is related to the mass of the electron. The overall mathematical treatment of the effect of the pico-gravity conjecture combined with quantum electrodynamics is probably extremely complex. Should this problem find a solution, an explanation could be found for the discrepancies observed between the predicted value and the most recent experimental measurements of this Lamb shift [11].

The finite range of these new dimensions also requires gravity to be carried along these dimensions through a massive graviton. An estimation of the mass of this graviton, is given by the Yukawa relation between its range r_{G} and its mass m_{G}:

$$r_{\mathrm{G}} = \frac{\hbar}{m_{\mathrm{G}} c} \quad (\text{with } c = \text{speed of light}) . \tag{16}$$

For $r_{\mathrm{G}} = 50$ pm, Eq. (16) yields $m_{\mathrm{G}} \approx 5$ keV. The minimum detectable mass of a particle being some 250 keV, this graviton would presently be undetectable. But this mass could explain why cross sections in reactions involving its action should be energy dependant. This might be an explanation of the discrepancies observed in the cross section of a deuteron beam and a deuterated target at very low energy of the deuteron, when compared to the cross section predicted by high-energy experiments [9].

One of the main practical problem, which could be due to the limited range of this hypothetical strong gravity, would be the need for a sizeable activation energy (tens of eV), to obtain a pico-chemistry reaction. Indeed, before reaching that range, the proton (deuteron) would be submitted to the full Coulomb repulsion of the nucleus of A. Some of the reactions presented in the above graphs, may be very difficult (if not impossible) to obtain.

Finally at femtometer scale, this increased gravitation would anyhow be some 10^{-4} weaker than the strong nuclear force and acting on quarks with mass close to 1/3 the mass of protons would have an ever weaker effect: strong gravity as required by the present model would also have been unnoticed. As regards the weak nuclear force at attometer scale, things are less clear, but two of the particles involved (electron and neutrino) have a small mass, probably closed to zero for the latter.

It is obvious that a great number of questions are still to be answered. Detailed study of the formation and characteristics of compounds such as, for example $\left[^{133}_{55}\mathrm{Cs},4^{2}_{1}\mathrm{H}\right]$, should shed more light on all those questions.

12. Conclusions

The novel working hypothesis proposed could open a new field of chemistry. It is proposed to call this new field “pico-chemistry”. In pico-chemistry enthalpies of reaction are some 100 times higher than ordinary chemical reactions (oil combustion for instance).

Moreover, a better knowledge of the variations of the gravitational constant with distance could help reconcile quantum mechanics and relativity. A massive graviton, with mass round 5 keV is predicted.

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