

OVERVIEW OF LIGHT WATER/HYDROGEN-BASED LOW ENERGY NUCLEAR REACTIONS

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This paper reviews light water and hydrogen-based low-energy nuclear reactions (LENRs) including the different methodologies used to study these reactions and the results obtained. Reports of excess heat production, transmutation reactions, and nuclear radiation emission are cited. An aim of this review is to present a summary of the present status of light water LENR research and provide some insight into where this research is heading.

1. Introduction

This review focuses on the transmutation reactions and excess heat production in experiments using light water electrolysis or hydrogen gas/plasma loading undergoing low-energy nuclear reactions (LENRs). Although most LENR (“cold fusion”) research has focused on heavy water, a considerable number of experiments have used light water electrolysis or hydrogen gas loading. A few experiments have attempted to compare the results from light versus heavy water,¹⁻⁴ but these comparisons remain inconclusive.

There are a wide variety of cold fusion nuclear reactions. As shown in Fig. 1, the original Pons-Fleishmann (P-F) reaction involved DD fusion, where unlike in hot fusion, the reaction channel is “interrupted” through deactivation of the excited He⁴ reaction product by energy transfer to the host lattice, ultimately heating the lattice. Alternately, a number of researchers have reported transmutation reactions that involve interactions between deuterium (or hydrogen) directly with atoms in the host lattice, typically heavy metals. This branch of “cold fusion” is commonly termed LENR, although recently there has been a move to also term P-F type DD reactions as LENRs as well.

The observation of nuclear reactions between electrolyte and host metal atoms is quite unexpected due to the very large coulombic barrier involved (much larger than for D-D reactions). Consequently, one purpose of this review is to bring together much of the data accumulated on this striking new phenomenon. The readers are

left to decide for themselves if the data is adequate to establish the case for such reactions and possibly to formulate new experiments that build on and extend this data base.

About 40 publications were included in this review (see references herein). This was intended to be representative but not exhaustive of the field. Researchers wishing to add information to the data base are invited to contact the authors.

<u>D-D Reactions</u>		% branching	
		hot fusion	<u>"P-F" type</u>
D-D	→ T + p	50	< 0.1
	→ He-3 + n	50	< 10 ⁶
	→ He-4 + gamma	< 10 ⁻⁵	99+
<u>LENRs</u>			
p + metal →		products or "fission" product array	

Figure 1. Comparison of LENR reactions and DD reactions occurring in hot and "cold" (P F type) fusion.

1.1. Methodology

A summary of various methods employed for this study is given in Table 1. A majority of the researchers cited used electrolysis to study LENR: Pd/Pt, Ni/Pt were commonly used electrodes. K₂CO₃ is a popular choice as an electrolyte, a trend perhaps started by the Mills and Kneizy's early experiments where extremely large reaction rates were reported. Gas loading is also frequently used while a few researchers have reported using a glow discharge (GD) plasma.

1.2. Early Studies at UIUC

Earlier work by one of the authors (Miley) in collaboration with Patterson represents one of the more extensive studies of light water electrolysis relative to reaction products and excess heat. About 1000 microspheres (~0.5 cm³ volume) were used in a packed-bed electrolysis cell. Thin films of Ni and/or Pd were coated on the beads to serve as the cathode. The electrolyte was 1 M Li₂SO₄ light water electrolyte with a flow rate of ~11 ml/min through the packed bed. Voltages across the bed were held at ~2-3 V, with several mA of current, giving an electrical input power of approx. 0.06 W. Significant excess heat and a fission-like reaction product array were reported. A detailed description of the experiment can be found in Ref. 1.

1.3. Reaction Product Analysis Method

Reaction products have been analyzed using a variety of precision mass analysis techniques. For example, Miley *et al.* used a combination of NAA, SIMS, Energy Dispersive X-ray (EDX) analysis and Auger Electron Spectroscopy (AES).¹ Cirillo

Table 1. Summary of various methods employed for light water/H₂ LENR studies (data collected for this and following tables and figures use Refs. 1-35)

Electrolysis	Total
Electrode	
Pt/Pd	14
Pt/Ni	5
Pt/W	3
Pt/Au	4
Pt/Sn	1
Pt/Rc	1
Pt/Ti	2
Pt/Ag	1
Pt/Pt	2
Electrolyte	
K ₂ CO ₃	10
H ₂ SO ₄	3
Na ₂ CO ₃	5
Li ₂ SO ₄	4
KOH	1
Na ₂ SO ₄	5
CS ₂ SO ₄	1
H ₂ O	2
GD plasma	1
Gas loading	5

and Iorio used SEM to study transmutation products.⁹ Arapi *et al.* used TOF-SIMS for product analysis.⁵ Iwamura *et al.* used XPS extensively in their studies, although they concentrated on D₂ gas experiments (versus H₂), so are not included in this survey *per se*.³⁶

2. Results

2.1. Transmutation Products

A quantitative measure of the yield of transmutation products (and isotopic shifts from natural distribution in key products) in four major atomic groups (6-18, 22-35, 44-54, and 75-85) were obtained by Miley *et al.*¹ Others also have reported significant nuclear reaction products and isotopic shifts in light water LENRs. In some cases of the observed elements were from the lanthanide group, including Lu, Tb, Pr, Eu, Sm, Gd, Dy, Ho, Nd, and Yb. It is widely accepted that these rare earth elements are less likely to be found as impurities, strengthening confidence in their results (although most researchers have tried to rule out mistakes due to impurities versus the common “product” elements such as Fe, Cu, Ag, Zn, Au, etc via analysis of cell components, electrodes and electrolyte prior to LENR runs).

Isotopic shifts are another key feature often cited against mistaken identification of impurities as reaction products. Violante's study showed that the $^{63}\text{Cu}/^{65}\text{Cu}$ isotopic ratio shifted.³³ In this Ni-hydride film work the most abundant copper isotope was ^{65}Cu with a shift from natural distribution by 1360%. Cirillo and Iorio found Re, Os, Au, Hf, Tl, Er, and Yb on the surface of the cathode, which was not present before the reactions.⁹ Ohmori *et al.* reported finding Hg, Kr, Ni, and Fe with anomalous compositions in Au electrodes during light water electrolysis.²⁹ In addition Si, Mg with other anomalous compositions were also detected in the precipitates separated from the Au electrode after electrolysis at extremely high current densities. They found significant deviations from natural values. Minor product elements such as Os, W, and Ru in particular showed large deviation, whereas elements with larger yields like Pb and Ag rarely showed significant deviations.

Yamada *et al.* also reported a large increase of Cr, Fe, Cu, and Ag in their experiment where Pd was loaded with hydrogen gas.³⁵ Arapi *et al.* found Be and Ni in heavy water while in light water LENR they report Li, Ba, and Ni.⁵ Dash *et al.* reported formation of Au and Ag in both light and heavy water LENR; however, the concentrations were somewhat higher in the heavy water experiments.¹⁰

Table 2 summarizes the list of elements observed in light water by the number of times they were reported being produced in their research by different research groups. Fe and Cu were commonly observed. Rare earth elements were reported less frequently. Also note that a majority of the transmuted elements reported have changes in their isotopic composition from the natural abundance.

It is interesting that the frequency of observation of light water LENR elements is not significantly different from heavy water LENR (for the latter see Ref. 37).

Table 2. The total numbers of reports that state the elements were produced in their experiment

Observation frequencies	Transmutation elements
1	As, Ge, S, Hg, Kr
2	Cd, Rr , Au, Hf, Th, Er, Yb, B, V, Cs
3	Li, Ba, Al, Os, C, Si
4	Mg, Mn, Co, Pb
5	Ag, Cl, Ti
6	Ni, K
7	Ca, Cr, Zn
8	Cu
11	Fe

One way to evaluate this data is to consider a confidence level of >6 observations. Then Ni, K, Ca, Cr, In, Cu, and Fe meet the criteria (Fig. 2). However, it can be argued that the potential impurity levels for some of the less frequently observed elements are very low, raising the signal/noise confidence level for those observations despite their less frequent observation.

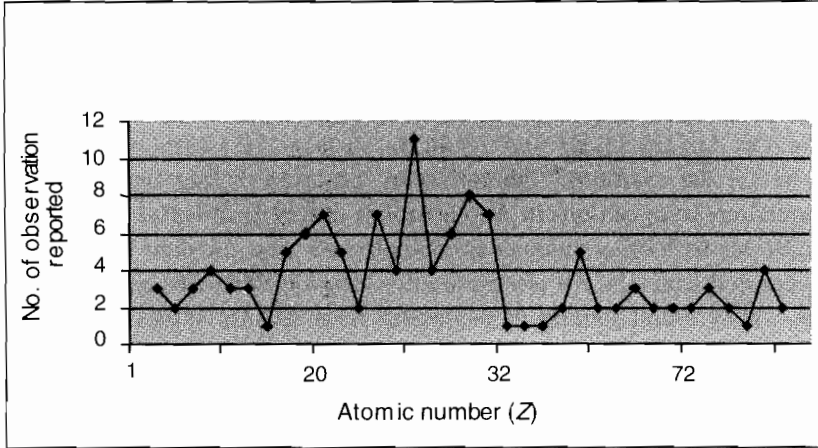


Figure 2. This graph shows the frequency of observation for various transmuted elements designated by atomic number.

2.2. Radiation Emission

Recent experiments using various methods of loading hydrogen have shown significant soft X-ray emission in certain specialized experiments, e.g. see Ref. 38. Also MeV energy charged particles have been reported. Alpha particles and protons have been identified with energies around 11.0–16.0 and 1.7 MeV, respectively. During electrolysis of thin Pd-film cathodes on dielectric substrates as well as from Pd-black electrode surfaces. Only very weak X-ray emission was found in these experiments, the upper dose limit (corresponding to ~ 5.0 X-ray photon/s \times cm² with $E_r = 10$ keV).³⁹ While there is evidence for energetic charged particles and soft X-ray emission in these studies, it remains to be determined if the mechanism for this emission is directly related to the transmutation/heat effect or is associated with auxiliary EM effects. In a unique experiment to explore possible radioactive waste disposal applications, Dash and Chicca reported that in light water experiment using U electrodes the intensity of the alpha, beta, gamma radioactivity of the electrodes increased after loading hydrogen.¹¹ The ²³⁵U and ²³⁴Th isotopic concentrations were also reported to have increased.

2.3. Excess Heat

Various researchers have reported excess heat generation suggesting that it is also one of the signatures of light water LENRs. Several such reports are mentioned here. Indeed, since the transmutation reactions involve $+Q$ values, some excess heat should be expected. However, the magnitude of the excess heat versus the input power remains an open question.

Cirillo and Iorio report a definitive excess energy in their light water experiment even after subtracting out energy associated with chemical reactions; energy related to the heating-up and fusion of the tungsten; energy used in expanding gas and

steam leaving the cell; energy lost by thermal and electromagnetic radiation; and loss of heat through the insulation.⁹

Dash *et al.* have performed extensive light-water experiments and report that excess heat generated in their light water LENR experiment was only slightly lower than in “equivalent” heavy water experiment.¹⁰ In their pioneering studies Mills and Kneizys reported 130 mW of excess heat.¹⁸ Nomiński repeated Mills and Kneizys light water Ni electrode experiment independently and reported 26–160% excess energy compared to input energy.²³ Dufour *et al.* reported excess energy of 7 mW in their H₂ gas loading experiment, corresponding to ~25–30% of the input energy.¹³ Ohmori and Enyo reported 907 mW of excess energy in a K₂CO₃, Sn electrode electrolysis experiment.³² Fujii *et al.* reported having excess energy of 7.8 W in a Li₂SO₄, Pd/Ni electrode electrolysis experiment, which is more than 5% excess.¹⁴ However, this excess heat was always reproducible.

It is not conclusive whether using light water or heavy water produces more excess heat. Some research has reported that heavy water produced relatively larger excess heat and more transmutation products,^{7, 10} while some have indicated that in both cases the excess heat and reaction products were similar.³¹ Direct comparison is complicated since many parameters are modified with an electrolyte substitution. Thus, much work is required before carrying out a meaningful comparison.

The excess energy for light water/H₂ LENR reported by various researchers tends to be either low (<10%) or high (>25%), with few reports of intermediate values (see Table 3, Fig. 3). More quantitative analysis is required to understand if this “two tier” result has a basic cause.

Table 3. The range of excess energy various reports have achieved in their experiment

Excess energy (%)	Number reported
0–5	2
6–10	2
11–15	0
16–20	0
21–25	1
26–30	3
31–35	0
35+	2

2.4. Historical Trends

A review of historical trends indicates that a majority of researchers have examined both the transmutation reactions and excess heat generation, strongly suggesting that they expect both phenomenon in light water LENR. However, considerable work has also continued to study these phenomenons separately. Table 4 shows that heavy activity occurred in the early 1990 period, and then decreased. However, starting in 2000 onward, research in light water LENR again increased in activity.

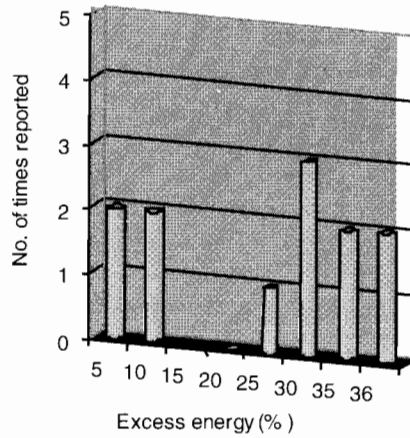


Figure 3. This graph shows Table 3 data in a graphical presentation.

This suggests that some time was required for researchers to digest the early work and become interested in devoting time to this new area of LENR.

3. Theory

Many different theories have been proposed for the mechanism of reactions that takes place in LENR. However, a definitive match of theory and experiment has yet to be achieved. Thus the “best” theory remains unclear. In order to explain how the large Coulombic barrier is overcome, many theories introduce a neutral particle in the reaction matrix. Some of the theories of this type include Neutron Cluster formation by Fisher,⁴⁰ Free Neutron Reactions by Kozima,⁴¹ R-Matrix Theory by Chubb,⁴² Shrunk Hydrogen by Mills,⁴³ Electron-Proton capture by Stoppini⁴⁴ and Proton/Deuteron Cluster by Dufour.⁴⁵ The challenge now is to sort out how any of these theories can explain the unique signatures of heat and varied transmutation products reported experimentally.

Table 4. Survey of the year and the key signatures of LENR focused in the study

Type of study	Years				Total
	1990	1994	1995-1999	2000-2005	
Excess head and transmutation		4	2	6	12
Excess head studies - transmutation not studied	6		1	1	8
Transmutation studies - excess head not studied			3	5	8
Excess head studies - transmutation not found				1	1
				Total	29

4. Conclusions

In view of the rather extensive data base for light water/hydrogen-based LENR, it is rather convincing that this phenomenon is real. Since the measurements are very tedious and demanding, some errors are no doubt contained throughout the database. (The authors did not feel qualified to rule out any seriously reported data by competent researchers.) However, it seems highly unlikely that all of the data are erroneous. From a practical point of view, the issue remains whether or not there is any unique advantage of light water/hydrogen LENR versus heavy water/deuteron LENR. Two applications are at issue for both: heat production and/or transmutation. However, the experiments surveyed here suggest that at this stage there is no clear evidence whether or not heavy water is more favorable than light water for either application. Clearly many more comparative studies are essential to clarify this issue. Another aspect is that the heat reaction in these two cases appears to produce different reaction products. Thus, for wide applications involving public exposure the reaction products need to be carefully evaluated relative to environmental compatibility and radioactivity. This evaluation not only applies to the main reaction but possible parasitic ("side") reactions.

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