

A Possible Mechanism For Cold Fusion

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Abstract. We describe a mechanism for cold fusion that is able to explain how two hydrogen ions may come close enough so as to fusion as well as many of the different and independent experimental observations made during years of experiments. We present the mechanism, its weak points, the way it explains the respective phenomena and suggest some experiments that may validate further the model described by us.

The initial work of Fleischman and Pons [1] produced a huge wave of experiments more than twenty years ago. Even if a lot of experiments have been done since then, the acceptance of the facts by the wide scientific community is still to be obtained. This reluctance in acceptance is due to two main reasons: a) the experiments are not yet fully reproducible; b) there is no clear explanation on how two positive ions may get so close, at room temperature, so as to fusion. As regards the argument “a)”, we may affirm that experiments are beginning now to acquire a high degree of reproducibility, se for example the site (www.lenr-canr.org). It remains only the second argument and we will show how such a mechanism may exist and explain this “exotic” phenomenon. In order to do this, we start from several observations: a) from the literature [2], [3] it results that in Pd hydrogen exists in Pd as a positive ion; b) the ions are moving in a periodic electrostatic potential given by the periodic location of the host lattice ions, being a superposition between the potential made by the positively charged metal ions, potential screened by the free electrons of the metal. This last aspect suggests an analogy with the case of electrons in solids [4], [5]. Starting from this point and having in mind also the theory of the Kronig-Penney potential [6] that predicts formation of energy bands in case of periodic potentials, we may conclude that the hydrogen ions exists in such energy bands in the solid. Each type of isotopes has its own energy band structure. We must mention here that a model based on energy band structure for the hydrogen ions was proposed earlier by [7], [8], but this fact was unknown to us when elaborating our model five years ago. However, we follow another route as compared to [7], [8], route that allows us to explain the main aspects of the mechanism and why cold fusion may take place at room temperature. The energy bands may be separated by forbidden energy gaps or may superimpose, as in the case of metals. We refer from now on only to the energy band structure corresponding to hydrogen ions. Following the usual route in solid state physics, we describe the kinetics of the hydrogen ion by its energy E and its wavevector k . There is always a relation $E = E(k)$ between these two parameters, relation that is called the dispersion relation. We may deduce from it another important parameter, the effective mass m^* of the ion within the lattice:

$$\frac{1}{m^*} = \left(\frac{\partial^2 E}{\partial k^2} \right) \quad (1)$$

In the general case, the effective mass is a tensor (we omitted this in the explicit form of eq.(1), but this is not important). The effective mass is applicable especially when considering the particle at one of the band edges, namely upper edge or lower edge. At the lower edge the effective mass is positive. At the upper edge the effective mass is negative [4], [5]. As it is known, an electrically charged particle with negative effective mass behaves in an electric field like a particle of positive effective mass but having an opposite charge [4]. In the case of hydrogen ions, this means that an ion that is excited at the top of an allowed energy band has a negative effective mass and it behaves, in an electric field, as a negative ion with a positive effective mass. This is a very important feature and is the key to our model. In figure 1 we present a sketch of an energy band (we do not show explicitly its structure obtained from the dispersion relation), the black circles representing the hydrogen ions.

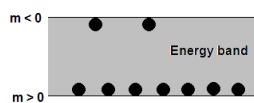


Figure 1 – Sketch of an energy band containing several hydrogen ions.

It must be taken into account that a particle may reach the upper part of an energy band only by excitation (thermal or of other nature) and it will stay only a certain interval of time in the respective state because of scattering on different quasi-particles (phonons, lattice ions, impurity ions, etc.). For the sake of simplicity, we consider throughout the work that hydrogen does not form any hydrides or, if it forms, the hydrogen

concentration in the material is so high that all the hydride-type bonds are saturated with hydrogen and the remaining hydrogen ions are moving relatively free within the "lattice" formed by the potential wells.

The mechanism we propose is as follows: a hydrogen ion is excited to an upper energy state having negative effective mass. This excited ion will stay a time τ in the excited state. During this period, the excited ion may interact electrostatically with another hydrogen ion that has a positive effective mass. The interaction is depicted in figure 2. The electrostatic repulsion takes place as normally, without the need to mitigate the Coulomb barrier, but the behaviour of the ion with negative effective mass is different from that of the usual, positive mass particle. The ion 2 will have an acceleration oriented in the opposite direction to the repulsion force, so that it will tend to move toward ion 1. If the accelerations satisfy the condition $a_2 > a_1$, then the net effect is that the two ions are approaching each other. The mechanism is also applicable for the case when both ions have a negative effective mass, case in which their accelerations were directed toward their centre of mass.

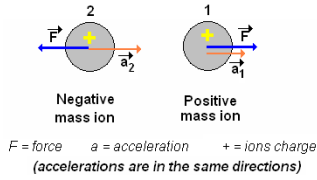
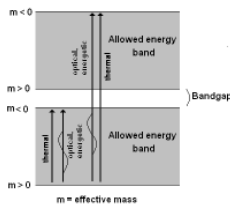


Figure 2 – Electrostatic interaction between two hydrogen ions, one with positive effective mass (ion 1) and one with a negative effective mass (ion 2).

That electrostatic repulsion becomes thus the mechanism by which the two ions may get close enough so as to trigger fusion. In fact, it is the case of two (quasi)particles moving in the central potential of electrostatic nature. There is the possibility of orbiting around the center of mass or to directly collide / coalesce. In the case of orbiting, a first temptation is to use the expression of Bohr radius but replacing the electron mass with that of the hydrogen ion. This approach indicates an orbiting radius of few tens of femtometers, small enough so that nuclear fusion takes place with a certain probability. It is mandatory to mention the fact that the two ions must be in different allowed energy bands so as they be able to get so close. If they would be in the same energy band, then the symmetry conditions will forbid them to form a closely orbiting system. That is, sharing the same Brillouin zone [5] will impose a certain distance between the two ions, a distance high enough (of the order of the host lattice constant) so as to prevent any fusion process. If we take into account that heavier ions will get closer than lighter ones, the sequence of fusion probability will be given by $T > D > H$, where T stands for tritium, D for deuterium and H for proton. For example, deuterium is twice heavier than proton, so that we expect that the orbiting radius for the case of deuterium be approximately half of that corresponding to the proton. In other words, the heavier isotopes are the most probable to fusion by such a mechanism, since the orbiting distance between them will be smaller. This approach is generic and useful for describing the basic mechanism of the model even if the use of the expression for the Bohr radius is very rough approximation. In reality, the overall potential (electrostatic repulsion + lattice) changes as the two ions get close each other. In such a situation, the energy band structure changes as well with the distance between ions and so does also the effective mass. An iterative computation is needed for obtaining a correct estimate of the orbiting distance. Moreover, the host lattice expands as hydrogen is incorporated into it. This means that the band structure (and the effective mass) varies with the content of hydrogen. Such a mathematical computation is complex and, especially, needs a high computational power so as to tackle the problem with sufficient precision. Because of that we cannot present here a more accurate estimation of the orbiting distance. Even if this approach is attractive as regards the increased fusion probability at this distance, there are two questions. The first one is simple and can be expressed as: which is the effective mass value of the hydrogen ions (both positive and negative effective mass) in the lattice ? The answer to this question can be given only by band structure computation and from experiments. As regards the computation, the second question is: is the effective mass approximation, as used in exciton theory, valid for such small distances between the ions and for such electrostatic interaction energy ? The usual answer, as presented also in [4], is no. However, we assume that, even for the two interacting hydrogen ions, the energy band structure is continuous everywhere in the lattice, as well as are its first and second derivatives with respect to the coordinates and, respectively, to the wavevector of the ions. It is obvious that the band structure varies dramatically in the region where the two ions interact, but there can still be defined a band structure and a local (position dependent) effective mass, an effective mass that is dependent on the distance between the ions. However, even with this problem, the model can explain in a unitary manner many experimental results presented in the literature, as will be seen further. The problem of the correct effective mass computation, as well as of the radius of the system formed by the two orbiting ions (value that determines the fusion probability), is open. Novel computational techniques (as regards the methodology of computation) should be developed for answering to the questions above. One of the aims of this paper is to initiate such an approach since there is a need to clarify these computational aspects as well as to use supercomputers devoted to intensive computing in order to tackle the band structure computation task. However, it must be taken into account that the effective mass approximation is a mathematical tool and not a physical principle. Thus, our model can be criticized for applying an inappropriate mathematical model but not be considered as being unphysical. This lack of mathematical formalism is the weak point of our model. When orbiting, the two ions form a bound system having a discrete energy spectrum, as in the case of excitons in solids [4] and electrons in atoms [6]. Because the interaction energy at such short distances is of the order of tens of keV, we expect that the specific energy spectrum of such a bound system be active in the X-rays region. Emission of X-rays with specific wavelengths was experimentally proven in [9], [10] as well as in [11], [12]. In [11] the authors claim that the emitted X-ray wavelengths are not specific to any characteristic X-ray spectrum of the known elements. We consider that the X-rays are emitted by the bound system

formed by the two orbiting ions, during system de-excitation to a lower energy state, analogue with the case of electrons in excited atoms. Because of the specific, discrete energy levels of the bound system, the emitted X-ray spectrum has wavelengths that are specific for the difference in energy between the levels involved in the de-excitation transition, wavelength that are not encountered in none of the characteristic X-ray spectra of the known elements. An interesting consequence of our model is that illuminating a hydrogen loaded sample with X-rays having wavelengths identical to these experimentally determined ones (that have a specific emission spectrum during reaction) will reduce the reaction rate. This is so because resonant excitation of the bound system will increase the orbiting radius, similar to electrons in atoms (resonant illumination of an atom excites the electron on a state that is further from the nucleus than is the fundamental state). This is a theoretical prediction that, to our knowledge, was not yet reported experimentally. Its experimental verification will check the validity of our model. Let us now consider the ways in which an ion may be excited to the upper energy state of negative effective mass. One way is by excitation at thermal equilibrium, when collisions with different quasi-particles existing in the lattice may give the ion enough energy to reach the top of the energy band. The higher the temperature is the greater is the number of ions with negative effective mass. Another way is to use external factors such as illumination with photons or bombardment with energetic particles (electrons, ions) [13]. Since we have an energy band structure,



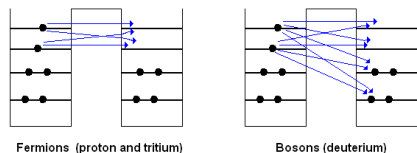
only photons with appropriate wavelengths may excite the ions to the energy states of negative effective mass. Such a resonant / selective excitation is observed in [14]. We mention that an estimate of an allowed energy band width, in the approximation of a Kronig-Penney potential, indicates a value of the order of several tens of meV ($1\text{meV} = 0.001\text{ eV}$). Excitation may take an ion from the bottom of a band to the top of the same band or may take the ion from the bottom of one band to the top of another band, as shown in figure 3.

Figure 3 – Sketch of the excitation path for a hydrogen ion.

In this case, the energy of excitation may vary from several meV up to several eV. Such a situation is encountered in [14-16]. We mention that in [15-16] the energy difference between the two incident light beams is claimed to have effect in enhancing the fusion process. It seems that the two beams excite a phonon in the metal, in the THz frequency range, this quasi-particle being responsible for the enhancement.

Let now make some discussions about the model. We assert that the Born-Oppenheimer approximation [5] is applicable to the hydrogen ion also. We make this assertion because we expect that the mass of the hydrogen ion in the lattice do not differ significantly with respect to hydrogen mass in vacuum. This assumption is based on the analogy with electrons in crystals. Hydrogen has a relatively high mobility in heavy metals that have an atomic mass of at least tens of hydrogen atomic masses. For example, Pd has an atomic mass that is 106 times greater than hydrogen mass [17]. On the other hand, hydrogen diffusion in metals is a slow process, the hydrogen ions being all the time in thermal equilibrium with the lattice / metal ions. Because of these two reasons, hydrogen ions are approximately ten times faster than the lattice ions, so that Born-Oppenheimer approximation may be applied without introducing great errors, of only few percent. As numerical values, we mention that an error of less than 10 % for proton in Pd and of approximately 16 % for tritium in Pd is obtained. These are acceptable errors. The Born-Oppenheimer approximation indicates to us that we may look at the "lattice" formed by the potential wells (for the hydrogen ions) as being frozen, hydrogen ions moving within this lattice. Because such a potential well is formed by the contribution of several atoms that oscillate in an uncorrelated manner, the potential well is also squeezed at the same frequencies as those of atom oscillations. Since the displacements of atoms, at room temperature, are small compared to the interatomic distance within the metal lattice, we may consider that the deformation / squeezing of the potential wells is small compared to the well size.

Let us consider also another aspect, namely that two hydrogen isotopes are fermions (proton and tritium) while deuterium is a boson. This is a very important feature. Consider two adjacent potential wells, one having a higher number of hydrogen ions than the other, as depicted in figure 4. In the left part, we have the case of fermions. In the right part, we have the case of bosons.



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Figure 4 – Sketch of the way in which fermions, respectively bosons, diffuse.

We simplify and consider discrete energy levels, but the explanation may be extended in a straightforward manner to band structure also. Let consider fermions first. The fermions from the left quantum well may diffuse / tunnel only on the un-occupied states in the right quantum well because of the Pauli exclusion principle. This means a low number of available states for transfer, as seen from figure 4. In the case of bosons, there is no exclusion principle and they may diffuse / tunnel on any of the states existing in the right-side quantum well since several bosons may share the same energy state. This means a higher probability of transfer from one well to the other than in the case of fermions because of the greater number of available states able to receive an ion. The same arguments are applicable also to the boson ions lying on the lower energy states of the left quantum well from figure 4. Because of that all the bosons participate in the diffusion process and not only those from upper energy levels. Thus, the energy band model may explain why deuterium diffuses easier in metals than

the other hydrogen isotopes. Because of the same reason, the boson character makes Pd able to load a very high concentration of deuterium as compared to the case of proton. The normal sequence for the diffusion coefficients would be $H > D > T$, since the heavier a particle is the lower is its diffusion coefficient. But taking into account the fermion / boson character of each ion and the above arguments, the correct sequence for the diffusion coefficients is $D > H > T$ (see figure 4), as is observed experimentally. Taking into account that the orbiting distance is smaller for heavier isotopes, it results that the most favorable isotope for observing cold fusion is deuterium. This is due to its higher mass (that allow him a smaller orbiting radius than in the case of proton) and to its bosonic character that allow him to diffuse faster and be incorporated in a greater amount than the other isotopes.

As regards the true potential in which the ions move, let's consider a direction in the crystal that is along the great diagonal of the lattice cube of Pd. This great diagonal passes through the center of the cube and also through two of the host lattice nuclei. Taking into account that hydrogen interacts electromagnetically with the screened electrostatic potential of the lattice ions but has also the ability to present strong interaction, it results that the hydrogen ion sees a potential formed by two kinds of quantum wells: electromagnetic and nuclear, as depicted in figure 5. The nuclear quantum well corresponds to the lattice ion. From the quantum mechanics point of view, there is no formal difference between an electromagnetic potential well and a nuclear potential well. Thus, we may consider that there is a coupling between lattice energy levels and host nuclei levels for the hydrogen ions. This is so because solving the Schrödinger equation for this system of quantum wells will results in energy levels / bands that are common to both types of wells, electromagnetic and nuclear. This phenomenon is specific only to the host lattice in its solid state. This fact suggests the possibility that nuclear reactions in solid state occur in a slightly different manner than in the liquid or gaseous state of the host lattice, cold fusion being only a particular case of that. The situation depicted in figure 5 is idealized, in the sense that we have drawn rectangular walls for the potential wells.

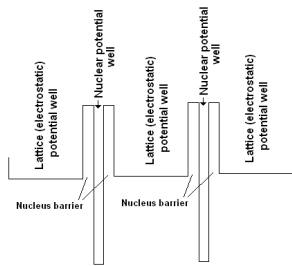


Figure 5 – The true quantum potential for the hydrogen ion in solids.

Let's now consider the behaviour of the system when cold fusion takes place. Suppose that in a certain place in the host metal a fusion process is initiated by using some means. The occurring of the nuclear fusion in that region of the metal produces heat, heat that locally increases the host temperature. Because of the increase in temperature, there will be an increased number of ions excited to higher energy states that are characterized by a negative effective mass. Thus, the number of ions with negative effective mass is increased. This increase in their number has as a result the increase in fusion processes that, at their turn, increase further the local temperature. In this way, a positive feedback appears, in the sense that, once initiated, the fusion process may go further without the need of any external action and can even be self-sustained as described in [18], [19]. Self-sustainability appears in the case when the system generates more energy than it dissipates. There is also a negative feedback, given by several mechanisms such as: a) the lifetime τ in the excited state decreases with increasing temperature because of the increased scattering on lattice specific quasi-particles, thus decreasing the time for the two ions to approach each other enough for fusing; b) consumption of reactant particles (at that specific site in the lattice) as a consequence of the fusion process, process that is faster than the supply made by diffusion from outside; c) the deterioration, and even melting, of the host lattice as a result of the collisions of the energetic ions resulted from fusion, deterioration that mitigates the local energy band structure and thus mitigates the mechanism for hydrogen ions approaching; d) hydrogen out-diffusion from the regions where fusion takes place, this process being due to the fact that an increase in local temperature produces an increased diffusion of hydrogen ions from the warmer region to the colder ones, this out-diffusion being able to reduce or even reverse the flux of ions coming from regions with a higher ion concentration; e) heat dissipation rate to the exterior, dissipation that allows the crystal to not overheat excessively (as in the case when is mounted in vacuum) and thus to limit the positive feedback loop. This process of dissipation depends on the metal (through density, specific heat and thermal conductivity) and on the cooling boundary conditions. If non-equilibrium (illumination or particle bombardment) excitation of hydrogen ions is made, a good dissipation of the generated heat to the exterior can make the difference between a successful experiment and an experiment having a more violent, explosive character. These negative feedback mechanisms may dominate at higher reactions rates because of the reasons told above. Thus, we may expect a reaction rate that depends on temperature in a non-linear fashion, having a maximum value at a certain temperature, as described in [20]. This happens because below that temperature, the dominant role is taken by the positive feedback, which tends to increase the temperature. Above the temperature corresponding to the maximum of the reaction rate, the negative feedback becomes dominant, which tends to reduce the reaction rate. There is necessary a threshold value of the hydrogen concentration because under this value: a) the fusion processes are rare; b) thermal conduction of the metal carries out the heat sufficiently fast so as the positive feedback be insignificant and no experimental observation of the heating be made; c) let "d" be the path length made by a negative mass ion during its stay in the excited state. If this path length is less than the average distance between ions (equal to $N_0^{-1/3}$ where N_0 is the total ion concentration), then the probability that the excited ion encounter another ion is reduced. As a consequence the reaction rate is reduced correspondingly. Increasing concentration lowers the average distance between ions and the encounter probability becomes higher, the same happening for the reaction rate. Let denote by "f" the fraction of ions having a negative effective mass N_0 be as above. "f" depends on temperature and is equal to 0.5 when temperature tends to infinity. It may be computed

from the Fermi-Dirac or Bose-Einstein distribution function (depending on the type of isotope) and the density of states specific to the ions. The concentration of ions with negative effective mass is thus equal to $f \cdot N_0$ while the concentration of ions with positive effective mass is equal to $(1-f) \cdot N_0$. The fusion reaction rate is equal to the product of these two concentrations (there is also the reaction cross-section that multiplies these two concentrations), being equal to $f \cdot (1-f) \cdot N_0^2$. Thus, from our model, it results that the fusion reaction rate is proportional to the square of the hydrogen ions concentration, as is observed experimentally. There is enough experimental evidence that shows that heat emission takes place only after a certain concentration of hydrogen is obtained in the Pd lattice. This can be explained by two main aspects. First, the observation of rise in temperature produced by the nuclear reaction depends on the sensitivity and speed of the devices used for measuring temperature (thermometer, infrared camera) and by the thermal noise of the Pd+calorimeter system. A very sensitive apparatus and a Pd/calorimeter system with very low noise will show a lower threshold concentration. The generated heat flux must be at least comparable to the heat loss flux in order to produce an observable effect (else, the signal is small and extinguishes fast with time). A system with a lower heat dissipation rate will show a lower threshold concentration. Secondly, it must be taken into account the explanation given above when comparing the average distance between hydrogen ions with the mean free path of the negative mass ion. A higher concentration increases the probability of encounter and thus the reaction rate. As regards the generated heat, there is an infrared emission of the metal surface, the spot corresponding to the highest temperature having a position that varies randomly onto the surface [21]. As we have mentioned earlier, the necessary condition for reaction is the thermal excitation of the hydrogen ions on energy states with a negative effective mass. This is a random process. A greater fluctuation (of thermal excitation) at a point may produce a greater reaction rate, with heat emission. The temperature increases at that point and positive feedback is triggered (above a threshold determined by the heat loss rate). This positive feedback consumes some part of the hydrogen at that point, so the spot extinguish in time. Then, another fluctuation appears at other place, in a random manner (the temperature and concentration fluctuations are random processes) and the process is repeated. A consequence of this explanation is that the bright spot never appears twice at the same place (or at least appears after a long enough time so as the ions concentration be recovered at that place), since the hydrogen ions in that place are consumed during the first spot. We don't have yet data or experimental results to prove this last assertion, it results from the model proposed by us. Another should also be addressed. The experimental data show that Pd under nanopowder form or with a nanostructured surface shows a better cold fusion effect than the smooth surface, bulk form of it. We may explain this by two mechanisms: a) first, a nanopowder / nanostructured material has a greater surface exposed to the hydrogen permeation than a sample with a smooth surface, so that it can absorb faster a greater amount of hydrogen; b) from the point of view of our model, nano-grains have a lot of surface states. As it is known from solid state physics [5], at the surface of a material allowed energy states exist in the forbidden gap. In a nanostructured material, the effect of these states is similar and even higher than that corresponding to the bulk. An ion from a lower energy band may access easier to a higher energy band by transitioning through these surface states. Thus, the overall effect is an enhancement / ease of the ions excitation from one allowed energy band to the next higher one, resulting in an increase of the reaction rate in nanostructured materials. There is also another effect produced by the nano-size of the grains: the variation of the energy band structure (allowed bands widths, distance between bands) as compared to the bulk host one, in a way similar to that of electrons in superlattices.

These are some of the experimental results that can be explained by our model. Our model does not contradict that one based on the screening effect made by the free electrons of the metal. In fact, screening proves a support for the ions to get closer. Thus, our model may accommodate the electrostatic screening as a factor supporting / easing the fusion process but not as a factor determining it. As regards the plasma wave model proposed by [22], the plasma wave may be considered as exciting the ions to upper energy states where they acquire a negative effective mass. However, even if the plasma wave model is an interesting model, it cannot explain why X-ray radiation with specific wavelengths is emitted during reaction and why the effect observed by Letts and Cravens is taking place. Our model does not have such a limitation. There is another interesting model proposed by [23]. In principle, our model does not contradict with this one too, in the sense that the Bose-Einstein condensation may be accommodated by our model. However, we consider the use of the Bose-Einstein condensation concept as being limitative, since such a condensation is achieved only on the lowest energy state of the system. This is not happening all the time. We consider that, more probably, the deuterium ions may form ensembles of entangled ions. Such an ensemble containing N ($N \geq 2$) ions behaves like an entity having N times the (positive or negative) mass of a deuteron and N times its positive charge. This is possible since several bosons may occupy the same energy state and be described by the same wavefunction. This entangled entity is more probably involved in the mechanism described in [23] and it may form on any of the energy states existing in an allowed energy band. We must also emphasize that our model is applicable to all cases where a periodic potential exists for the hydrogen ions (crystal lattice, long molecules in complex molecular systems in which exist mobile hydrogen ions as encountered in biological systems, etc.).

By the way of the work of [14], [15], we must say that a similar effect must be observed by using THz / millimeter / sub-millimeter radiation, with a frequency similar to or close to that mentioned in [15]. This should be so because of the resonant excitation of ions to energy states with a negative effective mass. However, the use of THz / millimeter / sub-millimeter radiation should be more favorable to observe enhancement effects than the use of visible or near-infrared lasers, because the skin penetration depth of the THz / millimeter / sub-millimeter radiation is larger than the skin depth corresponding to visible or near-infrared light. This feature makes that a greater number of hydrogen

ions be excited with THz / millimeter / sub-millimeter radiation than with optical light, fact that will increase the amount of generated heat. This assertion is also a theoretical prediction and should be checked experimentally. Another experiment that should be done is that of cyclotronic resonance in deuterium loaded Pd (both at low and at high hydrogen concentration), so as to measure the effective mass of hydrogen in the metal lattice. This measurement should give an experimental indication when trying to compute the concrete band structure for the hydrogen ions. In conclusion, some experiments that are based on our prediction may be done so as to check our model: a) illuminating a hydrogen loaded sample with X-rays having wavelengths identical to the specific ones emitted during reaction to see if the reaction rate will be reduced; b) illuminating with THz / millimeter / sub-millimeter radiation to see if an enhancement effect greater than that reported by Letts and Cravens is obtained.

At the end, we have to mention that the excitation of hydrogen ions to upper energy states with a negative effective mass is taking place all the time. Thus, even if the loading process is finished since a certain time interval, these excitations take place and may generate heat by the mechanism proposed by us. This fact explains why is observed the so-called “heat after death” [18], since the excitation processes are independent on the loading means and are occurring all the time during loading and after that. This has as one of the consequences the fact that emission of X-rays with specific wavelengths should be observed even after the external excitation of the Pd loaded sample is switched off, since the start of orbiting of the two hydrogen ions is not necessary to be made directly on the fundamental state of the ions bound system. This may offer an explanation for the experimental data obtained in [24]. Caution should be made when exciting the Pd+deuterium system by non-equilibrium means (photons, particle bombardment), since this may end with very energetic, explosive processes, as could be the case reported in [25].

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