The Process of Thermal Runaway Is the Reason of Fleischmann-Pons Effect

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Abstract: In the electrolysis of heavy water, Fleischmann and Pons found the effect of excess power. Then this effect was discovered by a number of other researchers. They explained this effect of "cold fusion" of deuterium nuclei. In the electrolysis of heavy water, it is very difficult to obtain the Fleischmann and Pons effect; it occurs spontaneously and is completely unpredictable. Therefore, a significantly larger number of researchers were unable to obtain the effect of Fleischmann and Pons. They consider this effect to be a mistake or an instrumental artifact. In this paper provides recommendations for obtaining the Fleischmann and Pons effect at will and reliably. Therefore, at present, every researcher can securely obtain the effect of Fleischmann and Pons and investigate it. The paper proves that the cause of the Fleischmann-Pons effect (of burst type) is the exothermic reaction of thermal runaway, which is caused by the desorption and recombination of atomic deuterium accumulated in the electrodes during the electrolysis of the electrolyte. In batteries with aqueous electrolyte, thermal runaway is due to a similar exothermic reaction. Therefore, the cause of the Fleischmann-Pons effect is not the "cold fusion" of deuterium nuclei. It is also shown that the cause of the Fleischmann-Pons effect (of weak type) is the partial recombination of deuterium and oxygen, i.e. in this case, the excess power is apparent or imaginary.

1 INTRODUCTION

In 1989, when studying the heavy water electrolysis in cells with palladium cathodes, Fleischmann and Pons (F&P) discovered the excess power effect (Fleischmann et al., 1989). This effect appeared suddenly after prolonged electrolysis of heavy water and lasted for several hours. In this case, the energy released by the cell was much greater than the energy received by the cell from an external power source. As Fleischmann and Pons did not find any obvious electrochemical reactions there, they assumed that the reason for the huge energy release was the deuterons synthesis nuclear reactions. Subsequently, the nuclear processes proposed by F&P became known as “cold fusion”. Studies by Fleischmann and Pons showed that the excess power effect (or Fleischmann-Pons effect) occurs randomly and extremely rarely.

Since then, some researchers managed to reproduce the Fleischmann-Pons (F-P) effect (Dominguez et al., 2014; Storms, 2007; etc.). However, much larger is the number of researchers, who failed to repeat this effect (Lewis et al., 1989; Williams, 1989; etc.). That is why currently, the majority of the researchers consider the Fleischmann-Pons effect to be a result of experimental errors (Shanahan, 2010).

However, now, the recommendations have been given (Galushkin et al., 2020) for the F-P effect reliable obtainment. From now on, any researcher can reproduce and investigate the F-P effect reliably, even if he is skeptical about it.

The F-P effect can be of two types.

(Type A). In this case, the power released by the cell was much greater than the power received by the cell from an external power source. This type of the F-P effect occurs only after prolonged (more than

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three months) electrolysis of the electrolyte and it lasts for several hours.

(Type B). In this case, the power released by the cell was just slightly exceeds power received by the cell from an external power source. This type of the F-P effect occurs after several days of electrolyte electrolysis and it can last for many days.

Some skeptics "explained" the F-P effect (type B) by experimental errors including calibration errors (Shanahan, 2010).

The F-P (type A) effect is very difficult to obtain, so the skeptics just rejected the existence of this effect (Lewis et al., 1989; Shanahan, 2010; etc.).

But currently, using the recommendations given in (Galushkin et al., 2020), the F-P (type A) effect can be reproduced reliably and purposely.

In this paper, the F-P effect is analyzed and recommendations for its reliable reproduction are given.

2 FLEISCHMANN-PONS EFFECT MECHANISM ANALYSIS

2.1 Mechanism of Fleischmann-Pons Effect (Type A)

As it was proved in the paper (Galushkin et al., 2020), the (type A) effect occurs according to the following scenario.

The reasons, which brings a cell gradually to the (type A) effect, is accumulation processes, and there are two types of the accumulations.

Firstly, during long-term electrolysis of the electrolyte (more than three months), large amounts of deuterium accumulate in the electrodes of the cell (Galushkin et al., 2020).

Secondly, this is deposits accumulation on the cathode.

As long as the deuterium accumulates in the electrodes, in parallel with the electrolyte decomposition reactions

$$2D_2O + 2e^- \rightarrow D_2 + 2OD^- \text{ (cathode)}, \quad (1)$$

$$2OD^- \rightarrow 1/2O_2 + D_2O + 2e^- \text{ (anode)}, \quad (2)$$

the electrochemical reactions of thermal runaway occur (Galushkin et al., 2020; Galushkin et al., 2015):

$$D_2O + D_{ads} + e^- \rightarrow D_2\uparrow + OD^- \text{ (cathode)}, \quad (3)$$

$$D_{ads} + OD^- \rightarrow D_2O + e^- \text{ (anode)}. \quad (4)$$

The overall reaction looks as follows:

$$D_{ads\ cat} + D_{ads\ an} \rightarrow D_2\uparrow. \quad (5)$$

For thermal runaway reactions (3,4), the rate-limiting step is the step of metal-deuterides disintegration (Galushkin et al., 2015).

$$MeD_x \rightarrow Me + D_x\,. \quad (6)$$

With due account of the deuterides decomposition reaction (6), the atomic deuterium recombination reaction (5) is a reaction with the heat release of 442.4 kJ/mol(D_2), i.e. this is a powerful exothermic reaction (Galushkin et al., 2020) and (7). While the combustion reaction of deuterium in oxygen has a heat release of only 295 kJ/mol(D_2) (Greenwood et al., 1997).

The enthalpy of exothermic thermal runaway reactions (3,4) ΔH_T differs from the enthalpy of the exothermic reactions of the free deuterium atoms recombination ΔH_{fex}=-443.32 kJ/mol(D_2) (Luo, 2007) by the value of the endothermic enthalpy of the deuterides decomposition ΔH_d. In the deuterides accumulated in metals with micro-defects (as in the F-P effect (Galushkin et al., 2020)), the deuterium atoms are bounded less strongly than in metals without micro-defects. Our experiments (similar to those from (Sakamoto et al., 1996)) showed that in metal-ceramic electrodes with a large number of dislocations, the enthalpy of decomposition of the PdD_x and PtD_x is approximately equal to ΔH_d = 0.92 kJ/mol(D_2). Hence, the enthalpy of the exothermic reactions (3,4) is equal to

$$\Delta H_T = \Delta H_{fex} + \Delta H_d = -443.32 + 0.92 = -442.4 \text{ kJ/mol } (D_2) \quad (7)$$

At the room temperature (25°C) and the current of 64 mA cm^{-2} (Table 1) (Galushkin et al., 2020), the deuterides (6) do not decompose at all (Galushkin et al., 2015). So the contribution of the reactions of the thermal runaway (3,4) to the total current of the electrolyte decomposition will be negligible (Galushkin et al., 2015).

It should be noted that if in the cell electrodes, the maximum possible amount of deuterium is accumulated, this does not mean necessarily that the Fleischmann-Pons (type A) effect will occur.

In the papers (Storms, 2007; Galushkin et al., 2020), it was proved that for the Fleischmann-Pons (type A) effect occurrence, the other mandatory condition is the accumulation of a large amount of deposits on the cathode surface.

The deposits are the highly destroyed crystal structures. In a metal, any defects of its crystal lattice are traps for deuterium because they reduce the deuterium atoms energy as compared to these atoms location in the normal interstice. Consequently, defects in the crystal structure of the electrodes facilitate the absorption of deuterium and its penetration into metals. The points of deposits on the cathode represent the most severely destroyed crystal structures. Therefore, the activation energy of sorption/desorption of deuterium at the points of deposits is the lowest.

The deuterides decomposition reaction (6) is the limiting step (Galushkin et al., 2015) for the reactions of the thermal runaway (3,4). That is why, in the deposits locations, the intensity of the reactions (3,4) will be much higher than in locations without deposits. In its turn, the intensity growth of the exothermic reactions (3,4) will result in even greater heat-up of the same spot, which leads to even higher speed of the deuterides decomposition (6), and so on. This way, in the deposits spot, a sharp increase will occur in the intensity of the thermal runaway reactions (3,4). As a consequence, there will be a release of the total amount of the atomic deuterium stored in this spot; it will be observed as a burst with a high energy release.

The heating-up of the cathode at the burst point results in heating-up of deuterides in nearby deposits, which leads to a burst occurrence in these deposits, too, and so on. This is how the Fleischmann-Pons (type A) effect develops (Fig.1 and Fig. 3 in (Galushkin et al., 2020)).

Thus, the Fleischmann-Pons (type A) effect is the totality of the bursts occurred due to the thermal runaway processes (3,4) in different spots of the cathode and at different times. This is how the change in the excess power generated by the cell looks like (as bursts) during the Fleischmann-Pons (type A) effect development Fig.1 (see also Fig. 3 in (Galushkin et al., 2020), Fig. 9A,B and Fig. 8A in (Fleischmann et al., 1990)). Many researchers of this process, including Fleischmann and Pons (Fleischmann et al., 1989), have noticed that the Fleischmann-Pons (type A) effect is a series of energy bursts. Besides, those energy bursts on cathodes were photographed clearly in the papers (Szpak et al., 1994; Mosier-Boss et al., 2011; etc.).

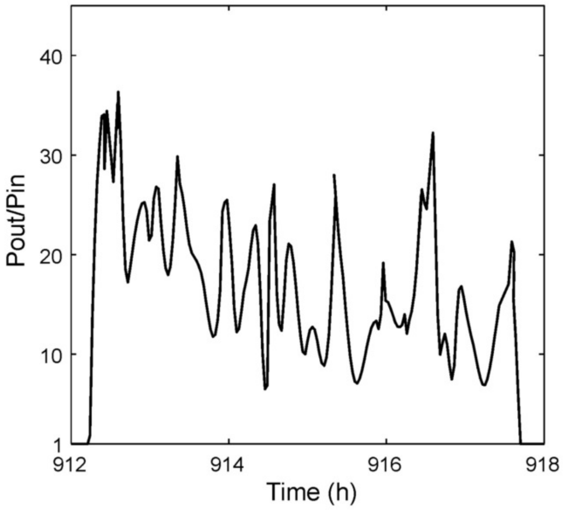

Figure 1: Change of the ratio of output power (Pout) to input power (Pin) of the cell during the F-P (type A) effect.

In (Galushkin et al., 2020), it was shown that based on the mechanism of the thermal runaway (3-6), it is possible to quantify precisely the excess energy releasing by a cell during the Fleischmann-Pons (type A) effect. In order to do this, it is necessary to measure the amount of the deuterium released during the development of the Fleischmann-Pons (type A). effect This amount must be multiplied by the heat release of 442.4 kJ/mol(D_2) (i.e. by the heat release taking place at the recombination of the released atomic deuterium). It was shown (Galushkin et al., 2020), that this calculated value of the excess energy coincides with the measured experimentally (by calorimetric method) excess energy with the accuracy up to the experimental error.

This is the direct proof of the correctness of the Fleischmann-Pons (type A) effect mechanism proposed in the paper (Galushkin et al., 2020). Thus, for the first time, the thermal runaway mechanism (the reactions (3-6)) enabled to quantify accurately the F-P (type A) effect.

It should be noted that any other of the currently proposed possible mechanisms of the F-P (type A) effect do not let quantify accurately the excess energy released. This fact is mentioned in many papers. In (Fleischmann et al., 1994), Fleischmann and Pons observed, "however, it remains true to say that the generation of excess enthalpy is the major signature and that, so far, there are no quantitative correlations between the excess enthalpy and the expected (or unexpected!) "nuclear ashes"."

However, the proposed in the paper (Galushkin et al., 2020) mechanism (3,4) of the Fleischmann-Pons (type A) effect solves in full the problems outlined in the papers (Storms, 2007; Fleischmann et al., 1994). Firstly, the strict quantitative correlation has been proved between the products of the reactions (3,4) (i.e. the released deuterium) and the excess enthalpy. Secondly, based on this mechanism (3,4) of the Fleischmann-Pons (type A) effect, the recommendations were given that enable obtainment of this effect reliably, whenever it could be needed (see Section 2.2).

Thus, the Fleischmann-Pons (type A) effect does not result in any energy production as many authors believe (Fleischmann et al., 1989; Storms, 2007; etc.). Since first at the long-lasted electrolysis of electrolyte (longer that three months), in the cells electrodes, the energy is stored in the form of the metal-deuterides. This energy accumulates very slowly due to external power source. Then the Fleischmann-Pons (type A) effect occurs and all the energy stored in the electrodes is quickly released (within a few hours); upon this, the excess power effect is created.

The mechanism of the Fleischmann-Pons (type A) effect (Galushkin et al., 2020) is quite similar to that of the thermal runaway in the alkaline batteries; the latter is studied in detail in the papers (Galushkin et al., 2015; Galushkin et al., 2016; etc.).

Summarizing our analysis of the occurrence mechanism of the Fleischmann-Pons (type A) effect, we make two remarks.

Firstly, when the electrolysis decomposes the electrolyte to the deuterium and the oxygen, only the deuterium is accumulated in the cell electrodes. The reason for this phenomenon is that the diffusion permeability of atomic deuterium in nickel is 10^{10} times higher than the diffusion permeability of atomic oxygen at 20°C (Voelkl et al., 1978). That is why during the electrolyte electrolysis, the oxygen leaves the cell, while the deuterium partially is accumulated in the electrodes and partially leaves the cell.

Secondly, by experiments, many researchers of the F-P (type A) effect (Fleischmann et al., 1994; Storms, 2007; etc.) proved the existence of the positive feedback between the temperature increase and the rate of generation of the excess enthalpy. However they failed to explain this correlation based on the “cold fusion” mechanism.

But according to the mechanism of the Fleischmann-Pons (type A) effect proposed in the paper (Galushkin et al., 2020) (the reactions (3-6)), the positive feedback presence is obvious. Indeed, an increase in the cathode temperature leads to an increase in the decomposition rate of the deuterides (the reaction (6)). In its turn, the deuterides decomposition reaction (6) is the rate-limiting step for the exothermic reactions of the thermal runaway (3,4). Hence, in proportion to the rate of the deuterides decomposition (6), increased will be the intensity of the exothermic reactions of thermal runaway (3,4) (i.e. the rate of generation of the excess enthalpy will be increased). The increase in the intensity of the exothermic reactions of the thermal runaway (3,4) will result in an even higher cathode temperature, and so on.

Thus, the positive feedback between the temperature increase and the rate of generation of the excess enthalpy is the basis of the F-P (type A) effect mechanism based on thermal runaway (Galushkin et al., 2020).

2.2 Reliable Reproduction of the Fleischmann-Pons Effect (Type A)

According to the classical theory of deuterides (Hagelstein, 2015) the deuterium occupies O-sites in bulk PdD_x near room temperature, and there is only a single O-site per Pd atom. This leads to an upper limit D/Pd near unity for bulk PdD_x. However, in (Nishimiya, 2001), it was proved that when palladium nanoparticles or palladium nanoparticles grown in zeolite are used, D/Pd = 2.

In our previous paper (Galushkin et al., 2020), it was experimentally proved that in the electrodes, where there were no microdefects of the dislocation type, the value of x=D/Pd couldn’t be more than unity. But in the electrodes, having a lot of microdefects such as dislocations the deuterium accumulation increases about 10 times. However, the microdefects should be in the form of diverse dislocations and other very small microdefects in which deuterium accumulates in the atomic form (in the form of the deuterides). In order to do this, it is better to use the metal-ceramic electrodes.

In (Dardik, 2004), when using the Transmission Electron Microscopy and the Scanning Electron Microscopy, it was proved experimentally the following fact. In the electrodes, where the Fleischmann-Pons (type A) effect was observed, the microdefects & dislocations density was many times greater than in the electrodes, where this effect had never appeared.

As was proved in (Galushkin et al., 2020) (and Section 2.1), for the occurrence of the Fleischmann-Pons (type A) effect, it is necessary to accumulate a large amount of deuterium in the electrodes and accumulate deposits on the cathode.

Therefore, firstly, according to the studies described above, in order for the electrodes of the F-P cell to accumulate a very large amount of deuterium, it is necessary that they contain a very large number of dislocations (metal-ceramic electrodes can be used, they are guaranteed to contain a very large number of dislocations).

Secondly, the density of deposits on the cathode surface (Galushkin et al., 2020) (and Section 2.1) is of great importance for the occurrence of the Fleischmann-Pons effect. Deposits are the activation centers for exothermic reactions of thermal runaway (3,4). The occurrence of thermal runaway reactions (3,4) is the F-P effect. The deposit density can be increased by adding palladium (or nickel) salts to the electrolyte, as was done in (Dominguez et al., 2014).

Thirdly, to start thermal runaway reactions (3,4), it is necessary to heat the active points formed by deposits located on the cathode (Galushkin et al., 2020). Under natural conditions, this occurs when a very large amount of atomic deuterium is accumulated in highly destroyed deposits on the cathode. Since both of these factors reduce the bond between atomic deuterium and the metal, then it leads to spontaneous desorption of atomic deuterium from the metal and its recombination. The exothermic reaction of the recombination of atomic deuterium heats up the place where the desorption of atomic hydrogen occurred, which leads to even more intense desorption of deuterium (6), etc. This is the F-P (type A) effect.

Heating of active points on the cathode can also be obtained artificially by passing a powerful current pulse through the cell, sufficient to decompose the deuterides (6) stored in the electrodes. The magnitude of the current pulse depends on the gap between the electrodes, the density of the deposit, etc. We usually used, to initiate the Fleischmann-Pons (type A) effect, a current pulse that provided an electric voltage on cell terminals of more than 50 V for 0.25–0.5s.

The Fleischmann-Pons (type A) effect can be obtained reliably if the above recommendations are used.

2.3 Mechanism of Fleischmann-Pons Effect (Type B)

In their paper (Fleischmann et al., 1990) (in Appendix 6), Fleischmann and Pons indicate that in order to obtain the effect of excess power (type B), conditions should be sought under which, along with the reaction (2) at the anode, an electrochemical reaction occurs

$$D_2 + 2OD^- \rightarrow 2D_2O + 2e^- \text{ (anode).} \tag{8}$$

To achieve reaction (8), Fleischmann and Pons advise to reduce the interelectrode gap in the cells (Fleischmann et al., 1990).

The occurrence of reaction (8) indicates that the hydrogen released at the cathode enters the anode and is oxidized on it. Consequently, the oxygen released at the anode can also get to the cathode and be reduced on it.

$$1/2O_2 + D_2O + 2e^- \rightarrow 2OD^- \text{ (cathode).} \tag{9}$$

For reactions (8.9), the overall reaction is as follows:

$$1/2O_2 + D_2 \rightarrow D_2O \tag{10}$$

Already the reaction of Fleischmann and Pons (8) is an exothermic reaction with heat emission in amount of 295 kJ/mol(D_2).

However, when calculating the energy balance of the Fleischmann-Pons (type B) effect, the heat release of reaction (8) is not taken into account (Fleischmann et al., 1990). This is the reason for the appearance of fictitious or imaginary excess power in the Fleischmann and Pons calculations.

The F-P (type B) effect was studied in more detail in our previous paper (Galushkin et al., 2020).

3 CONCLUSIONS

Based on the analysis performed and our previous experimental studies (Galushkin et al., 2020; Galushkin et al., 2015; etc), it follows that during the long-term electrolysis of heavy water, a lot of energy is accumulated inside the electrodes in the form of deuterides. The release of atomic hydrogen from deuterites and its recombination is a powerful exoteric reaction. The occurrence of this reaction is the F-P (type A) effect.

The reason for the F-P (type B) effect is that the cell energy balance in (Fleischmann et al., 1990) did not account for the exothermic reaction of Fleischmann and Pons (8).

Undoubtedly, the Fleischmann-Pons effect requires further both experimental and theoretical studies.

REFERENCES

Dardik, I., Zilov, T., et al. (2004) Excess heat in electrolysis experiments at Energetics Technologies. In *Eleventh International Conference on Condensed Matter Nuclear Science*. Marseille.

Dominguez, D. D., Kidwell, D. A., Grabowski, K. S., and Knies, D .L. (2014). Evidence for excess energy in fleischmann‑pons-type electrochemical experiments. *Journal of Condensed Matter Nuclear Science,* 14: 15‑28.

Fleischmann, M., Pons, S., and Hawkins, M. (1989). Electrochemically induced nuclear fusion of deuterium. *Journal of Electroanalytical Chemistry*, 261: 301‑308.

Fleischmann, M., Pons, S., Anderson, M. W., Li, L. J., and Hawkins, M. (1990). Calorimetry of the palladium-deuterium-heavy water system. *Journal of Electroanalytical Chemistry*, 287: 293‑348.

Fleischmann, M., Pons, S., Le Roux, M., and Roulette, J. (1994). Calorimetry of the Pd-D_2O System: the Search for Simplicity and Accuracy. In *Proceedings: Fourth International Conference on Cold Fusion*, Volume 1. page 1. EPRI. Palo Alto.

Galushkin, N. E., Yazvinskaya, N. N., and Galushkin, D. N. (2020). Mechanism of thermal runaway as a cause of Fleischmann-Pons effect. *Journal of Electroanalytical Chemistry*, 870: 114237.

Galushkin, N. E., Yazvinskaya, N. N., and Galushkin, D. N. (2015). Study of thermal runaway electrochemical reactions in alkaline batteries. *Journal of The Electrochemical Society*, 162: A2044‑A2050.

Galushkin, N. E., Yazvinskaya, N. N., and Galushkin, D. N. (2016). Thermal runaway as a new high-performance method of desorption of hydrogen from hydrides. *International Journal of Hydrogen Energy*, 41: 14813‑14819.

Greenwood, N. N., and Earnshaw, A. (1997). *Chemistry of the elements*. Butterworth Heinemann. Oxford. 2nd edition.

Hagelstein, P. L. (2015). Empirical Models for Octahedral and Tetrahedral Occupation in PdH and in PdD at High Loading. *Journal of Condensed Matter Nuclear Science,* 17: 35–66.

Lewis, N., Heben, M. J., et al. (1989). Searches for low-temperature nuclear fusion of deuterium in palladium. *Nature,* 340: 525‑530.

Luo, Y.-R. (2007) *Comprehensive handbook of chemical bond*. CRC Press. New York.

Mosier-Boss, P. A., Dea, J. Y., Gordon, F. E., Forsley, L. P. G., and Miles, M. H. (2011). Review of twenty years of LENR research using Pd/D co-deposition. *Journal of Condensed Matter Nuclear Science*, 4: 173‑187.

Nishimiya, N., Kishi, T., Mizushima, T., Matsumoto, A., and Tsutsumi, K. (2001). Hyperstoichiometric hydrogen occlusion by palladium nanoparticles included in NaY zeolite. *Journal of Alloys and Compounds*, 319: 312- 321.

Sakamoto, Y., Imoto, M., Takai, K., Yanaru, T., and Ohshima, K. (1996). Calorimetric enthalpies for palladium - hydrogen (deuterium) systems at H(D) contents up to about [H]([D])/[Pd] = 0.86. *Journal of Physics: Condensed Matter*, 8: 3229.

Shanahan, K. L. (2010). Comments on “a new look at low-energy nuclear reaction research”. *Journal of Environmental Monitoring*, 12: 1756‑1764.

Storms, E. K. (2007). *The Science of Low Energy Nuclear Reaction*. World Scientific. Singapore.

Szpak, S., Mosier-Boss, P. A., and Smith, J. J. (1994). Deuterium uptake during Pd-D codeposition. *Journal of Electroanalytical Chemistry*, 379: 121‑127.

Voelkl, J., and Alefeld, G. (Eds.), (1978). *Hydrogen Topics in Applied Physics. and Metals II*, page 321. Springer-Verlag. Berlin.

Williams, D. E., Findlay, D. J. S., et al. (1989). Upper bounds on ‘cold fusion’ in electrolytic cells. *Nature,* 342: 375‑384.