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# On the Reaction Product and Heat Correlation for LENRs

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## Abstract

"Low Energy Nuclear Reactions", or LENRs, typically involve electrolytes containing light water along with electrodes made of metals such as Ni, Ti and Pd. In these experiments a variety of reaction products (isotopes), with masses both higher and lower than that of the host electrode material, have been observed at the University of Illinois (U of IL). Related results, often termed "transmutation" studies, have been reported by other researchers. These observations suggest that proton-metal initiated reactions occur in such LENR cells. This paper discusses evidence that the production of these reaction products is correlated with the excess heat also frequently observed in LENR cells. Such a correlation for LENR reactions would be equivalent, in principle, to the correlation of He-4 with excess heat that is reported for heavy water-Pd experiments where a D-D reaction is postulated.

## Introduction

Considerable research effort has been devoted to the establishment of a correlation between He-4 and excess heat from D-D reactions postulated to occur in Pons-Fleischmann type cold fusion cells. Good progress has been made and recent measurements of the reaction product He-4 have achieved levels where background helium is a less significant factor in interpretation of the results [1]. These results indicate, with a reasonable confidence level, that a direct correlation exists between He-4 production and excess heat, supporting the D-D reaction hypothesis.

In contrast, in the case of LENRs, a variety of reaction products (isotopes) with masses both higher and lower than that of host electrode material imply that proton-metal initiated reactions occur [2, 3]. Earlier G. Miley, et al. [3, 4] considered the possible correlation of these reaction products with the excess heat observed in these experiments. Additional results are presented here that further support this conjecture. Still, uncertainties in absolute values of both heat and product measurements leave open a fairly large error band for the correlation; thus, some important issues remain e.g. whether or not some reactions also occur in LENRs that involve electrolyte salts.

Indeed, as discussed later, due to the rich variety of conceivable contributing mechanisms in LENR experiments, the reaction product-heat relationship is less useful for specifying a unique reaction responsible for excess heat than is $^4He$ production in $D_2O$-Pd cells. Still, the data provides important circumstantial evidence about the reacting species, hypothesized to be protons-metal atoms for LENRs.

## Prior Reaction Product Measurements

The earlier measurements of LENR reaction products at the U of IL are described in references [2, 3]. Several precision analytical methods were used to analyze both the metal electrodes and electrolyte before and after runs. A characteristic result, shown in Fig. 1, indicates that a variety of reaction products occur with masses lying well below and above that of the base electrode metal (Ni and Pd in this figure, of cf. numbers defined in the references).

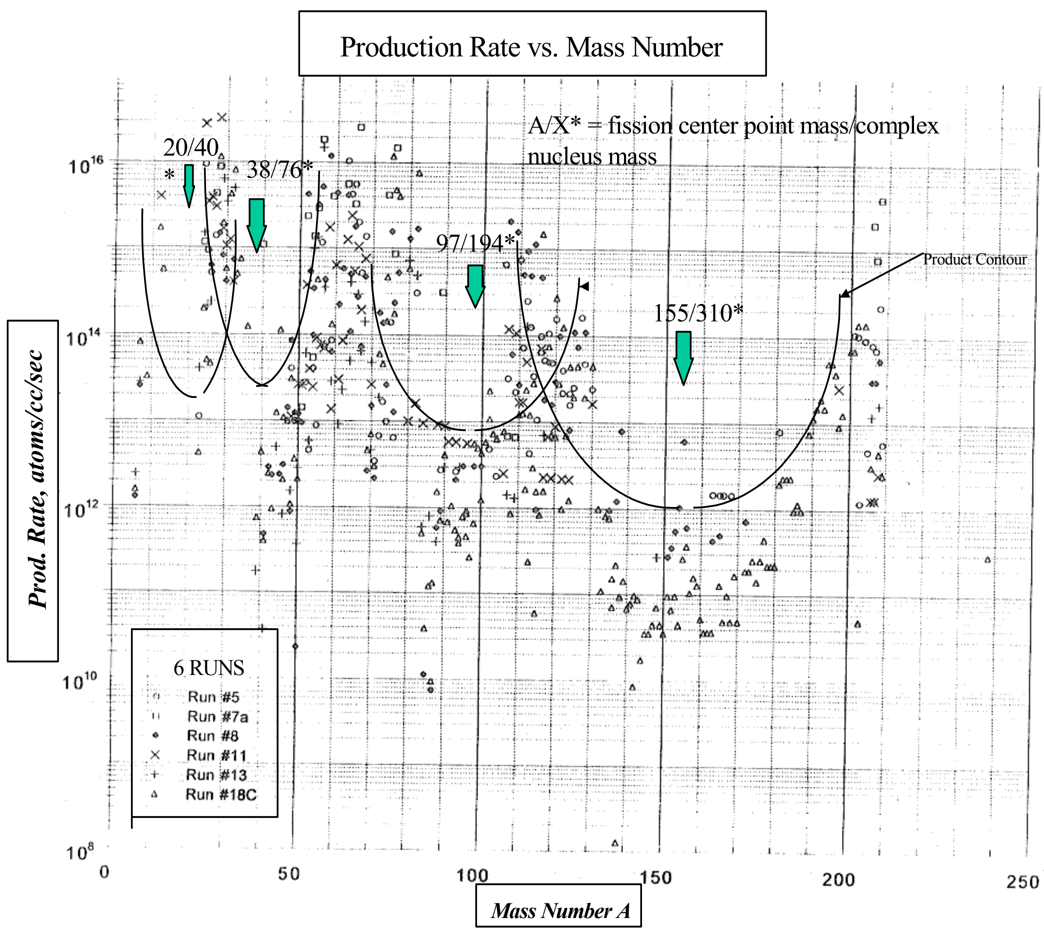


**Figure 1. Reaction Product Yield vs. Mass Curve (from Ref. 3)**

A striking pattern consistently observed in these measurements is that the high-yield reaction products occur in four mass ranges, roughly A = 20-30, 50-80, 110-130, and 190-210 [4]. Statistically significant shifts in isotope ratios from natural abundance are also observed for many of the products [2, 3]. Numerous precautions were taken to guard against impurities in these measurements (see references 2, 3). This includes use of special "clean" systems, blank runs, and precision diagnostics prior to and following runs. Consequently, the high-yield products (> $10^{13}$ atoms/cc-sec in Fig. 1) are well above background impurity limits, but some uncertainties due to possible impurities, especially in the electrolyte, still plague measurements of the lower yield products (< $10^{13}$ atoms/cc-sec in Fig. 1). For example, the yields of the high-yield products such as Ag and Cu in thin-film Ni cathodes typically exceeded the total amount (in weight) of impurity Ag and Cu found in the total system, (including both the electrodes and the electrolyte), by one or two orders of magnitude.

Other evidence of the nuclear basis for these results included the observation of low energy X-ray and/or beta emission from electrodes after a run and statistically significant shifts in isotope ratios for key elements. The general trends from these results are reasonably consistent with reaction product measurements by other workers (see the discussion and references in references 4, 5). However, others have often termed their work "transmutation studies" as opposed to "reaction product studies". For that reason, other studies have not generally focused on the total product yields or on correlations with heat.

## Energy/Nucleon Balances

The measurements of reaction products shown in Fig. 1 used analytic techniques that were benchmarked via neutron activation analysis techniques to allow a determination of absolute values of the yields as well as trends. The "production rates" shown represent a time average over the experiment run-time since, with the present experimental arrangement, it was only possible to take samples at the beginning and end of a run. Likewise, the excess heat reported represented an average over the run, so that a comparison of these two results is consistent.

To test for a possible correlation, the measured product yields or Fig. 1 are used along with their respective binding energies to compute a theoretical "excess power", $W_{excess}$, as illustrated in Fig. 2.

$$\Big[\sum_{RPs} (RP * BE/n) - \sum_{\substack{metal\ atom,\\ p\ burned}} (fuel * BE/n)\Big] / run\ time = P_{out}$$

$$\equiv W_{excess}$$

**Figure 2.** Computation of Excess Power from measured reaction products and binding energies where:
RP = reaction product yield or atoms of product formed nuclei
BE /n= Binding energy per nucleon for RP or fuel
fuel = metal nuclei + protons reacted (from nucleon balance)
p = proton

The computation is straightforward but tedious due to the large number of reaction products produced. Basically, $W_{excess}$ is computed by taking the product of all the isotope yield rates times their binding energies and subtracting the corresponding product for the "fuel". A key point is the determination of the amount of original material, that is consumed or "burned up." Since the decrease in the number of original metal atoms in the cathode is a small fraction of the original atoms, a direct measurement becomes imprecise (vs. the measure of new isotopes that differ from the base electrode material itself). However, the number "consumed" can be obtained from the measured products by invoking the basic requirement that nucleons are conserved in the reaction. A nucleon balance is performed by first computing the total number of nucleons in each of the measured reaction products. The basic assumption is that these nucleons come from the base electrode metal, e.g. Ni, plus the reacting protons. This calculation is done by first allotting the maximum number of reaction product nucleons to the metal nucleons. Then, any remaining nucleons are attributed to the protons, allowing for a variable proton/metal atom ratio to retain generality [6, 7]. This balance rests on the assumption that the protons plus the electrode metal (e.g. Ni in this case) are the reactants in LENR cells. This follows since protons in the light water electrolyte cannot react with themselves (as D-D reactions in heavy water electrolyte). Otherwise, this result does not rely on a knowledge of the reaction mechanism itself. While a counter view might assume the 'salt' employed in the electrolyte, e.g. $Li_2SO_4$, was involved in the reaction. There is no evidence for this in LENR reactions, and the fact that various workers have used different salts while still obtaining similar reaction products seems to rule out this possibility.

Product yield results from three runs (run numbers refer to experiments described in R. 2) where adequate information was available for this type of evaluation are summarized in Fig. 3.

| **Run Number (Ref. 2,3)** | ***Excess Power (W)*** | |
|---|---|---|
| | Calculated | Measured |
| #7 | 1.9 ±0.6 | 4.0 ±0.8 |
| #8 | 0.5 ±0.2 | 0.5 ±0.4 |
| #18 | 0.7 ±0.3 | 0.6 ±0.4 |

**Figure 3. Results from Energy Balance Calculations for Three Earlier Thin-Film Experiments. All experiments used $Li_2SO_4$ in $H_2O$ for the electrolyte and thin-film Ni coated cathodes.**

As seen from this figure, reasonably good agreement is obtained between the excess power measurement and the calculated values using the binding energy calculations described here. Two of the results show quite close agreement, but one has a mean measured value that is a factor of two larger than the calculated value. While these results are not definitive, still, in view of the many uncertainties in both of the calculated values (due to uncertainties in the yield measurements) and in the calorimetry, the agreement obtained strongly suggests a relation between products and excess heat.

More studies of this type are clearly needed to fully confirm the validity of this correlation. Still, this result, combined with the reaction product data itself, provides added evidence that proton-metal reactions are responsible for the anomalous isotope and heat phenomena observed in LENR experiments. The situation where heavy water is used instead of light water, as reported in some other LENR studies (e.g. see [5]), is less clear but again appears to involve proton-metal reactions. In that case, p-metal reactions could occur simultaneously with D-D reactions. More study is needed to resolve possible reactions involved this important regime.

Another way of viewing these data is to calculate the energy released (the observed excess heat times the run time) and divide by the number of Ni atoms reacted (based again on the number of nucleons associated with the measured quantities of reaction products observed). Then, for the runs of Fig 3, an energy release of order of 150 keV/Ni atom reacted is obtained. This value is consistent with nuclear as opposed to chemical processes. It is several orders of magnitude less than the energy released in neutron-induced fission, but is roughly in the range of "soft" fission releases predicted for LENR conditions [8].

These results also bear on an issue that is often raised about the LENR experiments: how can a positive excess power occur since the base metal involved, such as Ni, has a binding energy per nucleon near the peak of the binding energy-mass curve? In the present analysis this can be explained by noting that the "fuel" i.e. the reactants, are a mixture of protons and metal. Then the average binding energy of the reactants (p + metal) is reduced below that of the metal alone. As a result, there is an expanded range of reaction product masses lying around the mass of the base metal that offer a positive energy release, i.e. a positive Q-value for the reaction. Still, the fact that some reaction products lie outside of this range might seem to infer that reactions occur despite a negative Q-value, but then a very large input energy would be needed to drive the reactions. This dilemma is overcome, however, if the reaction occurs through multi-step excitation and/or formation of a compound nucleus which can split up or fission into a variety of reaction products of different masses [4, 8]. The energy balance requirement is that the formation energy of the compound nucleus must be supplied. Subsequently, the break-up energy is, in effect, shared among products.

## Conclusion

Detailed energy and nucleon balance calculations for LENR experiments where reaction products were quantitatively measured have been shown to be generally consistent with corresponding excess heat measurements. Such data is only available for a few cases, so additional experiments are needed to fully verify this correlation. However, the results to date support the hypothesis that proton-metal reactions are associated with the excess heat and reaction products observed in such LENR experiments.


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