Introduction to the main experimental findings of the LENR field

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Twenty-five years ago in March 1989, Martin Fleischmann and Stanley Pons announced their success in initiating fusion between deuterons in palladium used as the cathode in an electrolytic cell. Since then, a battle has waged between skeptics who reject the claim and people who observe behaviour that is consistent with the claim. This article briefly summarizes the major experimental observations. A companion article in this special section provides insight into how the observations might be explained.

Keywords: Excess energy, fusion, helium, transmutation.

Introduction

HUNDREDS of papers have been published about the claims made by Fleischmann and Pons (F–P), many peer reviewed; over a dozen books[1–9] have summarized the information; and the subject has been debated at conferences and reviewed in government reports. Of course, several books[10–12] emphasize the skeptical viewpoint. Consequently, confusion continues in many minds about what is known and what the behaviour means. No single paper proves that low energy nuclear reaction (LENR) is a real effect. The proof lies in the consistent agreement between many independent studies done over the last 25 years in at least eight countries using a variety of methods materials and while observing many different behaviours that are consistent with a novel nuclear process. Because this collection is too large to describe here, only a few examples are provided. The details can be found in two books by the present author with one[13] summarizing all observations made before 2007 and the other focusing on the important observations. These observations are then used to evaluate many explanations, including his own[14].

Two kinds of fusion involving isotopes of hydrogen are apparently possible. Because each occurs as a result of a different mechanism and produces different nuclear products, they are unrelated. These two fusion processes are called hot fusion and cold fusion. Attempts to use hot fusion to understand cold fusion have resulted in much confusion and frequent rejection of cold fusion.

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The well-known hot fusion is initiated by applying very high energy to tritium and/or deuterium in plasma, or by bombarding material containing deuterium with accelerated ions containing deuterium. This reaction has been studied for over 80 years and provides the conventional understanding of the fusion process. In this case, once two deuterons have fused, the resulting nucleus fragments into two parts consisting of a neutron and ^{3}He or a proton and tritium, with each fragment having equal probability of forming. The excess mass energy of 23.8 MeV manifests as kinetic energy of the fragments and eventually appears as heat energy.

The process of interest here, called cold fusion or more exactly LENR, is characterized by the following behaviours. The process takes place in solid materials under ambient conditions without application of significant energy. For this reason, the process is considered cold compared to the energy required to initiate hot fusion. When excess energy is detected, ^{4}He is also found in amounts consistent with the amount of measured heat energy, with an energy/helium ratio near 23.8 MeV/helium. Tritium is also produced on occasion in amounts well in excess of its local background, but not enough to produce detectable energy. The means for dissipating the excess mass energy has not been identified, but involves units of energy too small to permit easy detection. Although photons are detected, some people prefer to think most of the energy is released as phonons that cannot be detected.

The LENR process also is found to cause what is called transmutation. This process involves addition of hydrogen nuclei to a heavier nucleus such as palladium or other elements present where fusion is taking place. The transmuted nucleus can remain intact or fragment into two other nuclei. One of the major challenges is to explain how the large Coulomb barrier is overcome, since, prima facie, one expects that the hydrogen nucleus may not be able to reach the region where nuclear attraction takes over, because energies involved are low. But one must also remember that we are dealing here with nuclei in a solid matrix and that the inter-nuclear interaction could be different from those between bare nuclei. This challenge has caused the claims for transmutation to be rejected in spite of growing evidence[15–17]. When fragmentation occurs, the excess mass energy appears as kinetic energy of the fragments. However, on the occasions when fragmentation does not occur, explaining how energy is used up becomes a problem similar to the one created when cold fusion occurs without fragmentation of the resulting helium or tritium nucleus. Both kinds of transmutation are rare and generally appear to produce either stable nuclei or radioactive nuclei that quickly decay to a stable isotope.

The fusion process has been initiated on the cathode of an electrolytic cell (F–P method); on the cathode when a modest voltage is applied in low-pressure gas to form deuterium ion plasma (gas discharge); when an active material is simply exposed to D_2 or H_2 gas (gas loading), when excessive voltage is applied to an electrolytic cell to form plasma in the electrolyte (plasma electrolysis), and on a metal target exposed to ultrasound while in D_2O (sonofusion). All of these methods have generated excess energy along with some nuclear products found on or very near the surface of the active material. Apparently, the fusion process can be initiated in a variety of different conditions using a variety of materials as the environment.

The discovery promises a source of ideal energy and greater insight into nuclear interaction. In view of the failure of conventional energy sources to satisfy demand while poisoning the environment, both locally and worldwide, this source of clean energy demands increased attention.

Discussion

Because error can occur in any scientific study (some real and some imagined), replication by many independent investigators is required before an extraordinary claim can be accepted. In the case of LENR, replication of the process has been achieved many times, but it is not easy. Many efforts fail. These failures are then used to reject the claim. Over the years, many reasons why failure occurs have been identified and success has improved when this knowledge is applied. Even though success cannot be guaranteed, failure is not rational a reason to reject. Instead, failure shows that the required conditions were not achieved. This difficulty in achieving the required conditions demonstrates that many of the important variables have not yet been identified. For this reason, they cannot be controlled to cause LENR every time an attempt is made. This handicap is similar to the problem experienced by all new discoveries.

A few examples of how heat production is related to a few variables and how it is correlation with helium formation are described here. Too little space is available to describe tritium production, transmutation and radiation emission, which provide additional important evidence for a complex nuclear process.

Energy production

Heat energy is the most obvious and the most sought result of LENR. A bibliography available at www.LENR.org lists over 700 papers resulting from studies during which excess energy was produced by one or more samples. Excess energy means more energy is detected than can be accounted for by the applied energy or by a chemical in the apparatus. Generally, potentially active chemicals are few and the potential chemical reactions are well understood[18].

Figure 1 shows a comparison between the number of studies reporting values in the indicated power range compared to the reported excess power (see note 1) for results reported before 2007 using all six methods found to produce excess energy. Although small amounts of heating power are most common, large amounts of power are occasionally found. In all cases, the measured power is well in excess of the errors in measurement, which are generally between 25 and 200 mW, depending upon the amount of power the calorimeter is designed to detect. The distribution in Figure 1 is similar to the expected result of a process having random sources of energy that combine to create the total measured power. Because these sources rarely form, the probability of creating an increased number of active sites goes down as the number of energy-producing events goes up, i.e. as more power is produced. In other words, the behaviour is exactly what would be expected to result from a rare, statistically random process involving many independent events combing to produce the average measured power. In this case, the rare event is success in creating a nuclear active site (NAS). Consequently, the challenge for successful production of energy involves finding ways to create more NAS. Several methods have been suggested for improving success using the electrolytic method[19–22]. Unfortunately, many authors do not fully explain how success was achieved either out of ignorance or for commercial reasons. Consequently, success in reproducing the effect is handicapped.

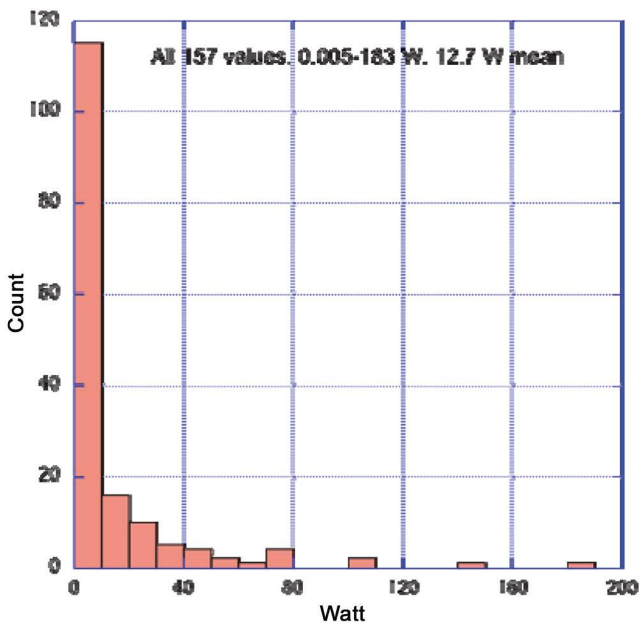

Figure 1. Histogram of power produced by 157 measurements reported before 2007 (ref. 55).

Because all calorimeters used to measure power are different and non-standard, an analysis of each method is required to judge the amount of error and how plausible the claimed value might be. Such an analysis has been done and applied to several individual measurements using the electrolytic method[23–28]. A few people have continued to suggest errors[29–32]. These critiques have been acknowledged and answered[33–36]. In general, the evaluations agree that the claimed excess energy is real, but not always as large as claimed.

Some of the claims have been replicated on purpose rather than by the usual method, which is trial and error while relying on random chance. The claims of F–P were replicated by Lonchampt *et al.*[37] in 1996 using a calorimeter of a design identical to that used by F–P. They concluded that 'The Fleischmann–Pons calorimeter with precautionary measures taken is simple and precise and their calorimeter is very accurate and well adapted to study cold fusion.' They were able to replicate excess energy at temperatures up to the boiling point of D_2O.

A study done at SRI by McKubre *et al.*[38] replicated the SuperWave[39–44] method. Two features are worth noting. First, an independent replication was be made by applying procedures found effective in a different laboratory in a different country. Second, the amount of power is shown to be related to the average D/Pd ratio in the sample, as has been found by many other independent studies[45–52] starting with F–P (ref. 53). Figure 2 shows a typical example of this relationship. A composition above a critical value must be achieved before detectable power is produced. This behaviour is key to explaining many failures, because such high compositions are not easy to achieve. It also shows an expected relationship, i.e. the concentration of fuel in the material influences the rate of the fusion process. This critical value is not universal but depends on the nature of the cathode.

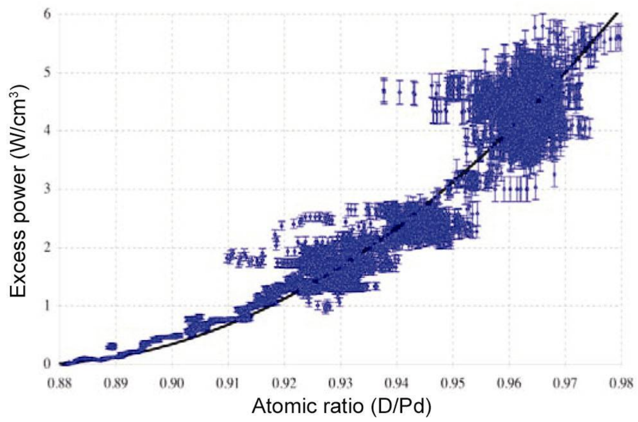

Figure 2. Relationship between D/Pd ratio in a Pd cathode and the resulting excess energy. The composition is measured using the resistance ratio[43].

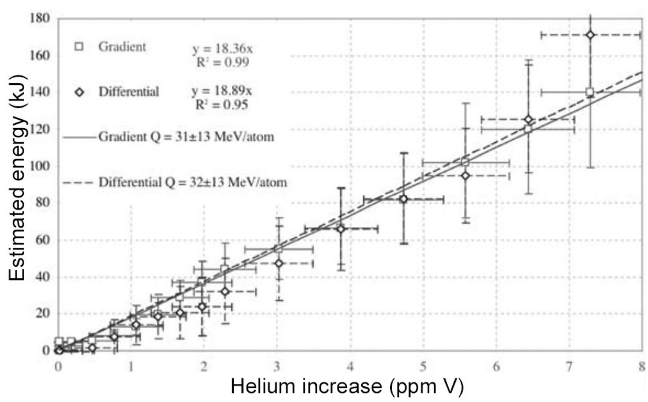

Figure 3. The amount of energy based on two methods for its determination as a function of accumulated helium from Pd deposited on carbon[56].

Helium

Of all the nuclear products, helium is found in the greatest amount and shows a clear correlation with excess energy production. Sixteen examples of this correlation have been identified, with a particularly clear one provided in Figure 3. This study done at SRI[54] used a sample containing 5% Pd applied to coconut charcoal. The study was undertaken by heating in pressurized D_2 gas, which caused the helium content inside the container to gradually increase as excess energy was detected until the helium concentration exceeded that in the surrounding atmosphere. The average MeV/He resulting from the study is slightly greater than the expected value of 23.8 MeV/He,

Table 1. List of studies that resulted in a value for the ratio of amount of helium compared to the amount of excess energy expressed as He/W-s (ref. 14)

Source (reference)	Power (W)	He/W-s ($\times 10^{-11}$)	Method
57	0.1	2	Electrolytic
	0.05	2	Electrolytic
	0.02	5	Electrolytic
58	0.055	1.6	Electrolytic
	0.04	2.5	Electrolytic
	0.04	1.4	Electrolytic
	0.06	0.7	Electrolytic
	0.03	0.75	Electrolytic
	0.07	1.2	Electrolytic
	0.12	1.0	Electrolytic
59	0.047	1.7	Electrolytic
	0.035	1.3	Electrolytic
	0.055	1.6	Electrolytic
56		2.0	Gas loading
60	0.1	1.0	Electrolytic
61		1.3	Electrolytic
		4.4	Omitted as outlier
		1.5	Electrolytic
62	60	2.4	Sonic
Average		1.9	
Standard deviation		1.1	

because some helium was apparently retained by the Pd. This retention is commonly observed regardless of the method used to initiate the effect. Table 1 lists all the studies that report a relationship between power and helium production. Although the scatter in values is large, both as result of errors as well as a variable amount of helium being retained by the palladium, the average ($1.9 \pm 1.1 \times 10^{11}$ He/J) is consistent with the value (2.4×10^{11} He/J) expected to result when D–D fusion makes He.

Conclusion

Proof for the existence of a new kind of nuclear interaction is now overwhelming. The next challenge is to explain how it can occur. Once this challenge is met, a useful source of energy can be designed. This information is gradually being acquired and applied. The only question is, 'when will this ideal energy be available and which country will first have access to its benefits?'

Note

1. Power is measured using a calorimeter and the amount of energy is calculated by multiplying the power by the time during which power is generated. Excess power is calculated by subtracting all power added to the cell while power is being measured. While bursts of power might result from a brief chemical reaction, these are small when they occur and do not add enough energy to the total to affect the conclusion. The possible chemical reactions that might occur in an electrolytic cell have been evaluated by Kainthla *et al.*[18].

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