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#### Search for neutron emission from deuterium-loaded palladium

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The recent reports of neutron emission due to nuclear fusion of deuterium during the electrolysis of heavy water with a palladium cathode are investigated. The results for an electrode with a deuterium-to-palladium atom ratio of 0.6 show that, at the two-sigma level, fewer than 0.002 neutrons/gsec are emitted. A search for very high neutron-multiplicity events caused by multiple muon catalysis in the palladium cathode showed no such events.

The attribution of excess heat in the electrolysis of heavy water with a palladium cathode to a nuclear fusion reaction is of great interest<sup>1</sup> for its potential use as a power source. The report of radiation that is much smaller than expected from the excess heat, as well as a second report<sup>2</sup> of an even weaker neutron emission in a similar situation, is also of great interest. In their paper, Fleishman, Pons, and Hawkins<sup>1</sup> report neutron emission on the order of 40000 neutrons/sec from a cell with a palladium cathode of approximately 15 g. Jones *et al.*<sup>2</sup> report neutron emission from both titanium and palladium electrodes. A value of about 0.4 neutrons/sec from 3 g of titanium was used in estimating a cold-fusion rate.<sup>2</sup>

This report is on two experiments aimed at detecting neutrons emitted in cold fusion. Our results were obtained during electrolysis of heavy water with cathodes of palladium and of titanium. Most of the data were taken with palladium. The palladium electrode consisted of 15 g of the metal in the shape of a bar with approximate dimensions of  $2.7 \times 12 \times 41$  mm. It was made by cutting a 31 g bar into two pieces, one for the cell of heavy water and one for the cell of ordinary water. The electrolyte was 45 ml of  $0.1M$   $^6\text{LiOD}$ . About 85% of the palladium was below the surface of the solution. The current used varied from 2 to 12 mA/cm<sup>2</sup> of cathode area. The loading of the palladium with deuterium was inferred by weighing the electrode; it gained 44 mg in the first 16 h and was

found to be  $149 \pm 2$  mg heavier after loading by electrolysis for 9 d. This mass corresponds to a deuterium-to-palladium atom ratio of 0.6. The same loading was observed after another five days of electrolysis. Care was taken to carry out the weighing rapidly, as deuterium leaves the electrode as soon as the potential is removed.

Neutrons were detected in a 6.9 cm diameter  $\times$  3.6 cm thick liquid scintillator detector of NE213 placed near the cell. Figure 1 is a particle identification spectrum projected from the two-dimensional<sup>3</sup> raw data. It shows that the neutron and gamma-ray pulses from a plutonium-beryllium source are well separated. Figure 2 shows particle-identification spectra taken with heavy water (upper part) and light water (lower part) plotted on a logarithmic scale. The gamma-ray group of pulses is far more intense than the neutron group, but the neutron group is still clearly defined. For these spectra the pulse heights in the scintillator were restricted to correspond to electron energy losses from 250 to 630 keV. This range gives the detector about 20% efficiency for detecting neutrons of energy 2.45 MeV.

In one geometry we obtained the following values for the number of neutrons detected per hour: background,  $20.4 \pm 0.9$ ; palladium cathode,  $20.5 \pm 0.7$ ; titanium cathode,  $20.5 \pm 0.7$ . Including solid angle, the total efficiency of the detector for the expected 2.45 MeV neutrons was 1.0%. Additional data were taken with the cell and sup-

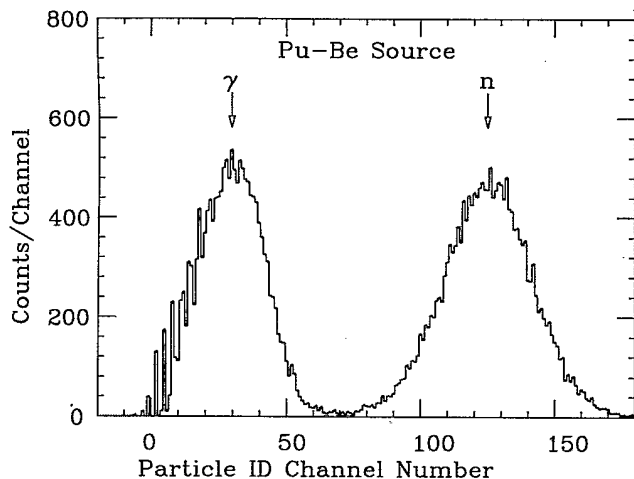


FIG. 1. Particle identification spectrum from a Pu-Be source.

porting ring stand removed and replaced with 0.5 l of  $D_2O$ , 0.5 l of  $H_2O$ , or with nothing. No significant difference in the neutron counting rate was observed among these latter runs.

In a second series of runs, the passage of muons through a thin scintillation detector located above the electrolytic cell was recorded. The neutrons were found to be uncorrelated with the passage of muons. By placing the cell directly on top of the liquid scintillation detector, the overall efficiency for detection of 2.54 MeV neutrons in this series was increased to 2.0%. The resulting neutron hourly counting rates were as follows: background,  $20.0 \pm 0.7$ ; palladium cathode,  $19.0 \pm 0.7$ .

Our data are consistent with zero neutron emission with a two-sigma limit of 0.002 neutrons per gram of palladium per second.

In a separate experiment an array of nine 22 cm diameter  $\times$  7 cm thick liquid scintillators was set up to detect the presence of muon catalyzed fusion events with very large multiplicities. A recent proposal that such a process could explain some of the observed neutron flux was made by Guinan, Chapline, and Moir,<sup>4</sup> with the conclusion that as many as 700 fusions could be catalyzed per stopped muon in deuterium loaded palladium. The time of arrival of the nearly coincident neutrons should provide a highly characteristic signature of high-multiplicity catalysis, since neutrons are expected to be produced throughout the survival time of the muons. The electronics were arranged to record the arrival time of the neutrons over a 5- $\mu$ sec interval, more than twice the muon mean life.

A single event was recorded in which three detectors observed neutrons within the 5- $\mu$ sec window during measurements lasting a total of 3.2 d. In this event the three

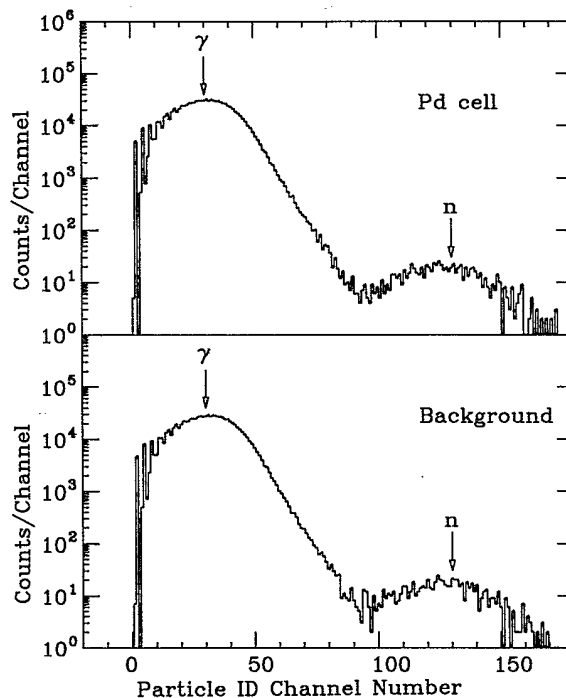


FIG. 2. Particle identification spectrum from the electrolytic cell with palladium cathode in  $D_2O$  (upper) and from the control cell, palladium in normal water (lower).

neutrons arrived within 0.1  $\mu$ sec. There was no instance of four or more detectors recording neutrons. Based on one stopped muon per day per gram of palladium,<sup>4</sup> we estimate 43 muons stopped in the palladium cathode. A Monte Carlo simulation of the probability of detecting neutrons in three or more detectors per stopped muon as a function of neutron multiplicity predicted 38 such events for a neutron multiplicity of 100 and 6 for a multiplicity of 25. Assuming the one candidate event to be an average value, the neutron multiplicity would be 13. Thus our result indicates that a fusion multiplicity of several hundreds does not occur, and it is likely that muon capture in palladium quickly removes the muons from the sample.

While the electrolytic cell used in the present work may not duplicate exactly that of either Ref. 1 or Ref. 2, it is similar enough to expect that some of the reported radiation of neutrons would be detected. Instead, our limit for palladium is many orders of magnitude less than reported in Ref. 1 and, with two standard deviations, is lower than reported for titanium in Ref. 2 by a factor of 70.

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<sup>4</sup>M. W. Guinan, G. F. Chapline, and R. W. Moir, Lawrence Livermore National Laboratory Report No. UCRL-100881.