

Can Water be the Origin of Excess Energy?

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Abstract. This study was initiated due to the concern of some critics of LENR research that small energy changes in many H₂O or D₂O molecules in electrochemical cells can explain observed excess heat. More than three hundred LENR papers from 1989 to 2008 that reported excess energy were acquired and reviewed to extract quantitative results and other information. Excess energies and cell volumes were found in 17 papers. These data were used to compute eV per water molecule values. Most experiments showed excess energy outputs that would lead to ratios below the vibrational energy of water molecules at room temperature (0.04 eV/molecule). However, 65% of the papers, which reported both excess energies and cell volumes, indicated values significantly higher. The highest reported value was 42.6 eV/molecule. Eleven ratios are far beyond what is plausible for water to be the source of anomalous heat. Therefore, it is concluded that some unknown rearrangement of water molecules in many LENR experiments is not the source of excess heat.

1. Introduction

Ever since first publically announced in 1989 by the two chemists, Martin Fleischmann and Stanley Pons, the discovery of Cold Fusion has caused great controversy. Criticism stems partly from the lack of theoretical understanding. And, there are substantial implications of the field, which promises abundant and distributed energy sources with little radiation, in competition with other developing energy sources. One main criticism that faced this field throughout its past 20 years has been the source of reported excess energy, whether or not it can be attributed to nuclear mechanisms, chemical reactions, or molecular rearrangements. Excess energy is defined as the final energy output in excess to the energy applied to an experimental cell.

Several papers have been published in the defense of LENR. Their main objectives were to explain the validity of the observed excess heat to rebut critics and minimize skepticism. One such paper published in 1989 was the “Eight Chemical Explanations of The Fleischmann-Pons Effect” [1]. It highlighted possible factors responsible for the 3W/cm³ observed in the author’s experiments. In another response to critics, it was shown that energy stored in defects in an electrode could not account for observed excess energies.

This study was designed to quantitatively examine the possibility that small energy changes in the many water molecules in electrochemical LENR experiments could account for measured excess heat. Lists of scientific papers, articles, and reviews were thoroughly screened to create a database of reports of excess heat. Cell volumes and excess energy data from these papers were tabulated and graphed. The results counteract claims that attribute excess energy to water molecule rearrangements. A secondary goal of this work was to create a database for additional useful information. Later publications will be based on that information.

2. Water Energies

Water is arguably the most important chemical on earth. As a result, it might be the most studied. And, it is also a very unusual substance. For example, water is most dense at about 4 C above its melting point, unlike most substances that are denser in the solid phase rather than in the liquid phase. Hence, water ice floats. Were that not true, the world would be very different. Despite its unusual and complex properties, there are only two component elements in water, and its structure is simple. The water molecule is polar, with more negative character on the side with the oxygen atom and more positive character on the sides with the two hydrogen atoms. This enables electrostatic hydrogen bonding, as indicated in Fig. 1. The attraction between any two neighboring molecules is very transient due to the constant thermal motions of the water molecules.

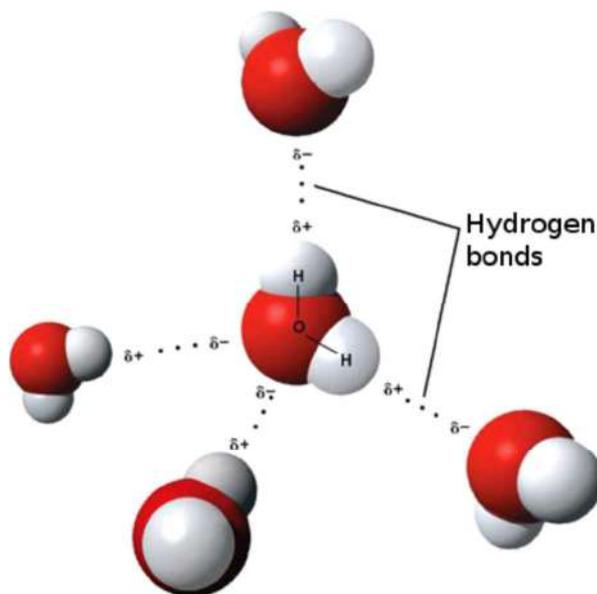


Fig.1 - Schematic of five water molecules, showing the 104.5 degree H-O-H angle and the hydrogen bonding between molecules. [2]

However, despite the chaotic dynamics, there is a net time-averaged attractive force between nearby molecules. It is such hydrogen bonding which is responsible for the relatively high boiling point and large heat of vaporization of water.

Some critics still attribute the perceived excess heat to the recombination of free hydrogen or deuterium with oxygen, as given off by electrolysis, to form liquid water. It is known that, in the presence of a catalytic material, those gases can easily recombine. This recombination gives off the heat of formation of water and can result in the erroneous appearance of excess heat. However, recombination is not the source of excess heat for two reasons. First, a properly conducted experiment will spend energy to electrolyze water and then recapture that energy when electrolysis occurs. And, very high values of measured excess energy cannot be due to recombination of atoms that were in the experiment at its outset.

Besides the heat of formation there are other characteristic energies for water molecules. They include the heat of vaporization, which is the energy to cause a molecule to transition from the liquid to the gas phase. The heat capacity of water is high, and there is an energy associated with raising the temperature of water. And, at a given temperature, there is a thermal vibrational energy associated with each water molecule. Some of the energies of water in table 1 provide a baseline for assessment of the eV/molecule values measured in LENR experiments.

Table 1. Water Molecule Energetics.

Heat of Formation (Recombination)	1.48 eV/molecule
Heat of Vaporization	0.42 eV/molecule
Energy to Heat Water from “room T” to boiling	0.06 eV/molecule
Vibrational Energy ($3kT/2$) at “room T”	0.04 eV/molecule

Rearrangement of water molecules involves energies from a few percent to almost half of 1 eV. Such energies are very low in comparison to those due to nuclear reactions, which are in the order of mega-electron Volts. The lowest value in Table 1, the vibrational energy of water at room temperature, will be used for comparison with eV/molecule values reported from LENR experiments. It will be seen that many measured

eV/molecule values fall below the vibrational energy. However, some values are well beyond even the molecular heat of formation.

3. Methodology

Several lists of Cold Fusion papers were examined to generate a broad and unbiased database for the study. Those lists included: (a) the Craven-Letts tabulation for ICCF-14, (b) Rothwell's website (www.lenr-canr.org) [3], (c) the Britz compilation of Cold Fusion papers, and (d) a list of papers submitted for the proceedings of ICCF-14 [4]. For our purposes, only papers that reported incidents of temperature increases and generation of excess heat, rather than production of tritium, neutrons or atoms, were included.

In all, 335 papers were examined. The information extracted from them formed an Excel spreadsheet. Experimental parameters, such as cathode material and dimensions, reference electrode, anode characteristics, Pd loading ratio, electrolyte composition and volume, type of water, current density, operating and delta temperatures, operating time, applied voltage and current, power, and excess energy were tabulated. However, our main focus for this study was directed towards information pertaining to excess energies and cell volumes. These factors were either provided explicitly, or else calculated by subtracting the input energy from the total energy output to obtain "excess energy". Grams of heavy water were converted to milliliters, or cubic centimeters, for the "cell volume". Some of the papers included numerous experiments with varying outcomes. In such cases, values were averaged to obtain a single representative value. eV/molecule values were obtained using the conversions:

$$\frac{kJ}{ml D_2O} \times \frac{6.34 \times 10^{21} eV}{1kJ} \times \frac{1ml D_2O}{1g D_2O} \times \frac{18g D_2O}{1mol D_2O} \times \frac{1mol}{6.02 \times 10^{23} molecule}$$

4. Results and discussion

The documented values were used to create four plots. The first plot compares excess energy and water volume information on a logarithmic scale. It has two purposes. One is to provide an overall comparison of the excess energies and cell volumes. The second is to permit assessment of a possible correlation between the two factors. The other three plots are histograms: (a) one that represents the distribution of excess energies, (b) another that presents the distribution of cell volumes, and lastly, (c) one that shows the distribution of eV/molecule values. The first two histograms are used to exhibit the overall trend in reported values for both excess energies and cell volumes. The third histogram is essential to demonstrate the number of papers that reported values higher than the vibrational energy of water molecules at room temperature.

Excess energy and water volume values were available from only 17 papers. They are plotted in Fig. 2. The trend of the data points suggests a rough correlation between both factors, where higher cell volumes seem to result in higher excess energies.

Only 40 out of 335 papers provided quantitative results for the amount of excess energy achieved in LENR experiments. The rest either failed to report any information about the output or reported excess power instead of energy. 60% of the 40 papers, as indicated in Fig. 3, reported results of 200 kJ or below. 200 kJ is enough energy to light a 100W bulb for about half of one hour. Such low values are considered by many as insufficient evidence to properly address critics of LENR. Only 40% of the papers reporting values for excess energy showed results above 200 kJ, with the highest documented value being 200 MJ. Notably, excess energy values up to 900 MJ were reported in experiments involving hydrogen-loaded nickel systems.

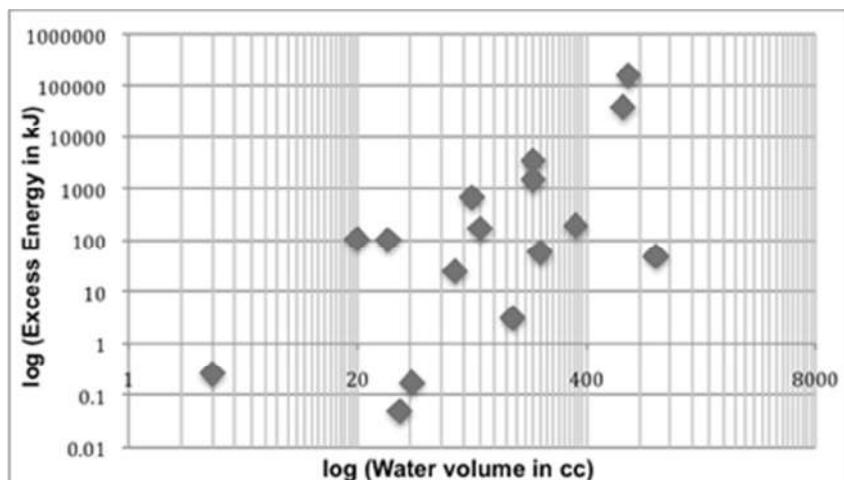


Fig.2 - The plot shows the relationship between excess energy and heavy water volume.

Only 57 out of 335 papers indicated the amount of heavy water or the amount of electrolyte used in the experiments, as can be seen in Fig. 4. Most experiments involved cells with volumes at or below 200 cc, with the highest volume used being 1000 cc in Lautzenhiser's Amoco experiment in 1990 [5].

Lastly, excess energy per water molecule values were calculated from papers that reported both values and a histogram was created, as shown in Fig. 5. Many of the reports had high eV/molecule outputs. In fact, 11 of the papers resulted in energy per molecule values higher than that of the vibrational energy of water at room temperature. Those papers are listed in table 2. The highest value obtained is 42.6 eV/molecule. The fact that some of the papers had very high eV/molecules is enough to conclude that there is some other explanation of excess energy than new molecular rearrangements.

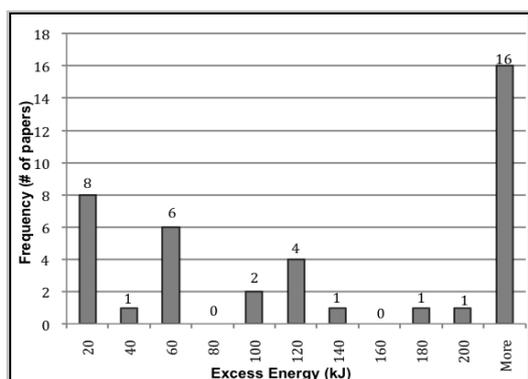


Fig. 3 - Histogram showing the distribution of excess energy values.

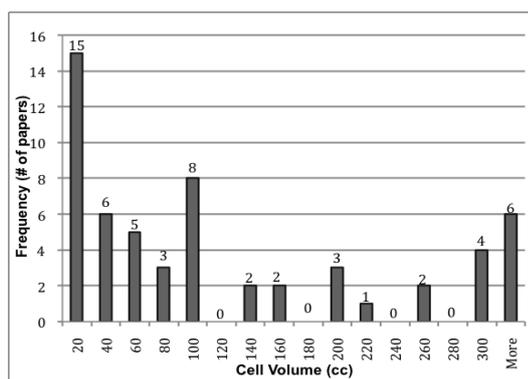


Fig. 4 - Histogram showing the distribution of experimental cell volumes.

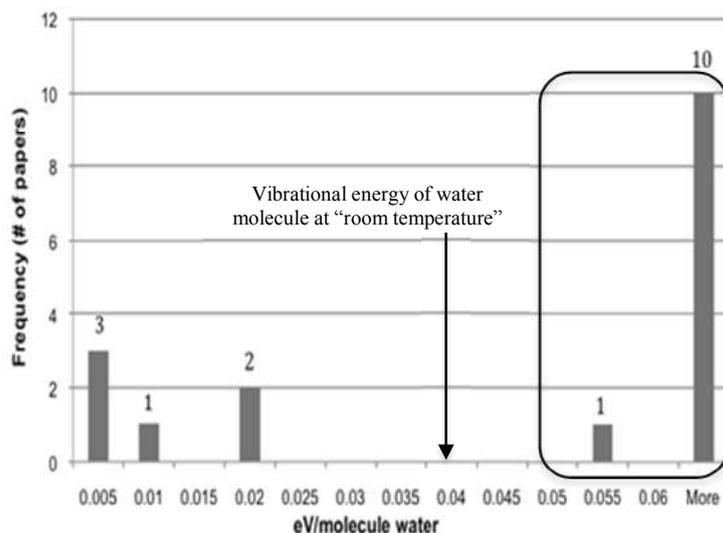


Fig. 5 - Histogram showing the distribution of eV/molecule values based on data provided by LENR papers.

Table 2. LENR articles that showed excess energy per water molecule values above the vibrational energy of water at room temperature.

Author	Reference	Year	eV/molecule
Oriani	6	1990	0.051 *
Lonchamp	7	1996	0.067 **
Takahashi	8	1998	0.106
Ohmori	9	1993	0.328
Storms	10	2006	0.659
Miles	11	1990	1.03
McKubre	12	1992	1.40
Miles	13	2001	1.45
Dardik	14	2008	3.27
Bockris	15	1993	11.2
Takahashi	16	1992	42.6

* highest value amongst 11 experimental runs.

** highest value amongst 6 experimental runs.

5. Conclusion

An extensive study of LENR papers has been performed to tabulate experimental conditions and data on excess energy. The goal was to address the question in the title of this paper. But, some unexpected results emerged during the course of the study. We summarize them, and then return to the question of the possible role of water in the production of excess energy.

Fewer than one out of five of the many papers examined reported the water volumes used in electrochemical experiments. More surprisingly, only one in eight papers gave the integrated excess powers, that is, the total excess energies for the experiments they described. Only 17 papers gave both the electrolyte volumes and the excess energies. After two decades of research on LENR, and thousands of experiments, it is noteworthy that the documentation of the experimental conditions and results is so sparse. There is clearly a need for more conscientious documentation of what was done and found in LENR experiments.

The second unexpected result is seen in Fig. 2, which shows the relationship between excess energy and heavy water volume. That plot is suggestive of a correlation between electrolyte volume and excess energy. Higher excess energy values tend to come from larger cells. However, there may be no basis for such a correlation, if the generation of excess energy occurs on or in the cathode and not in the volume of the electrolyte. Such a correlation might exist if the production of excess energy depended on some elements dissolved in the electrolyte. In that case, the greater the amount of electrolyte, the greater the amount of a reactant and the more excess energy, assuming adequate movement of the reactant elements to the reaction sites on or in the cathode.

Even if there were some reason for a correlation between excess energy and cell volume, the data in Fig. 2 are very scattered. Hence, it is not worth computing a correlation coefficient. However, it might be useful to conduct parametric experiments in which the same concentrations of the solutes in the electrolyte are used in cells of markedly different sizes. If one of the nuclear reactants is in solution at the start of an experiment, then the excess power might scale with electrolyte volume.

The range of cell volumes used in LENR experiments was quite well known. But, this study showed quantitatively that 44 of 57 cases had volumes of 200 cc or less. In fact, 37 of the 57 instances had electrolyte volumes equal to or less than 100 cc.

The experimental papers showed that 24 of the 40 reports of excess energy were equal to or below 200 kJ. Hence, only 16 were greater than 200 kJ. A few of the values of excess energy were in excess of 1 MJ. The more common and relatively small values for excess energy, some gotten during runs of days and weeks, emphasize the need for scaling up power and energy production in LENR experiments. Such scaling would also broaden the range of potential applications of LENR generators.

Returning to the motivating question for this study, we found that the values of eV per water molecule from some experiments are far beyond what is reasonable for water to be the source of observed excess heat. It is thus concluded that some unknown rearrangement of water molecules in an LENR experiment is not the source of anomalous heat production.

The mechanism(s) causing LENR remain mysterious. However, the experimental database evidencing the ability to trigger nuclear reactions using chemical energies is robust. That information has not been studied by most scientists in the physics community. The existence of LENR is still criticized occasionally, usually by people who have not read the available literature. Criticism is absolutely basic to scientific research and communications, as it brings up many useful questions. Nonetheless, it is crucial that scientists who think that LENR is real, even if not fully understood, respond to critics on the basis of experimental data. That motivated this study. It has shown that further experimentation, long-term and detailed data logging, and thorough documentation are required. Better experiments and reporting may render this field more acceptable to the broader scientific community.

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6. References

- [1] Kainthla, R. C., M. Szklarczyk, L. Kaba, G. H. Lin, O. Velev, N.J.C. Packham, J. C. Wass, and J. O'M Bockris. "Eight Chemical Explanations of the Fleischmann-Pons Effect." *Int. J. Hydrogen Energy* **14.11** (1989): 771-75. Print.
- [2] http://en.wikipedia.org/wiki/Properties_of_water.
- [3] Rothwell, Jed. LENR-CANR. Web.

- [4] Proceedings of The 14th International Conference on Condensed Matter Nuclear Science, Washington, DC. Print
- [5] Lautzenhiser, T. and D. Phelps, *Cold Fusion: Report on a Recent Amoco Experiment*. 1990, Amoco Production Company.
- [6] Oriani, R. A., John C. Nelson, Sung-Kyu Lee, and J. H. Broadhurst. "Calorimetric Measurements of Excess Power During the Cathodic Charging of Deuterium into Palladium." *Fusion Technology* **18** (1990): 652-58. Print.
- [7] McKubre, M.C. H., et al. *Excess Power Observations in Electrochemical Studies of the D/Pd System: The Influence of Loading. Proceedings of the Third International Conference on Cold Fusion. "Frontiers of Cold Fusion"*. 1992. Nagoya Japan: Universal Academy Press, In., Tokyo, Japan.
- [8] Bockris, J. O'M, Sundaresan, R., Minevski, Z., and Letts, D. *Triggering of Heat and Sub-Surface Changes in Pd-D Systems. Proceedings of the Fourth International Conference on Cold Fusion. "Transactions of Fusion Technology"*. 1993. Lahaina, Maui: Electric Power Research Institute.
- [9] Ohmori, Tadayoshi, and Enyo, Michio. "Excess Heat Evolution During Electrolysis of H₂O with Nickel, Gold, Silver, and Tin Cathodes." *Fusion Technology* **18** (1993): 293-95. Print.
- [10] Lonchampt, G., L. Bonnetain, and P. Hieter. *Reproduction of Fleischmann and Pons Experiments. Proceedings of the Sixth International Conference on Cold Fusion, Progress in New Hydrogen Energy*. 1996. Lake Toya, Hokkaido, Japan. New Energy and Industrial Technology Development Organization, Tokyo Institute of Technology, Tokyo, Japan.
- [11] Takahashi, Akito, Hirotake Fukuoka, Kenichi Yasuda, and Manabu Taniguchi. "Experimental Study on Correlation between Excess Heat and Nuclear Products by D₂O/Pd Electrolysis." *International Journal of The Society of Material Engineering for Resources* **6.1** (1998): 4-13. Print.
- [12] Miles, M., M.A. Imam, and M. Fleischmann, *Calorimetric analysis of a heavy water electrolysis experiment using a Pd-B alloy cathode*. Proc. Electrochem. Soc., 2001. **2001-23**: p. 194.
- [13] Storms, E., *Anomalous Heat Produced by Electrolysis of Palladium using a Heavy-Water Electrolyte*. 2007, LENR-CANR.org.
- [14] Focardi, S., et al., *Large excess heat production in Ni-H systems*. Nuovo Cimento Soc. Ital. Fis. A, 1998. **111A**: p. 1233.
- [15] Takahashi, A., et al., *Excess Heat and Nuclear Products by D₂O/Pd Electrolysis and Multibody Fusion*. Int. J. Appl. Electromagn. Mater., 1992. **3**: p.221.
- [16] Dardik, I., et al. *Ultrasonically-excited electrolysis Experiments at Energetics Technologies. Proceedings of the ICCF-14 International Conference on Condensed Matter Nuclear Science, 2008*, edited by D. J. Nagel & M.E. Melich, Washington, DC.