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Abstract

A new equation accurately relates the helium-four production with the excess power for the Pd-D_2O electrochemical system based upon the assumption of 23.85 MeV per He-4 atom produced by cold fusion (also called LENR). This equation is He-4(ppb) = 55.91 (Px / I), where Px is the excess power in Watts, and I is the cell current in Amperes. For our most accurate measurements of He-4, there was exact agreement for one study that could not likely be just a coincidence. Two other experiments were also reasonably close to agreement with this equation and even suggested small calorimetric errors which have been identified. These three studies indicate that the He-4 produced in these LENR experiments readily escapes from the palladium cathodes used. This is often not the case for other electrodes, especially for palladium alloys such as Pd-B that yield somewhat smaller amounts of He-4 than the theoretical calculations. Several other applications of this equation are also presented.

Key Words: Calorimetry, Current, Fleischmann-Pons Effect, Fusion, Work.

1. Introduction

The cold fusion announcement by Fleischmann and Pons on March 23, 1989, briefly excited the world about a new pathway for fusion energy [1, 2]. However, this important discovery was soon dismissed by several major scientific laboratories (Caltech, MIT, and Harwell) that failed to find any fusion effects in their brief experiments [2]. Unfortunately, ridicule was also often used against this new discovery [2,3].

The early rejection of the cold fusion discovery was mainly initiated by presentations by Caltech at the American Physical Society (APS) meeting in Baltimore on May 1, 1989 – just weeks following the Fleischmann-Pons announcement [2, 3]. The 1989 APS presentation by Nate Lewis of Caltech has recently been shown to contain many errors resulting in the misrepresentation of the accurate Fleischmann-Pons calorimetry [3]. This premature rejection of cold fusion led many scientific journals to reject manuscripts that reported cold fusion effects. As a result, most cold fusion research is now published in the Journal of Condensed Matter Nuclear Science (JCMNS). For example, the recent report of the LENR research program at NASA (U.S.A.) is found in the 2024 issue of JCMNS [4].

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The major valid question by critics in 1989 was: "Where is the fusion product (or "ash") that would relate to the reported excess heat?" In less than two years (1991), the U.S. Navy laboratory (NAWCWD) at China Lake, California in collaboration with the University of Texas at Austin was the first to report helium-4 as the major fusion product that correlates with the excess heat in these experiments [5, 6]. Many following studies at this Navy laboratory over several years consistently showed He-4 as the major fusion product [7, 8]. There are now many other research groups that have identified He-4 production in these Pd/D_2O electrochemical experiments [8,9].

2. Experimental

The isoperibolic heat conducting calorimetry used in these experiments has been described in previous publications [10,11]. It should be noted, however, that the small amount of electrolyte used (18 mL) made the China Lake calorimetry more sensitive for the excess heat, but it also resulted in calorimetric errors due to relative larger changes in the electrolyte level [11]. The sensitivity of this calorimetry was determined to be about 10-20 mW for excess power measurements.

The equations for calorimetry were essentially the same as used by Fleischmann and Pons except that our heat transfer was mainly by conduction rather than by radiation [11]. The fundamentals of isoperibolic calorimetry for cold fusion experiments are given in detail elsewhere [12]. Our methods for the collection of electrolysis gas samples were the same as used in previous experiments [5]. The very accurate measurements of helium-4 for our experiments by Brian Oliver of Rockwell International are described in Appendix D of the Hoffman book [13].

The palladium electrodes used in these studies were small-diameter wires of 0.1×2.0 cm produced by Johnson-Matthey.

3. Results and Discussion

These 1991-1992 experiments involving NAWCWD and Rockwell International were designed to test for possible relationships between the excess power in cold fusion experiments and helium production. The experiments were Double Blind because results were reported only to an independent third-party at the University of Texas. Our calorimetry measured 0.100 W, 0.050 W and 0.020 W for these three experiments [8 ,14] while Oliver reported the number of He-4 atoms per flask as 1.34×10^{14}, 1.05×10^{14}, and 0.97×10^{14}, respectively [13, 14]. It is obvious that these He-4 results are in the correct order, but do they agree with theory? Note also that these Oliver results were accurately extrapolated back to the day when each gas sample was collected. This minimizes any small errors due to the atmospheric He-4 diffusing into each glass collection flask (0.2 ppb per day) [13]. The initial results reported for the cell current (I), the experimental excess Power (Px), and the helium-4 measurements are given in Table I. [13,14]. There were also periods of radiation detection during these experiments [14].

Table I. China Lake and Rockwell Results

I (A)	Px (W)	He-4 (atoms/flask)
0.525	0.100	1.34×10^{14}
0.525	0.050	1.05×10^{14}
0.500	0.020	0.97×10^{14}

The comparison of the experimental excess power (Px) and the He-4 in parts per billion (ppb) is made by use of our new equation:

$$\text{He-4 (ppb)} = 55.91\ (Px/I) \qquad [1]$$

where Px is expressed in Watts and I in Amperes. This equation assumes a net fusion reaction producing 23.85 MeV/He-4 such as 2D → He-4. It is also assumed that all the He-4 produced readily escapes into the gas phase. The derivation for Eq. 1 is given in the Appendix. This equation is the ratio of two independent calculations for the He-4 produced by fusion and for the $D_2 + O_2$ gases produced by electrolysis and does not suggest any relationship between Px and I.

The use of Eq. 1 requires that both the cell current (I) and the excess power (Px) remain constant during the collection of a gas sample for He-4 measurements. A constant current was always used in these experiments, and the calorimetry never detected any significant changes for the excess power during these gas collection time periods.

The application of Eq. 1 requires converting the reported He-4 atoms per flask by Oliver [13] into He-4 in ppb. The number of gas molecules ($D_2 + O_2$ + He-4) contained in the 0.500 L collection flask at the laboratory pressure (0.921 atm) and temperature (296.15 K) is given by $N = PV/RT \times 6.023 \times 10^{23} = 1.141 \times 10^{22}$ molecules (0.01894 mol). The Rockwell results are then 11.7, 9.20, and 8.50 ppb.

There is also a small term due to the work done by the generated gases [12] that is given by:

$$Pw = -RT\ (0.75\ I/F) \qquad [2]$$

that slightly adds to the excess power measurements (see Appendix). This term was unknown until recently and adds 0.010 W to each Px value in Table I. Therefore, a more accurate summary of the experiment results is given in Table II. The comparison of He-4 with theory from Eq. 1 is also shown in Table II.

Table II. Comparison of Experiment and Theoretical He-4 Amounts

I (A)	Px (W) [a]	Exp. He-4 (ppb) [b]	Theoretical He-4 [c]
0.525	0.110	11.7	11.7
0.525	0.060	9.20	6.39
0.500	0.030	8.50	3.35

[a] Corrected for Pw = 0.010 W.
[b] Measured by Oliver at Rockwell.
[c] Calculated from Eq. 1.

The calorimetric result of Px = 0.110 W agrees exactly with the Rockwell measurement of He-4 (11.7 ppb) within the 3 significant figures reported. This seems very unlikely to have happened just by chance. The other two experiments were near the measurement limits of our calorimetry. Nevertheless, they were both reasonably close to agreement and could be explained by small calorimetric errors. In fact, notebook records show that the cells were somewhat overfilled in these two experiments which could explain the He-4 differences.

The use of Eq. 1 in the rearranged form of

$$Px = [\text{He-4 (ppb)}]\ I/55.91 \qquad [3]$$

shows that the He-4 measurements by Rockwell provide a much more accurate estimate of the excess power than provided by our calorimetry. The reported Rockwell error of $\pm 0.01\times10^{14}$ He-4 atoms per flask is only ± 0.09 ppb for He-4. From Eq. 3, this would yield an error of only ± 0.8 mW for the excess power at the cell currents used.

The calorimetric excess power is compared with the excess power calculated from these accurate He-4 measurements by using Eq. 3. This is shown in Table III.

Table III. Calorimetric Excess Power and the Theoretical Excess Power from He-4 Measurements

I (A)	Calorimetric Px (W) [a]	Theoretical Px (W) [b]
0.525	0.110 W	0.110 W
0.525	0.060 W	0.086 W
0.500	0.030 W	0.076 W

a From corrected calorimetric measurements.
[b] Calculated from He-4 results using Eq. 3.

Note again the exact agreement for the 0.110 W values. The somewhat larger Px values calculated from the He-4 measurements for the two other experiments are likely more correct than the calorimetric values due to the reported cell over-filling for these two measurements. The higher electrolyte level would cause more power than reported to be transported across the cell boundary.

The value of 23.8 MeV /He-4 can be directly calculated from the experimental data for our most accurate experiment (Px =0.110 W, I = 0.525 A, He-4 =1.34 x 10^{14}atoms/flask). For the time required to generate the 0.500 L gas sample (4644 s) at a constant excess power of 0.110 W yields an energy of 511 Joules (3.19 x 10^{15} MeV). This energy value of 511 J yields an experimental value of 23.8 MeV/He-4 for this fusion reaction. The literature value based on the mass change is 23.8465 MeV/He-4. Perhaps this cold fusion study provides one of the most accurate experimental values reported for this 2 D = He-4 fusion reaction. It is also interesting that the theoretical value of 2.617 x 10^{11} He-4 /J multiplied by the experimental energy value of 511 J yields Oliver's result of 1.34 x 10^{14} He-4 for this experiment. This exact agreement would not be possible if either the calorimetry or the He-4 measurements for this experiment contained significant errors.

Equations 1 and 2 were also applied to many other experiments involving helium measurements [6]. Although the He-4 measurements were considerably less accurate than the Rockwell measurement, approximate agreements were observed. Four examples are shown in Table IV where the accuracy for He-4 was about +/- 3 ppb.

Table IV. Comparisons of the Experimental and Theoretical He-4 for Other Measurements

I(A)	Px(W)	Exp. He-4 (ppb)	Theoretical He-4 (ppb)
0.500	0.120[a]	9.4	13.4
0.500	0.070	7.9	7.8
0.400	0.060	6.9	8.4
0.400	0.035	9.0	7.7

[a] For a Pd-B electrode. All others were for Pd electrodes.

The use of Eq.1 also provides reasonable He-4 amounts in ppb for our first report of He-4 that were originally based on the size of mass spectrometer peaks [6]. These calculated He-4 amounts ranged from 7.4 to 48.7 ppb He-4 [8]. This also gives a detection limit for He-4 of about 5 ppb for these measurements at the University of Texas. The small diffusion of atmospheric He-4 into our flasks (0.2 ppb per day) would not be a problem at this detection limit.

Both Caltech and MIT reported a He-4 detection limit of one part per million for their cold fusion experiments which would be 1000 ppb [8]. Based on Eq.2, the excess power in their cells at I =0.500 A would have to be 8.94 W just to reach their He-4 detection limit. Most calorimetric cells would be driven to boiling before even reaching such a large amount of excess power. Furthermore, Eq.1 also shows that there would be no point in even looking for He-4 if their cells really showed no excess power effects.

Many electrodes used in our LENR experiments showed less helium-4 produced than theoretically calculated from Eq. 1. This could be explained by the slower rate of release of He-4 from an electrode than the rate for the He-4 production. An example is a Pd-B alloy electrode where the amount of He-4 detected was only 70 % of the theoretical amount based on Eq. 1(see Table IV). It was also observed that the deuterium gas escape from the Pd-B alloy electrodes was more than 10 times slower than for Pd electrodes [7]. Boron atoms accumulating in the grain boundaries may slow the escape of both D_2 and He-4 gases. In general, small-diameter electrodes, as used in these experiments, give helium amounts closer to the theoretical calculations.

Nearly all our palladium electrodes that produced the excess heat effect were made under conditions that minimized oxygen contamination [7]. This includes the Johnson-Matthey palladium made using a cracked ammonia atmosphere ($N_2 + H_2$), the Pd-B electrodes made by the Naval Research Laboratory [15, 16] (Boron is an oxygen getter), and co-deposition where the palladium is deposited at the cathode from a $D_2O + PdCl_2 + LiCl$ or related electrolytes [17,18].

The NAWCWD calorimetric results and the Rockwell International reports of their He-4 measurements have co-existed in the scientific literature for many years [6-8, 13, 14], but this is the first time that these results have been directly compared by this accurate theoretical equation (Eq. 1). This is certainly additional proof that He-4 is the main product for cold fusion in the Pd-D_2O electrochemical system. This also solidifies that the cold fusion reaction releases 23.85 MeV of energy per He-4 atom produced.

The consistency between the He-4 and the excess power measurements depends upon three factors: 1. Accurate He-4 Measurements, 2. Accurate Calorimetric Measurements of Excess Power, and 3. The Rate of He-4 Release from the Palladium. When all three factors are sufficient, then exact agreement may be observed.

The correlation between the experimental excess heat and the He-4 production was shown in nearly every cold fusion experiment at the China Lake Navy laboratory [7]. The probability of random errors producing such results in our 33 experiments was only 1/750,000 or 0.0013% [7].

4. Acknowledgments

The author (M.H.M.) appreciates that the Office of Naval Research (ONR) provided support for this cold fusion research at China Lake over several years. Unfortunately, this support abruptly ended in 1995, and this was followed by the banning of further cold fusion research at China Lake by my management. This ending of my support at China Lake coincided with the 1995 attack on

my cold fusion research by Steve Jones of BYU who did not inform me in advance. Thus, I could not prepare a "back-to-back" rebuttal in this issue of the Journal of Physical Chemistry which is the usual and proper custom for such cases of scientific journal disputes.

Brian Oliver of Rockwell International was never considered as a supporter of cold fusion, but his very accurate He-4 measurements were essential for this correlation of excess heat and He-4 production.

5. Appendix

A. Derivation of He-4 (ppb) = 55.91 (Px/I)

This involves the calculation of the He-4 produced per Joule (J) and the calculation of the electrolysis gases ($D_2 + O_2$) produced per Coulomb (C).

Assuming 23.85 MeV per He-4 yields

$N_1 = [(23.85 \times 10^6 \text{ eV/He-4}) (1.6023 \times 10^{-19} \text{ J/eV})]^{-1} = 2.617 \times 10^{11}$ He-4/J

The electrolysis reaction $0.50\ D_2O \rightarrow 0.50\ D_2 + 0.25\ O_2$ yields 0.75 moles ($D_2 + O_2$) per Faraday (F). Thus

$N_2 = [0.75 \text{ mol } (D_2 + O_2)/F] [6.023 \times 10^{23} (D_2 + O_2)/\text{mol}]/96{,}485 \text{ C/F} = 4.681 \times 10^{18} (D_2 + O_2)/C$

Using J = W· s and C = A · s yields C/J = A/W.

Thus $N_1/N_2 = 55.91 \times 10^{-9}$ (Px/I)

or He-4 (ppb) = 55.91 (Px/I)

when Px is in Watts, and I is in Amperes

B. Derivation of Pw = -RT(0.75 I/F)

For P-V work (W): W = -PdV

Expressed as Power (Pw): Pw = dW/dt = -PdV/dt

Assume Ideal Gas: V = nRT/P

dV/dt = (RT/P) dn/dt

From 0.75 Moles ($D_2 + O_2$)/F

dn/dt = 0.75 I/F (mol/s)

Thus

Pw = -RT(0.75 I/F)

Notes: This Pw will generally be slightly greater because the contribution by D_2O gas escaping the cell is neglected.

The time required to generate n moles of $D_2 + O_2$ is given by t = n / dn/dt. For I =0.525 A and n = 0.01895 mol/Flask where dn/dt = 0.75 I/F = 4.081×10^{-6} mol/s yields t = 4644 s.

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