Alternate Interpretation of the Original Fleischmann and Pons Experiments

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Abstract:

A case is made for the fusion reactions apparently occurring in the original Fleischmann and Pons (F-P) experiments to be the result of free D+ ions formed at the anode during electrolysis colliding with deuterons trapped in the Pd lattice of the cathode, rather than trapped deuterons being squeezed together by the lattice. The data from the experiments show that the energy output of F-P cells was essentially proportional to the energy input, independent of the cathode size or the current strength, which implies that the cathode plays a passive role in the energy production. The number of D+ ions produced at the anode and their velocities are proportional to the current used in the cell, so that the number of D+ ions that survive the trip across the gap between the anode and the cathode is greater for greater currents. The larger numbers of D+ ions from the higher currents result in more collisions with trapped deuterons in the cathode producing more energy.

In their original 1989 paper [1], Fleischmann and Pons reported on three types of experimental setups. They listed results for nine experiments using rods as cathodes, one using a sheet, and one using a cube; however, the bulk of the discussion centered on the experiments using rods. Very little information about the experimental setups was given in the report other than that the anodes were Pt and the cathodes were Pd; cathodes came in two lengths: 10 cm and 1.25 cm, and three diameters: 0.1 cm, 0.2 cm, and 0.4 cm; and that the experiment was conducted in a Dewar-type cell. The report did say that the Pt anode wire was wound around a cage of glass rods, but did not tell what length of Pt wire was wound around the cage, how many turns around the cage were made, how many glass rods the cage was made of (three, four, five, etc.?, was it a regular polygon?), or what distance the anode was from the center of the cathode. These would seem important pieces of information for some trying to reproduce their results. In a follow-up paper published in early 1990 [2] discussing additional rod experiments done, Fleischmann and Pons did provide a diagram (no dimensions) of the typical cell used in their experiments, and indicated that the anode wires were “tightly wound with a close spacing on the cage of glass rods surrounding the cathodes,” but still no dimensions. Based on all of this, it seems that they had decided that the cathode was the major player in whatever was causing the phenomenon. The anode was just incidental.

Including the work reported in the 1990 paper, experiments were done using cathodes made from three different batches of Pd (designated batches 1, 2 and 3), and three different electrolyte solutions: solution a – 0.50 M Li_2SO_4, solution b – 0.1 M LiOD and solution c – 0.1 M LiOD + 0.45 M Li_2SO_4, all in D_2O. Electrical currents ranging from 0.25 to 1.6 amperes were used to induce the electrolysis and provided the energy into the experiments. The energy out of the experiments was determined by measuring their temperatures and performing calorimetric analyses. The energy produced by the cell, the "excess energy" in the reports was taken to be the difference between the output energy and the input energy. A current density was reported for each case that is apparently the current applied to the experiment divided by the surface area of the cathode used in the experiment. The voltage of the cell during the run was also reported. Table 1 provides a summary of the results given for the rod-cathode experiments.

No.	Batch and Electrolyte	Rod Dia. (cm)	Rod Len. (cm)	I_{cell} (mA)	Current Density (mA/cm^2)	E_{cell} (V)	Q_{in} (W)	Q_{out} (W)	Q_{excess} (W)
1	1b	0.1	10.00	25	8	2.754	0.030	0.038	0.0075
2	1b	0.1	10.00	200	64	3.602	0.412	0.481	0.0790
3	1b	0.1	1.25	200	512	8.995	1.491	1.573	0.0820
4	1b	0.2	10.00	50	8	2.702	0.058	0.094	0.0360
5	1b	0.2	10.00	400	64	4.231	1.070	1.570	0.4930
6	1b	0.2	1.25	400	512	8.461	2.770	3.150	0.3780
7	1b	0.4	10.00	100	8	2.910	0.137	0.290	0.1530
8	1b	0.4	10.00	800	64	4.860	2.660	4.410	1.7500
9	1b	0.4	1.25	800	512	8.655	5.690	9.040	3.3500
10	2b	0.1	10.00	400	128	4.000	0.984	1.144	0.1600
11	2b	0.1	10.00	800	256	5.201	2.930	3.243	0.3130
12	2b	0.1	10.00	1600	512	6.085	7.270	8.320	1.0500
13	2b	0.4	10.00	800	64	5.419	3.100	3.363	0.2630
14	2b	0.4	10.00	1600	128	6.852	8.500	9.550	1.0500
15	2b	0.4	8.75	700	64	4.745	2.240	2.357	0.1170
16	2b	0.4	1.25	400	256	7.502	2.380	2.691	0.3110
17	2b	0.4	1.25	800	512	10.580	7.230	8.880	1.6500
18	2c	0.4	1.25	100	64	3.519	0.198	0.199	0.0005
19	3a	0.1	1.25	25	64	2.811	0.032	0.033	0.0010
20	3a	0.1	1.25	50	128	3.325	0.089	0.094	0.0050
21	3a	0.2	10.00	400	64	4.780	1.300	1.306	0.0060
22	3a	0.2	10.00	800	128	4.044	0.250	0.278	0.0280
23	3a	0.2	1.25	800	1024	7.953	5.130	7.930	2.8000
24	3b	0.1	1.25	400	1024	11.640	4.040	5.070	1.0300
25	3b	0.2	10.00	800	128	8.438	5.520	7.170	1.6500
26	3c	0.2	10.00	400	64	3.930	0.956	0.980	0.0240
27	3c	0.2	1.25	200	256	6.032	0.898	0.954	0.0560
28	3c	0.2	1.25	400	512	9.042	3.000	3.603	0.6030

Table 1: Summary of parameters and results from the 1989 Fleischmann and Pons experiments

From the discussion in Reference 1, it appeared that Fleischmann and Pons believed (as did many others) that the source of the excess energy produced by the cell was likely clusters of deuterons being fused together in the cathode by pressure imposed upon them by the Pd lattice, after the Pd had absorbed a sufficient amount of the deuterium. This is still the primary theory of heat generation in the LENR cells today [3], and the data in the table above does seem to loosely support this explanation. If the cathode was actively producing the excess energy observed in the cells, then scaling the cathode should directly influence the amount of energy produced. If the phenomenon occurs throughout the cathode volume, then doubling the diameter of the cathode, which increases its volume by four times, should increase the energy produced by it by a factor of four. Or, if the cathode is producing the energy near its surface, then doubling the diameter would double its surface area and its energy production. Table 2 compares the excess energy output of cases from Table 1 that have only different cathode diameters at constant current densities and constant currents. The table shows that, with the exception of cases 14 and 10, when the current density is held constant, the excess energy appears to change roughly with the change in cathode volume. In the two instances when the cell current was held constant, the excess power essentially did not change when the cathode diameter was changed.

No.	Batch and Electrolyte	Rod Dia. (cm)	Rod Len. (cm)	I_{cell} (mA)	Current Density (mA/cm^2)	Q_{excess} (W)	Q_{excess} Ratio	Surface Area Ratio	Volume Ratio
4 1	1b 1b	0.2 0.1	10.00 10.00	50 25	**8** **8**	0.0360 0.0075	4.8	2	4
5 2	1b 1b	0.2 0.1	10.00 10.00	400 200	**64** **64**	0.4930 0.0790	6.24	2	4
7 4	1b 1b	0.4 0.2	10.00 10.00	100 50	**8** **8**	0.1530 0.0360	4.25	2	4
8 5	1b 1b	0.4 0.2	10.00 10.00	800 400	**64** **64**	1.7500 0.4930	3.55	2	4
7 1	1b 1b	0.4 0.1	10.00 10.00	100 25	**8** **8**	0.1530 0.0075	20.4	4	16
8 2	1b 1b	0.4 0.1	10.00 10.00	800 200	**64** **64**	1.7500 0.0790	22.15	4	16
14 10	2b 2b	0.4 0.1	10.00 10.00	1600 400	**128** **128**	1.0500 0.1600	6.56	4	16
13 11	2b 2b	0.4 0.1	10.00 10.00	**800** **800**	64 256	0.2630 0.3130	0.84	4	16
14 12	2b 2b	0.4 0.1	10.00 10.00	**1600** **1600**	128 512	1.0500 1.0500	1.0	4	16

Table 2: Effects of scaling the diameter of the cathode on cell energy production

However, there is another way to interpret the data given in Table 1. Figure 1 is a plot of the energy out of each cell as a function of the energy put into each cell for all of the cases listed in Table 1 that were done using electrolyte solution b. The figure shows that 17 of the 19 points fit very well to a line that indicates that, for electrolyte b, the energy out of the cell is essentially 1.175 times what is put into the cell, regardless of the cathode length or diameter, the current or current density of the cell, or which batch the cathode came from. This suggests that the cathode plays only a passive role in the energy production and that some other aspect of the cell is driving the energy production. Since the energy into the cell is directly related to the current in the cell, it appears that the current somehow drives the energy production. This is consistent with the analysis in Table 2 that showed that when the currents were constant in cathodes of different diameters, the energies produced by the cells were the same. With power production seemingly dependent on the current input into the cell, but not on the any variation of the cathode, the anode becomes of interest.

As mentioned earlier, not much attention was paid to the anodes in these experiments since whatever was happening to produce the energy was clearly happening at the cathode. However, just because the show was playing at the cathode doesn't mean that the anode didn't have a big role in the production. Recall that during electrolysis of water, H^+ ions are produced at the anode. If the water is D_2O, the ions produced are D^+ ions. Normally in electrolysis, the D^+ ions would migrate toward the cathode several centimeters away, but encounter OD^- ions before reaching it and combine with them to form new D_2O molecules. However, in these experiments, the Dewar cell has only a 2.5 cm diameter chamber [4], so with thicknesses of the anode and cathode considered, the distance from the edge of the anode to the edge of the cathode is roughly one centimeter. In such a short distance, it seems possible that a fraction of the D^+ ions formed at the anode could make it across the gap between the two electrodes to bombard the deuterium-rich Pd cathode. Since the deuterium trapped in the Pd lattice is elemental and neutral, and the negatively charged Pd cathode is actually attracting the positively charge D^+ ions, conditions may allow collisions between the accelerating D^+ ions and the fixed deuterium nuclei to occur.

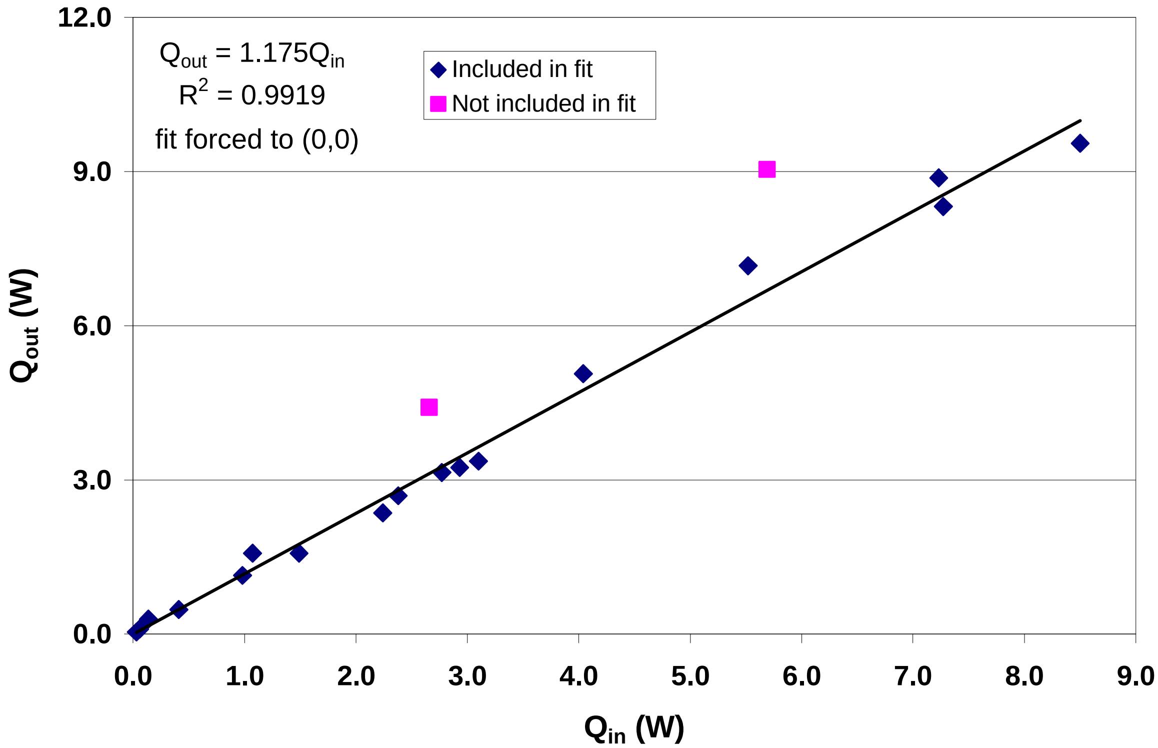

Figure 1: Q_{out} versus Q_{in} for all electrolyte b experiments

The apparent velocities the D^+ ions possess in the anode-cathode gap of the cell seem far too low to allow the ions to penetrate the Pd cathode and collide with deuterium nuclei. With cell voltages on the order of 10 volts, the D^+ ions would have energies in the range of 10 eV, which are nearly 1,000 times smaller than what is normally needed to bring two deuterons together in “hot” fusion. However, this situation is different than that of hot fusion. In hot fusion, both deuterons are free energetic particles. In the Fleischmann and Pons cells, one deuteron is free while the other is held in place by the Pd lattice. This difference may make it much easier for the two deuterons to react.

The D-D and T-T reactions in hot fusion have maximum reaction cross sections of about 100 millibarns that occur at energies between 2,000 and 3,000 keV. The maximum reaction cross section for the D-T fusion reaction is 5,000 millibarns, about 50 times the D-D and T-T cross sections; and it occurs at about 100 keV, 20 to 30 times less energetic. Since the reaction cross section is related to the probability of the reaction occurring, the D-T reaction appears to be more than 50 times more likely than the other reactions to occur, at energies 20 to 30 times lower than required for the others. Why is this? Especially since the Coulomb barriers in the D-D and the T-T reactions are essentially the same as that of the D-T reaction?

One explanation may be that when a deuteron collides with another deuteron, or a triton collides with another triton, both particles are equal and neither takes on the role of a target. There is an exchange of energy, assuming the collision is elastic, and essentially the same particles exist after the collision as before. However, when a deuteron collides with a triton, the triton takes on the role of the target since it is the more massive of the two. The energy exchange between the two leaves a deuteron and a triton that are different after the collision than before.

This may somehow facilitate the nuclear binding process. It may make it easier for the two particles to stick to each other while they are together. It is hard to say what exactly is going on during the collision, but it seems that having one particle in the collision more inert than the other greatly enhances the probability of the fusion occurring, with less energy needed. The triton is only 1.5 times as massive as the deuteron, but increased the fusion cross section by a factor of 50 and reduced the energy needed to cause the fusion by a factor of 25. If it were another 1.5 times as massive as the deuteron would it increase the fusion cross section by another factor of 50 to 2,500,000 millibarns and lower the required energy another factor of 25 down to about 4 keV? Who knows?

Back to the cold fusion cell, having one of the deuterons involved in the collision fixed in the Pd lattice may create the illusion of a heavier particle, like the triton, to the free deuteron in the collision, but much heavier than the triton. As alluded to above, the Coulomb barrier does not appear to play a major role with regard to the effect of the big-particle – small-particle collision dynamics. Even having the same Coulomb barrier, the mismatched reaction occurred much easier than the reactions with like reactants. So, in spite of the Coulomb barrier between the two particles, perhaps it is a lot easier for the free D^+ ions from the electrolysis to collide and react with the fixed deuterons in the Pd lattice than with other free deuterons.

If the fusion occurs because D^+ ions from the anode bombard the deuterons in the cathode, then two factors play a role in determining the energy output of the cell: the number of D^+ ions arriving at the cathode, and the number of deuterons embedded within the cathode. Whichever of these is the smaller determines the energy produced by the cell. The data from the Fleischmann and Pons experiments suggest that the D^+ ions arriving at the cathode is the limiting factor. Recall that Figure 1 showed that the power out of the cell was proportional to the power into the cell independent of the size of the cathode. This suggests that all size cathodes contain enough deuterons to accommodate whatever number of D^+ ions is reaching them. Figure 2 shows a plot of the excess power generated by a cell as a function of the current input into it for the three sizes of cathodes. While the distinct differences in the curves for the cathode size (with the larger cathodes generating more power for a given current) could be interpreted as something the cathode is doing to produce the power; the data suggests that the larger cathodes may produce more power because more D^+ ions reach them than for the smaller cathodes.

The legend in Figure 2 gives the diameter of the cathode corresponding to the data plotted. It also gives the size of the gap between the anode and the cathode assuming the anode is against the inside wall of the Dewar cell, some 1.25 cm from the cell’s center, and the diameter of the anode is 0.1 cm, so that the distance from the center of the cathode (assumed at the center of the cell) to the edge of the anode is 1.15 cm. This makes the edge of a 0.1 cm cathode 1.10 cm from the anode, the edge of a 0.2 cm cathode 1.05 cm from the edge of the anode, and the edge of a 0.4 cm cathode 0.95 cm from the edge of the anode. The slope of each line fit to the cathode data given in Figure 2 indicates how much excess power the cell produces for each amp of current provided to the cell. During the electrolysis of D_2O, the number of D^+ ions produced at the anode is directly proportional to the current in the anode, so the slope is an indication of how many fusion reactions occur at the cathode for each D^+ ion produced at the anode. Assuming that the cathodes all look the same to the D^+ ions, the only factor that can affect the power produced is the number of D^+ ions getting to the cathode. And, the only reason a D^+ ion that is being drawn to the cathode’s negative charge would not make it to the cathode is if something got in its way and effectively removed it from the ion flux. The farther the D^+ ions have to travel to make it to the cathode, the more likely they are to be removed before they get there.

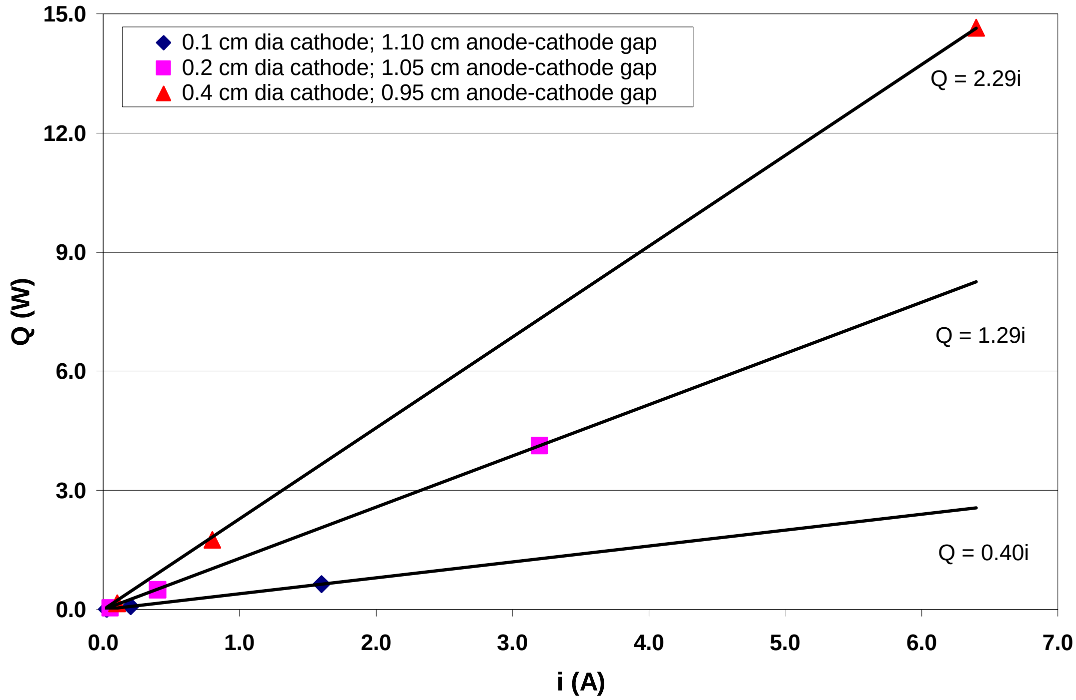

Figure 2: Graph of excess power produced as a function of current input into cell

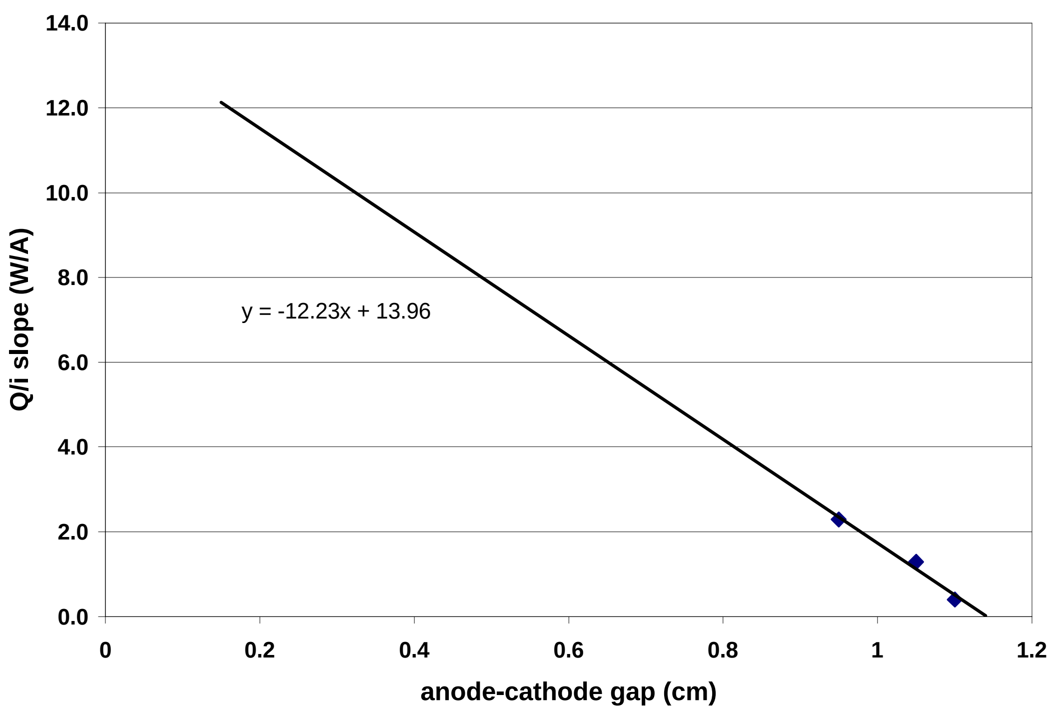

Figure 3: Plot of the slopes from the lines in Figure 2 versus gap size between the anode and the cathode.

Figure 3 shows a graph of the slopes of the lines from Figure 2 as a function of the gap distance between the edge of the anode and the edge of the cathode. The graph implies that the removal of D^+ ions within the gap is linear with the distance traveled by the ions (at least for the range of data available). It also indicates that for a gap greater than 1.14 cm, no D^+ ions reach the cathode and no fusions would occur. This may be why some experiments do not produce excess power.

Another indicator that the excess power may be influenced by D^+ ions being removed from their paths to the cathode from the anode is the cell power generation for the various electrolytes. Table 3 summarizes the three electrolytes used in the Fleischmann and Pons cells and the ion concentrations they produced in the cell solutions. To see the effects of the electrolytes on the power produced, experiments that vary only the electrolyte must be compared. The only cathode batch that used all three electrolytes was batch 3. Cases 22 and 25 from Table 1 are the same except case 22 used electrolyte a, and case 25 used electrolyte b. If case 22 is used as the datum, then changing the electrolyte from b to a reduces the excess power the cell produces by a factor of 59, to 0.017 times that of case 22. Using cases 21 and 26 from Table 1, changing the electrolyte from a to c increases the excess power the cell produces by a factor of 4, which makes the power ratio of electrolyte c relative to electrolyte a 0.068. These power ratios are listed in Table 3. Clearly, adding sulfate and lithium ions to the solution suppresses the excess power produced by the cell, which may be an indication that fewer D^+ ions are reaching the cathode because they are somehow being removed from the flux by these additional particles.

Label	Electrolyte	Solution ion concentrations (M)			Power Ratio
		Li^+	SO_4^{-}	OD^{-}	
b	0.1 M LiOD	0.1	0.00	0.1	1.000
c	0.45 M Li_2SO_4 + 0.1 M LiOD	1.0	0.45	0.1	0.068
a	0.5 M Li_2SO_4	1.0	0.50	0.0	0.017

Table 3: Electrolytes used in the 1989 Fleischmann and Pons experiments

Further evidence for D^+ ion bombardment of the cathode can be found in studies done that show the heat and transmutation products generated during the electrolysis appear to form only at the surface of the cathodes [5]. Cathode melting from the heat generation was also observed only on its surface, not in its interior. So, while the popular theories and beliefs about what occurred within the Fleischmann and Pons cells in 1989 certainly have merit, there are bases for an alternate, somewhat more traditional, interpretation of the results. Having free D^+ ions colliding with fixed deuterons in the Pd lattice is similar to the well-known D-D hot fusion reaction, but the low energies at which these collisions would have to occur given the physics of the cells seems counter to what is known about fusion. Still, as shown above, a case can be made for this mechanism from the available data.

References

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