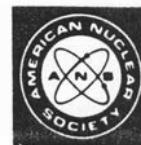


## COMMENTS



The following two technical notes, "Anomalous Reactions During Arcing Between Carbon Rods in Water" and "Verification of the George Oshawa Experiment for Anomalous Production of Iron from Carbon Arc in Water," are unique among the various papers that have been published in *Fusion Technology* in the area of cold fusion and nuclear reactions in solids. The first discusses experiments intended to prove or disprove earlier reports of anomalous production of iron in a carbon arc, while the second discusses a variety of possible related nuclear transmutations. Both studies are directly, or indirectly, related to the subject of nuclear reactions under non-hot-plasma conditions, i.e., closely related to the field of possible nuclear reactions in electrodes during electrolysis in materials like palladium with deuterium implanted by high gas pressure, plasmas, or electrical discharges. Both studies imply that reactions might occur under electron volt background conditions that are even further removed from hot-plasma reaction conditions than those encountered in electrolytic cells. (However, even in electrolytic cells, there have been sporadic reports of the measurement of various product elements that imply nuclear transmutations can occur under these conditions. [See V. A. Tsarev and D. H. Worledge, "Cold Fusion Studies in the USSR," *Fusion Technol.*, **22**, 138 (1992) and R. T. Bush, "A Light Water Excess Heat Reaction Suggests That 'Cold Fusion' May Be 'Alkali-Hydrogen Fusion,'" *Fusion Technol.*, **22**, 301 (1992).])

By anyone's standards, these results seem bizarre—indeed, the authors themselves stress the need for much more work. Because of this, four referees, with widely varying backgrounds, were used to review each of these technical notes. The decision to publish came down to the fact that the referees were mostly "neutral" in their assessments, saying that they could find no egregious errors but that the studies were not definitive and, hence, may be premature. Still, based on the responsibility for a journal to disseminate information to the community in a timely way so that further work is fostered or that pertinent issues are raised, the majority recommendation was to publish these technical notes now. Readers should keep in mind the purpose of these technical notes, namely, to provide provocative observations about a possible new field involving fusion-like nuclear reactions.

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# ANOMALOUS REACTIONS DURING ARCING BETWEEN CARBON RODS IN WATER

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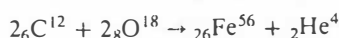
## NUCLEAR REACTIONS IN SOLIDS

### TECHNICAL NOTE

KEYWORDS: *anomalous nuclear reactions, nuclear transformations, iron formation*

*Spectroscopically pure carbon rods were subjected to a carbon arc in highly purified water. The arc current varied from 20 to 25 A and was passed intermittently for several hours. The original carbon contained ~2 parts per million (ppm) iron, and the detritus contained up to 286 ppm of iron. The carbon rods remained cool to the touch at >2 cm from their tips. Adsorption of iron from water or the surrounding atmosphere was established as not being the cause of the increase of iron. There is a weak correlation between the iron formed and the time of passage of current.*

*When dissolved O<sub>2</sub> was replaced by N<sub>2</sub> in the solution, no iron was formed. Hence, the mechanism*



*was suggested as the origin of the iron. The increase in temperature of the solution was consistent with expectation based on this reaction.*

## I. INTRODUCTION

During the last few years, numerous reports<sup>1-10</sup> of tritium formation from deuterium held under solid-state confinement have been published. It is much less well known that long before results of such reactions were revealed, a number of other reports had been made concerning stimulation of nuclear reactions by ultralow-energy changes. Thus, Kervran<sup>11</sup> claims to have brought about the formation of <sup>103</sup>Ru from <sup>206</sup>Pb under chemical conditions. Kushi and Ohsawa<sup>12</sup> claim that iron, cobalt, and nickel may be formed from carbon following arcing in the presence of oxygen. Experiments recently carried out at the Bhabha Atomic Research Center, India<sup>13</sup> indicated that the iron content in the carbon detritus after the arcing was much higher than that expected on the basis of normal chemical considerations. The presence of several new elements in palladium electrodes after glow discharge experiments has been reported by Karabut et al.<sup>14</sup> Similar happenings, involving the incorporation of deuterium into palladium nuclei, have been reported by Passell.<sup>15</sup>

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Three other claims having the same implications have been made in recent times. Bush and Eagleton<sup>16</sup> and Notoya and Enyo<sup>17</sup> have claimed that new calcium has been formed as a result of the electrolysis of H<sub>2</sub>O on nickel in a potassium carbonate solution. Komaki et al.<sup>18</sup> and others<sup>19</sup> have recorded the dependence of potassium and phosphorus in certain bacteria, as a function of the presence and absence of potassium and phosphorus in the nutrient liquid (in half the samples, these materials had been removed). They claim that the missing elements are formed in nuclear biological processes.

In all these cases, the formation of new elements appears to be occurring in the cold, as is indeed the case with the formation of tritium from deuterium, which the authors regard as well established (see Refs. 3, 5, and 10).

In the following, we report work in which the chemically stimulated formation of iron from carbon is described. The work has concentrated on the obvious possibility that these anomalous formations should be from contaminants.

## II. EXPERIMENT

### II.A. Carbon Rods

Carbon rods, 6.14 mm in diameter and 30 cm in length, were obtained from Johnson Matthey. They were AGKSP grade, ultra F purity materials. Specifically, the iron impurity is reported to be <2 parts per million (ppm) (see the analysis below).

### II.B. Water

Distilled water, which was passed through a train of ion-exchange columns made by Millipore-Q, was used. The resistivity of the water was 13 MΩ. This was further purified before use, as described later.

### II.C. Power Supply

An ORIEL Corporation arc lamp power supply, capable of providing currents up to 50 A and voltages up to 70 V, was used to strike an arc between the two carbon rods immersed in water. The current, used to initiate the arc, was ~20 to 25 A in the initial experiments but was later lowered to ~15 A. The voltage during the arcing was ~10 V.

### II.D. Arcing Arrangement

Two carbon rods were immersed ~5 cm deep in ~1 l of purified Millipore-Q water contained in a Pyrex glass trough. The cathode was held vertical. The anode was aligned to within 1 mm to this cathode and was held at a 45-deg angle by means of a holder assembly made of brass that could be moved laterally back and forth. This arrangement (Fig. 1) enabled the continuous alignment of the anode close enough to the cathode to keep the arc running inside the water.

### II.E. Methodology of Determination of Iron in Carbon

A spectrophotometric method, which uses the measurement of the optical density of a solution of the colored complex of iron thiocyanate at 470 nm, was followed. The method was calibrated by using a standard  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  solution in a HCl medium. The calibration curve was constructed with iron content ranging from 27 to 135  $\mu\text{g}$  iron present in 10-ml solutions. A linear curve was obtained to within  $\pm 5\%$ .

### II.F. Determination of the Iron Impurity in the Carbon Rods

About 3 g of the carbon rod was crushed to a fine powder in a mortar. This was taken in a platinum boat, put in a silica tube, and heated at  $900^\circ\text{C}$  in a furnace in a slow stream of oxygen for ~12 h (usually overnight). After that, the boat was removed and treated with 50 ml 5% HCl for 2 h, warming the solution to ~70°C. The platinum boat was then removed, and the solution was reduced in volume by evaporation to ~2 ml.

Alongside this sample solution, 1 ml of a standard  $\text{FeSO}_4$  solution, containing 27  $\mu\text{g}$  iron, was treated with 50 ml 5% HCl, and the solution reduced in volume by evaporation to ~2 ml.

A blank was prepared by reducing 50 ml 5% HCl to ~2 ml in a third beaker.

All these three solutions were then treated with 2 ml 5% HCl and 5 ml of 2.5 M NaSCN, and the volume made up to 10 ml.

The optical density of the sample was measured within 5 min at 470 nm against the blank as the reference, by using

a Perkin-Elmer Lambda 3b UV-VIS spectrophotometer. Similarly, the optical density of the standard was also measured.

The iron content in the sample was calculated by comparison of its optical density with that of the standard.

The iron content in the carbon rods before the arcing was found to be ~2 ppm (see below). This being in the range of the sensitivity limits of the detection method, it was further checked by adding known amounts of iron in the form of  $\text{FeSO}_4$ , FeS, and iron filings dissolved in dilute nitric acid, to the carbon powder and determining the total iron content in ash obtained by incinerating the carbon powder. The results are reported in Table I. The amount of iron initially present in the carbon rods was found by subtracting the amount of iron added (column 2) from the total iron found (column 3).

The mean iron impurity in the original Johnson Matthey carbon rods before arcing was calculated as 2.03 ppm, in conformity with that claimed by the supplier. (The last value in Table I was not considered as is explained later in this technical note.)

### II.G. Determination of Iron Pickup by Carbon from Water

To examine a possible contamination effect due to adsorption of iron from water, the following experiment was carried out.

According to Kushi and Ohsawa,<sup>12</sup> the conversion of carbon to iron needs oxygen. Consequently, arcing was done in a gaseous nitrogen atmosphere, i.e., in the absence of oxygen and water, and the resulting detritus (which should not, according to Ref. 12, have undergone a change to iron but was otherwise similar to the detritus collected in our experiment) was left in contact with ~1 l of Millipore-Q water for varying periods of time. After that, the iron content in the carbon was determined as before (Table II). The amounts of iron, reported in column 3, represent what was originally present in the rods plus that which was adsorbed by the carbon from the water. Even after prolonged contact with water, the amount of iron that was found was very small and was just about detectable by the current method. Iron pickup by carbon from the water may, therefore, be taken as negligible.<sup>a</sup>

### II.H. Iron Impurity in the Water

The iron content in tap water is reported by the Office of the Texas State Chemist at the Texas A&M University System as 70 parts per billion (ppb). There is no known value of iron in Millipore-Q water, but it is claimed by the Millipore Company to be "negligible." The resistivity of the Millipore-Q water is 13 M $\Omega$ . This corresponds to total ionic impurities of ~20 ppb. According to the Millipore Company, the majority of this is organic impurities, and the iron contribution to the total content of conducting material is <2 ppb.

### II.I. Further Purification of Millipore-Q Water

Two carbon rods were crushed to a fine powder in a silica mortar to give ~30 g of carbon powder. This was left in contact with 3 l of Millipore-Q water, which percolated through the carbon slowly over 2 days. This was done so that

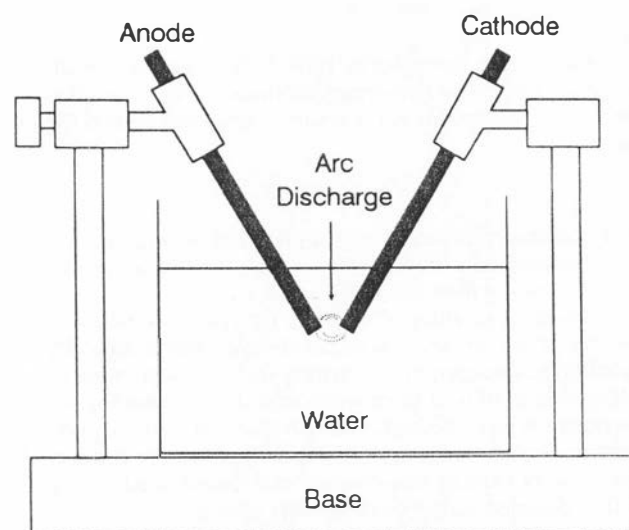


Fig. 1. Holder assembly for the cathode.

<sup>a</sup>The iron impurity in air outside the laboratories is reported by the Texas Air Control Board as 1.2  $\mu\text{g}/\text{m}^3$  iron sampled over 24 h (1978 measurements).

TABLE I  
Iron Content in the Carbon Rods Before Arcing

Weight of Carbon (g)	Amount of Iron Added ( $\mu\text{g}$ )	Amount of Total Iron Found ( $\mu\text{g}$ )	Iron Present Initially in the Carbon ( $\mu\text{g}$ )	Microgram Iron per Gram of Carbon
2.760	---	5.5	5.5	2.0
3.025	54.0 ( $\text{FeSO}_4$ )	61.3	7.3	2.4
2.960	38.1 ( $\text{FeS}$ )	45.3	7.2	2.4
3.020	100.0 (Iron)	107.1	7.1	2.3
3.120	50.0 (Iron)	59.0	9.0	2.9
14.6	---	40.0	40.0	2.7
14.4	---	9.0	9.0	0.6
14.9	---	13.0	13.0	0.9
14.8	---	104.0	104.0	7.0

TABLE II  
Adsorption of Iron by Carbon from Water

Weight of Carbon Detritus (mg)	Time of Contact with Water (h)	Iron Content in the Carbon Detritus ( $\mu\text{g}$ )
80	1.0	0.7
95	10.0	0.9
98	127.0	1.6

the carbon would adsorb iron from the water and would lessen the iron impurity. Water, purified in this manner, was used in the arcing experiments.

### III. RESULTS

In the first series of experiments, a fresh pair of carbon rods was used in each experiment, and the arcing was conducted for periods of between 1 and 3 h. The arc was initiated with a current of 20 to 25 A, and the voltage was  $\sim 10$  V. The iron content in the carbon detritus after arcing was determined as explained earlier. The results are given in Table III.

A second series of experiments was carried out to see the effect of duration of arcing with the same pair of electrodes. After carrying out the arcing for a specified time, the carbon detritus was collected, and the iron content was determined. Then, using fresh water but the same electrodes, arcing was carried out for a longer period, and the experiment was repeated. In this manner, three different pairs of electrodes were used, and each pair was subjected to different periods of arcing ranging from 1 to 10 h. In this series, the arcing current was lowered to be between 12 and 15 A, and the voltage was  $\sim 10$  V. The iron contents in the carbon detritus obtained from this series of experiments are reported in Table IV and depicted in Fig. 2.

### IV. DISCUSSION

The results obtained in this preliminary investigation are quite interesting although they appear not to conform to the

TABLE III  
Values of Iron in the Carbon Detritus After Arcing: Series I

Experiment Number	Weight of Carbon Detritus (mg)	Iron Content ( $\mu\text{g}$ )	Iron in Carbon (ppm)
1	269	45	167
2	116	---	---
3	167	---	---
4 <sup>a</sup>	361	45	125
5 <sup>a</sup>	103	15	146
6	231	---	---
7	192	11	57
8	183	5.5	30
9	163	13.5	80
10	143	---	---
11	138	---	---
12	130	5.5	42
13 <sup>a</sup>	471	53	112
14 <sup>b</sup>	477	196	410

<sup>a</sup>Same rod.

<sup>b</sup>This value and the last value in Table I are abnormally high, and the analyses were performed on the same day; it is possible that an instrument malfunction might have caused the error.

normally accepted principles of physics and chemistry. The various possibilities of the presence of iron in the carbon detritus after arcing may be considered.

An adventitious entry of iron into the system is a distinct possibility. However, the experimental design was specifically oriented in the direction of eliminating such an event; adsorption/absorption of iron from water and the surrounding air was negligible, and the high-purity water was further purified before arcing. Also, the iron impurity present in the carbon rods before arcing was checked and found much lower than that detected in the detritus after arcing.

It is important to ask if the iron impurity in the carbon rods (the total amount may be in the range of 20 to 40  $\mu\text{g}$ )

TABLE IV  
Values of Iron in the Carbon Detritus After Arcing: Series II

Time (h)	Electrode 1			Electrode 2			Electrode 3		
	Weight of Carbon (mg)	Iron ( $\mu\text{g}$ )	Iron in Carbon (ppm)	Weight of Carbon (mg)	Iron ( $\mu\text{g}$ )	Iron in Carbon (ppm)	Weight of Carbon (mg)	Iron ( $\mu\text{g}$ )	Iron in Carbon (ppm)
1	24.5	3.43	140	30.3	1.4	46.2	25.1	1.94	77.3
3	79.1	9.62	121.6	83.6	22.8	272.7	86.3	15.0	173.8
5	140.9	1.1	8	142.7	4.5	31.8	<sup>a</sup>	<sup>a</sup>	<sup>a</sup>
10	<sup>a</sup>	<sup>a</sup>	<sup>a</sup>	<sup>a</sup>	<sup>a</sup>	<sup>a</sup>	286.1	39.9	139.5

<sup>a</sup>Experiments not done.

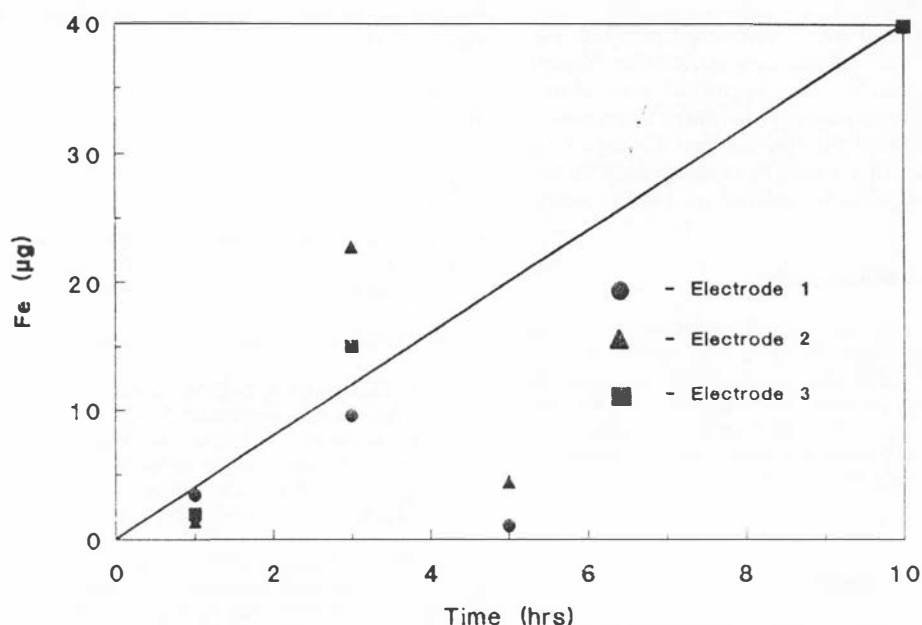
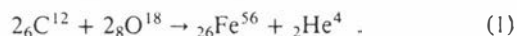


Fig. 2. Effect of time of electrolysis on the formation of iron.

would diffuse to the tip of the rod during arcing. There is no available data for the diffusion of iron in carbon but, as a first approximation, may be assumed to be the same as for nickel for which data are available.<sup>20</sup> It is seen that the diffusion coefficient is  $1 \times 10^{-6} \text{ cm}^2 \cdot \text{s}^{-1}$  at  $1000^\circ\text{C}$  but falls sharply to the order of  $10^{-26} \text{ cm}^2 \cdot \text{s}^{-1}$  at  $100^\circ\text{C}$ . Thus, during the arcing, only the tip of the carbon rod, say to a 0.1-cm length, would be at a temperature of  $>1000^\circ\text{C}$ , and there is a sharp decrease in temperature along the rest. Therefore, there will be significant diffusion of iron inside carbon in the tip region only, which is easily seen to be negligible.

We may now consider the possibility that carbon combines with oxygen during arcing to form iron according to the scheme



The following considerations have been taken into account in suggesting this scheme:

1. The formation of iron occurs only in the presence of oxygen. When the arcing was carried out in a nitrogen atmosphere (Sec. II.G), iron was not formed. An  $^{18}\text{O}$  isotope was considered because of mass balance considerations.

2. The scheme suggests formation of alpha particles. The arcing, therefore, is not accompanied by neutrons or gamma radiations.

3. Considering the various atomic masses, the reaction is favored as written. The mass defect amounts to an excess energy of 56.55 MeV.

The energy released by this reaction as well as the joule heating due to arcing would raise the temperature of the water in the trough. The extent of this heating may be considered next.

The average amounts of iron formed over a 3-h arcing experiment was of the order of  $15 \mu\text{g}$ . This, according to the

suggested reaction scheme, would be equivalent to the release of an average energy  $G$  of  $135.2 \text{ J} \cdot \text{s}^{-1}$  or a power of 135 W.

The joule heating due to the electrical power input was calculated by taking into account the current and voltage during the running of the arc. Though the current to initiate the arc was 10 A or more, it always fell to a lower value of  $\sim 5$  A while the arc was continuous. The electrical power input, under these conditions, would then be  $\sim 50$  W.

The combined power input due to the energy released in the suggested formation of iron and electrical power input in running the arc would thus be  $\sim 185$  W. According to a separate experiment that showed an average temperature rise of  $\sim 18^\circ\text{C}$  for a power input of 50 W, this would indicate that the temperature of the water in the trough would be raised by  $\sim 67^\circ\text{C}$  and would reach  $\sim 87^\circ\text{C}$ . In fact, the temperature of the water in the trough rose to  $\sim 80^\circ\text{C}$  during the experiments. Also, the arc was kept running for only  $\sim 20$  to 30 min at a time with a break of  $\sim 15$  to 20 min in between to avoid excessive heating.

Thus, it appears as if the transformation of carbon to iron is possible under the experimental conditions described. Recently, Karabut et al.<sup>21</sup> showed that new nuclei were formed up to a concentration of 0.1% over a  $1\text{-}\mu\text{m}$ -thick layer of palladium cathode in a deuterium glow discharge experiment. It is, however, expected that the iron formed during arcing would be different from that found in nature with a different isotopic distribution. This is a subject for further study.

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