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Abstract

Following the announcements of cold nuclear fusion being observed in electrochemical cells by Fleischmann and Pons[1] and by Jones[2], we have searched for the characteristic radiations of the $d+d$ and $p+d$ fusion reactions in cells similar to those described in the refs.(1,2). No fusion product neutrons or gamma rays have been observed from either palladium or titanium cathodes. From measured D/Pd ratios in the systems with the palladium cathodes, we set upper limits on the fusion rates for our systems.

Keywords

Cold fusion, Feischmann and Pons, Jones, neutrons, upper limits

1 Introduction

The televised announcement of the observation of cold nuclear fusion by Pons and Fleischmann[1] and the subsequent similar announcement by Jones[2] caused a great stir in the scientific community as a whole. Was this to be a great breakthrough leading to the production of cheap and virtually inexhaustible electric power? With the enormity of the implications of such a process, it became very important for rapid confirmation by other groups of the process of cold nuclear fusion of deuterium. Following the descriptions that were provided in refs.(1,2), our group attempted to detect the characteristic radiations from the $d + d$ and $p + d$ fusion reactions. Neutrons, gamma rays, and induced radioactivity in the cathodes were searched for.

2 Experimental

A 50-cm by 1-mm diameter palladium wire from Johnson Matthey, and a 2.5-cm by 8-mm diameter palladium rod obtained from the Lawrence Livermore National Laboratory were used as cathodes. Two titanium cathodes were also used. One was a 1-cm^3 cube, the second a 1-cm by 1-cm by 8-cm rod. Both were fabricated by in-house shops from available titanium stock. 99% D_2O was obtained from Cambridge Isotopes. Natural Li metal was obtained from Fisher Scientific. ^6Li, enriched to 99.3%, was obtained from the Oak Ridge National Laboratory. The chemicals that were used to produce the Jones[2] type electrolyte "soup" were used from stocks obtained from Allied

Chemical.

The cells were powered by either a Lambda Model LA-200 Regulated DC Power Supply or an in-house constructed constant voltage supply. Current measurements were made using a Fluke digital multimeter.

Neutron detection was performed with an NE-213 Liquid Scintillator detector with pulse shape discrimination to differentiate between fast rise time gamma signals and slow rise time neutron signals. The detector was calibrated with a ^{238}Pu-^{13}C source. Neutrons were also looked for using Kodak dosimeter film, and by looking for induced radioactivities in the palladium cathodes.

Gamma rays were detected with a high efficiency 3-in by 6-in NaI(Tl) detector, calibrated using the 6.13 MeV gamma-ray from the same ^{238}Pu-^{13}C source that was used for the neutron calibration. Calibration from 0.088 MeV to 2.0 MeV was done using an Amersham mixed radionuclide gamma standard.

Radiation measurements were performed using an ORTEC ACE data collection system installed in an IBM-PC.

3 Results

We searched for the characteristic radiations from the following reactions:

$$1) d + d \rightarrow {}^{3}\mathrm{He} + n(2.45 \text{ MeV})$$

$$2) d + d \rightarrow t + p(3.0 \text{ MeV})$$

$$3)\ d + d \rightarrow {}^4\mathrm{He} + \gamma(23.8\ \mathrm{MeV})$$

$$4)\ p + d \rightarrow {}^3\mathrm{He} + \gamma(5.5\ \mathrm{MeV})$$

Reactions 1) and 2) are expected to occur with equal probabilities[3]. The ratio of reactions 3) to 2) have been measured[4] and found to be on the order of 10^{-7}. We did not measure products from reaction 2).

Our measurements were performed in a special low background facility at the Lawrence Berkeley Laboratory. The neutron background was found to be 0.118 ± 0.001 n/sec in our detectors. Direct comparison of spectra from both detectors taken with the cell power on and off was used to determine the limits on the gamma rays and neutrons produced in these fusion reactions.

Following the description by Fleischmann and Pons[1], we electrolyzed D_2O containing 0.1 M Li obtained by dissolving 0.694 g of lithium metal directly in 0.1 L of D_2O. For the cell using the 50-cm by 1-mm diameter palladium wire cathode, the wire was coiled inside the outer wall of the cell. The platinum anode was suspended in the center of the cell. The gamma and neutron detectors were placed on either side of the cell, and the whole apparatus was shielded by about four inches of lead on all sides. For the cell containing the 2.5-cm by 8-mm palladium rod, the relative cathode and anode positions were interchanged.

Following the Jones type experiment[2], we also looked for fusion with heavily poisoned titanium electrodes. A 1-cm^3 titanium cube was suspended in the center of the cell. Coiled inside the outer wall of the cell was a 10-cm by 2-mm diameter platinum wire anode. A 1-cm by 1-cm by 8-cm titanium rod was also used in this same physical setup.

In each of the Jones style and Pons style experiments 10% H_2O was added to the cell for some of the runs to enable us to look for $p+d$ fusion reactions. The cell parameters are listed in Table I.

The evolved D_2 and O_2 gases were allowed to escape to the atmosphere, and sufficient D_2O was added during the electrolysis to keep the solution level at a constant volume. The titanium cells were operated for a total period of 12 days. The longest single operation time was 2.6 days for the cubic cathode. The "rod" cathode operated for 2.5 days. The palladium cells were operated for a total time of 17 days. The longest single operation was 5 days for the wire cathode and 3.6 days for the rod cathode.

The D/Pd ratio for the palladium cathodes was determined by weighing the electrodes before and after the electrolysis to determine the mass of deuterium that had been absorbed into the metal. After the final weighing, the electrodes were baked in air for one hour at 600-1000°C and weighed again. They were found to return to their original pre-electrolysis weight. In the case of the titanium electrodes, we could not determine the deuterium content in the metal because of the subsequent plating of the poisons that were present in the solution.

No radiation above background was observed in any of the experiments. We also did not observe any radiation from the cells containing 10% H_2O. We were able to set limits on the possible fusion reactions in the palladium systems using the observed D/Pd ratios and the detection limits of our detectors. These upper limits are based on a one-sigma (68%) uncertainty in the (signal - background) calculation. Upper limits for the systems contain-

Table I: Conditions used in our electrochemical setup.

Cathode Type	Current (amps)	Voltage (volts)	Current Density A/cm^2	Ratio D/Pd	Electrolyte Type
Ti cube	0.25	4.0	0.042	NM[a]	Jones "soup"
Ti "rod"	0.25	6.0	0.029	NM	Jones "soup"
Pd wire	0.25	4.0, 2.0	0.016	0.5	0.1 M Li
Pd rod	0.4	2.0	0.640	0.77	0.1 M Li

[a]Not measured.

ing 10% H_2O were not calculated due to the unknown deuteron/proton ratio inside the electrode. Table II shows the results of our measurements.

In addition, we looked for the activity which should be induced in the palladium cathodes if the neutrons from fusion reactions are present. We did not observe any neutron-capture products in the cathode material. However, because the cross sections for neutron capture under these conditions cannot be accurately estimated, we cannot assign an upper limit based on these results.

In some of the runs, ^{6}Li was used instead of natural Li. No difference between these electrolytes was observed.

4 Conclusion

From the observed D/Pd ratios in the cathodes, and the absence of any observable radiation from the possible fusion reactions, we set one-sigma limits on the cold fusion reactions $d(d,n)^3$He and $d(d,\gamma)^4$He of $\leq 2.1 \times 10^{-24}$ and $\leq 2.7 \times 10^{-24}$ reactions per deuteron per second, respectively. We conclude that if cold fusion is occurring under these conditions, it is below these limits. These limits are inconsistent with a nuclear mechanism for the generation of heat reported by Pons and Fleischmann(1). These limits are also about a factor of 10 below the rates reported by Jones *et al.*(2).

Table II: Upper limits for the fusion probability based on one sigma limits of the (signal - background) counts.

Pd Form	Neutron Limits (n/sec)	$d(d,n)^3He$ Limit per d per sec	23.8-MeV gamma rays (cts./sec)	$d(d,\gamma)^4He$ Limit per d per sec
Wire	≤ 0.75	$\leq 5.4 \times 10^{-23}$	≤ 0.4	$\leq 2.9 \times 10^{-23}$
Rod	≤ 0.14	$\leq 2.1 \times 10^{-24}$	≤ 0.18	$\leq 2.7 \times 10^{-24}$

5 Acknowledgements

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6 References

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