TITANIUM DEUTERATION WITH NEUTRON EMISSION THROUGH ELECTRICAL DISCHARGES

NUCLEAR REACTIONS IN SOLIDS

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To search for the absorption of deuterium gas in titanium plates and the neutron emission from this process, electrical discharges between two titanium electrodes in a deuterium atmosphere have been performed. During the discharges, a temperature >300°C on the surface of the electrodes was measured. A typical characteristic of the phenomenon observed was the deuteration of the electrodes. Pressure reduction was notorious when the chamber was previously cooled with liquid air. Deuterium absorption seemed to be present in all experiments whether or not liquid air was added on the deuteration chamber. Sheets of CR39 plastic detectors, a Bonner sphere, and a fission chamber were used to look for neutron emission.

I. INTRODUCTION

The possibility of inducing nuclear fusion reactions at low temperature in solid-state materials has been widely discussed.[1,2] The evidence for such reactions is based mainly on three types of experiments. In the first group, the electrolysis of an aqueous heavy water solution is utilized to load deuterium in palladium and titanium structures;[1–4] in this experiment the deuterium separates from the aqueous solution and penetrates either the palladium or titanium lattice. In the second type of experiment, the titanium lattice is loaded with deuterium at a high pressure.[5] In the third type of experiment, titanium electrodes are immersed in a deuterium atmosphere, and the deuterium is forced into the titanium structure by electrical discharges.[5–8] Once inside the lattice, the deuterium may be involved in fusion reactions.

Deuterium forced into the lattice structure of metals such as titanium and palladium can produce the conditions to induce fusion reactions. This assumption is based on two reported experimental observations: neutron emission and the release of a considerable amount of heat.[1,9,10] There are some theoretical models to explain the neutron emission from the fusion reactions $D(d,n)^3He$ and $D(d,p)T$ (Refs. 11 through 14). One of these models suggests that Coulomb barrier tunneling[11] produces fusion reactions. Other theoretical models assume that the fusion reactions are partially due to a reduction in the dimensions of deuterium atoms inside the lattice.[11,13,14] Finally, other models developed around the same problem have been proposed on the basis of new particle interactions that demand drastic changes in our way of understanding the cold fusion phenomenon.[15]

The objective of this work is to obtain experimental data to support the deuteration phenomenon and the neutron emission, according to the third type of experiment, using electric discharges. A vacuum chamber was built to induce deuteration in titanium electrodes through electrical discharges in a controlled deuterium atmosphere. In contrast with other authors, we have used massive titanium electrodes, ~2 kg in all, immersed in a deuterium atmosphere up to 10^2 Torr (Ref. 16).

The vacuum chamber and the measuring devices are described in Sec. II. Section III contains the experimental sequence as well as its main outcome. Conclusions are provided in Sec. IV.

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II. EXPERIMENTAL SETUP

The experimental setup, shown in Fig. 1, consists of a cylindrical stainless steel, 0.2-m-diam, 0.6-m-high vacuum chamber labeled as *a*. The vacuum chamber contains two sets of titanium electrodes; the first one (*b*) is composed of four 0.003- × 0.05- × 0.45-m plates and is kept at a negative potential. The second set acts as a positive electrode and consist of two titanium bars (*g*), with a 0.005-m radius and a 0.5-m length. The total mass of both positive and negative electrodes is ~2 kg.

Two turbomolecular 500 ℓ/s vacuum pumps (*c*), a Pirani vacuum gauge (*d*), and a 10^{-11} to 10^{-4} Torr ion gauge (*f*) were used for providing and assessing pressure conditions. CP-grade D_2 (*k*) at room temperature is admitted into the chamber by means of a micrometric sapphire valve (*h*). With the exception of the electrode circuit, the equipment is kept at a floating potential.

A power source supplies 50 V/300 A for electrode degassing, and another one supplies 4500 V/5 A for the breakdown and sustainment of the discharge.

In some experiments the electrodes were cooled at cryogenic temperatures by partially immersing the vacuum chamber in a liquid air reservoir (*i*).

Analysis of residual gases taken from the experimental device was carried out using a Leybold Heraeus Q 200 mass spectrometer (*j*). Temperature measurement was made using five K-type thermocouples (*e*), which were distributed along the titanium electrodes and on the interior wall of the vacuum chamber.

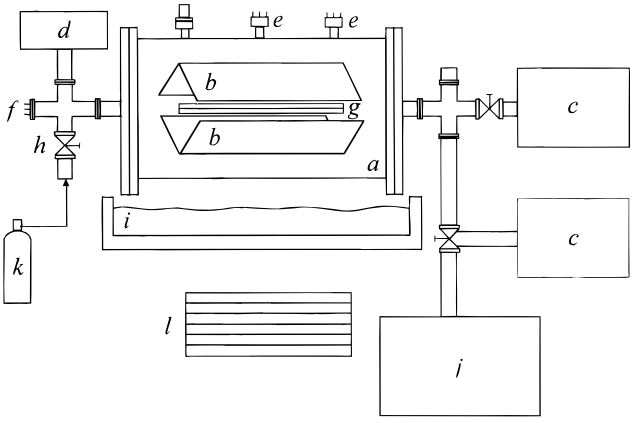

Fig. 1. Schematic of the experiment. The configuration of electrodes inside the vacuum chamber is shown. (*a*) Vacuum chamber; (*b*) negative titanium electrodes; (*c*) vacuum pumps; (*d*) Pirani vacuum gauge; (*e*) thermocouples; (*f*) ion gauge; (*g*) positive titanium electrodes; (*h*) sapphire valve; (*i*) liquid air reservoir; (*j*) mass spectrometer; (*k*) deuterium cylinder; (*l*) plastic detectors and paraffin blocks.

Three types of neutron detectors were included in the experimental setup for detecting possible neutron emission: a 93% ^{235}U fission chamber, a Bonner's sphere, and CR39 plastic detectors (*l* in Fig. 1). All detection efficiencies were calibrated using a californium neutron source and paraffin wax absorbers of different thicknesses.

Three sets of ten CR39 plastic detectors were used. The first one was inserted between 0.04-m-thick paraffin wax blocks (*l*) outside the chamber, ~0.45 m from its axis. In this set, one-fourth of the CR39 plastic detection area was covered with lithium borate to increase the thermal neutron detection efficiency. The second set of bare plastic detectors, without lithium borate, was allocated at the inner wall of the chamber. Both sets of plastic detectors remained there throughout the 3-month experimentation period. A third set of plastic detectors, kept in the same laboratory but far from the experimental setup, assessed the background signals from environmental radon.

III. EXPERIMENTAL DESCRIPTION AND RESULTS

Most of the contamination on the electrode surfaces was removed by polishing and cleaning with detergent, acetone, and isopropyl alcohol. Later, the electrodes were degassed by heating up to 700°C in the vacuum chamber for 30 min by means of a 300-A electric current. The vacuum chamber was conditioned at the same time as the electrode degassing with a 2.5-h pumping until a 3.3 × 10^{-6} Torr pressure was attained.

Deuterium was injected into the chamber to reach a pressure of 10^2 Torr through the sapphire valve (*h*). The electrodes were polarized, thereby increasing the voltage up to the breakdown point, according to the growing deuterium pressure. This process finally ended when arcing conditions were attained.

In this manner, several relevant results were obtained. The vacuum chamber pressure was reduced by one order of magnitude in a time >40 min when the chamber was partially sunk in liquid air without electric discharges in the electrodes, as can be observed in Fig. 2. In Figs. 2, 3, and 4, the voltages between electrodes are displayed as well as the times in which the liquid air was added. When no liquid air was used, the chamber pressure always increased, depending mainly on the initial pressure value and the discharge intensity (see Fig. 3). However, when liquid air was added at room temperature, the chamber pressure reduction was remarkable during the electrical discharges between the titanium electrodes (see Figs. 2, 3, and 4).

Thus, during the electrical discharges, when the chamber was cooled down, the pressure decreased at a rate faster than by cooling only, even though the electrode temperature increased. Without liquid air cooling, the pressure grew during the electrode electric discharge, as

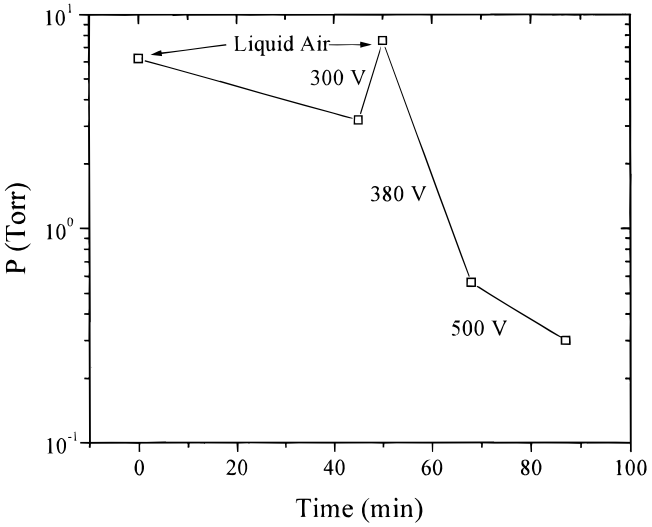

Fig. 2. Time evolution of the vacuum chamber pressure. Liquid air cooling was applied to the chamber at the indicated times. Electric fields between titanium electrodes were maintained during the intervals labeled with the corresponding voltage values. In the first part of the curve, only liquid air was added. The pressure reduction was much less than one order of magnitude. After that, electrical discharges between electrodes were applied.

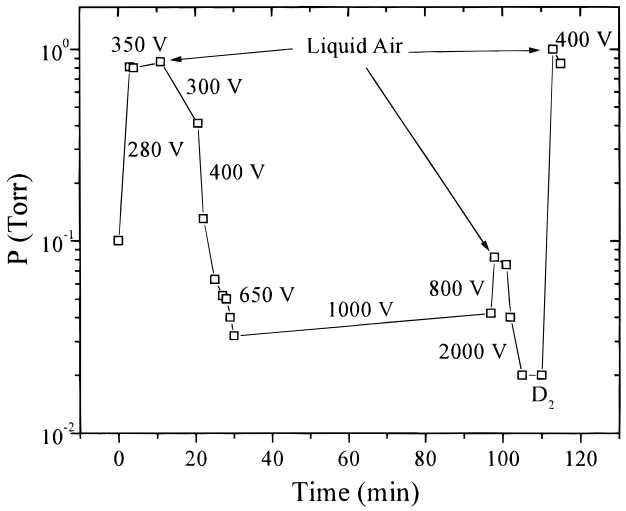

Fig. 3. Time evolution of the vacuum chamber pressure. Liquid air cooling was applied at the three points indicated. Without liquid air the pressure always increases (e.g., the intervals where voltage between electrodes were kept at 280 and 800 V). When liquid air was added, the chamber pressure reduction is remarkable. After switching off the electrode voltage, deuterium is admitted to the chamber at $t \sim 110$ min.

shown in Figs. 3 and 4. Although, during discharges, the typical temperatures measured on the electrode surfaces were ~200°C, the highest temperatures registered in the same positions reached >300°C. These temperatures rapidly decreased to typical values once the discharges ended.

Both fission chamber and Bonner sphere neutron detectors registered counts only when the electrical discharges were in progress. The number of counts in the two detectors was related to the intensity of the discharge. Yet, in these electronic detectors, the neutron counts and the electrical noise signals could have been mixed together, making the spectra not completely reliable (see Figs. 5 and 6).

The CR39 detectors showed a track density higher than the background levels. One-fourth of the area of the surface of each detector was covered with a 300-μm coat of lithium borate to increase the sensitivity of detection. Thus, we have four curves in Fig. 7 showing the track density as a function of paraffin wax thickness. The vertical axes on the right sides refer to the radon concentration using the conversion factor 9.25 Bq/m^3, equivalent to 10^4 track/m$^2 \cdot$day. The first three plastic detector curves, corresponding to three quarters of the surfaces without lithium borate [curves (a), (b), and (c)], exhibit more than 2×10^7 tracks/m^2. The last curve (d), which corresponds to the plastic area covered with lithium borate, reaches a density up to little more than 4.5×10^7 tracks/m^2. In these curves (Fig. 7) there are two peaks corresponding to two different energies. The

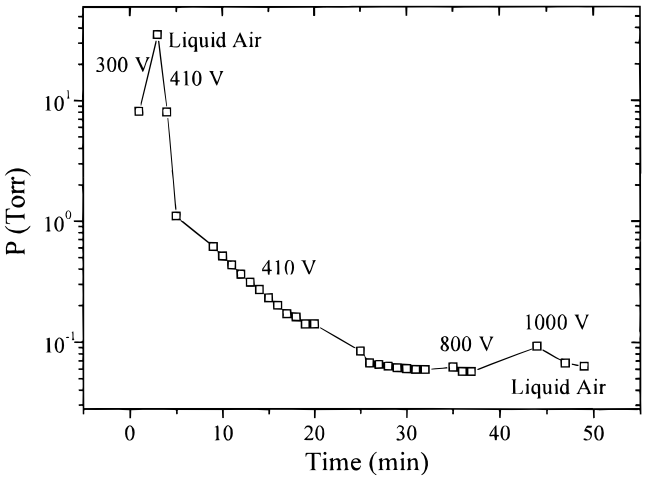

Fig. 4. Time evolution of the vacuum chamber pressure. Liquid air cooling is applied at $t \sim 3$ min and at $t \sim 44$ min only. Without liquid air, the 300-V electrical discharge increases the chamber pressure. During the liquid air cooling effect, the pressure always decreased. The 410-V current between electrodes is maintained from $t \sim 3$ min to $t \sim 35$ min.

analysis of residual gases from the mass spectrometer does not show any signal of tritium.

In comparing the peaks corresponding to the cases in which the lithium borate converted foil were used

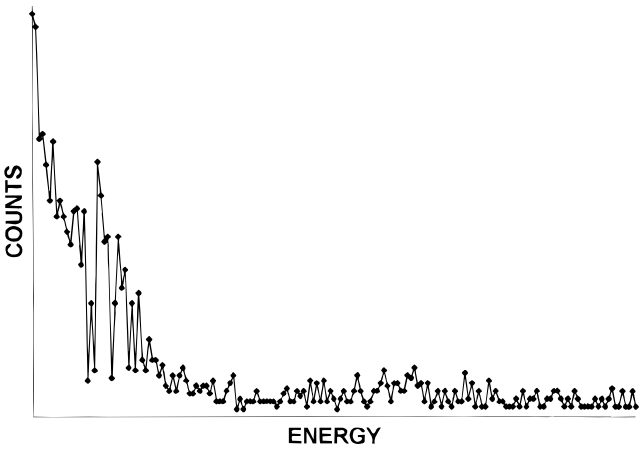

Fig. 5. Energy spectrum obtained under the electrical discharges using a Bonner's sphere.

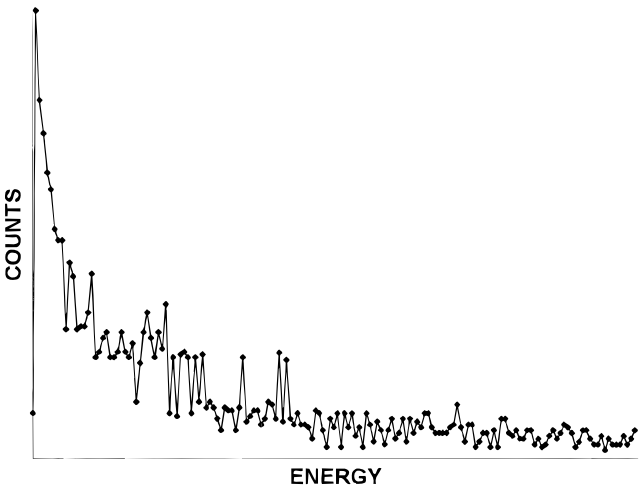

Fig. 6. Energy spectrum obtained under the electrical discharge using a fission detector.

with those without it, three facts were taken into consideration:

1. The total track density ρ due to neutrons in a CR39 detector is

$$\rho = \sum N^i \int_{E_0}^{E} F^i(E)\sigma^i(E)\phi(E)\,dE \ ,$$

where

i = each of the nuclei yielding charged particles through nuclear reactions induced by neutrons in the plastic detectors and in the converter foil

$\sigma^i(E)$ = cross section for the i'th nuclear reaction

N^i = number of the nuclei i per volume unit

$\phi(E)$ = neutron flux while F^i is the corresponding efficiency factor.

So, for a bare detector and neutron energies $E_n > 100$ keV, the main neutron detection process is by proton recoiling from the hydrogen contained in the detector itself and in the wax ($\sigma \sim 4$ b). For energies >2 MeV there is an alpha-particle contribution from the reaction $^{14}N(n,\alpha)^{11}B$ with a cross section value <0.4 b. The lithium borate converter foil provides alpha and tritium particles out of the reactions $^{6}Li(n,\alpha)T$ and $^{10}B(n,\alpha)^{7}Li$ with Q values of 4.78 MeV and 2.792 MeV, respectively, and cross sections of 150 and 600 b for a neutron energy of 1 eV. Both cross-section values drop rapidly with the neutron energy as $\sigma(E) \approx E^{-1/2}$, reaching 0.2 b at 1 MeV.

2. There is a logarithmic neutron fluence reduction, by the wax blocks resulting from the absorption and scattering of neutrons, down to 1% for energies of 2 MeV at a 0.04-m wax thickness. A fluence reduction also arises from the solid detection angle.

3. There exists a neutron energy reduction due to multiple neutrons scattering in the wax blocks.

Thus, the explanation of the peaks present in Fig. 7 can be drawn from these three facts. A reproducible curve shape is systematically observed in the set of detectors (a), (b), and (c) with a peak well above the radon background. No neutron signal is observed at large paraffin thickness (~0.2 m) because of the reduction both in neutron fluence down to 1% and in the solid detection angle.

At high paraffin thickness values, one might expect a higher track density in the plastic detector because, as the neutrons reduce their energy, the cross section values of the two aforementioned nuclear reactions increase nearly three orders of magnitude. However, the solid angle reduction and the escape of neutrons from the main beam seem to be dominant.

Although the contribution of protons from the wax block is screened by the lithium borate foil, the peak high in curve (d) is twice as high as those in curves (a), (b), and (c) because the T and alpha particle contribution at high neutron energies from the reaction $^{6}Li(n,\alpha)T$ overcomes such a screening effect.

Some experimental problems arise when defining neutron spectra using an electronic detector such as the Bonner's sphere: The neutron flux ($n/m^2 \cdot s$) is too small, and the noise introduced by the electric discharges in the equipment interferes with the neutron signal. We are in the process of modeling the neutron detection system on the basis of plastic detectors to increase the detection efficiency.

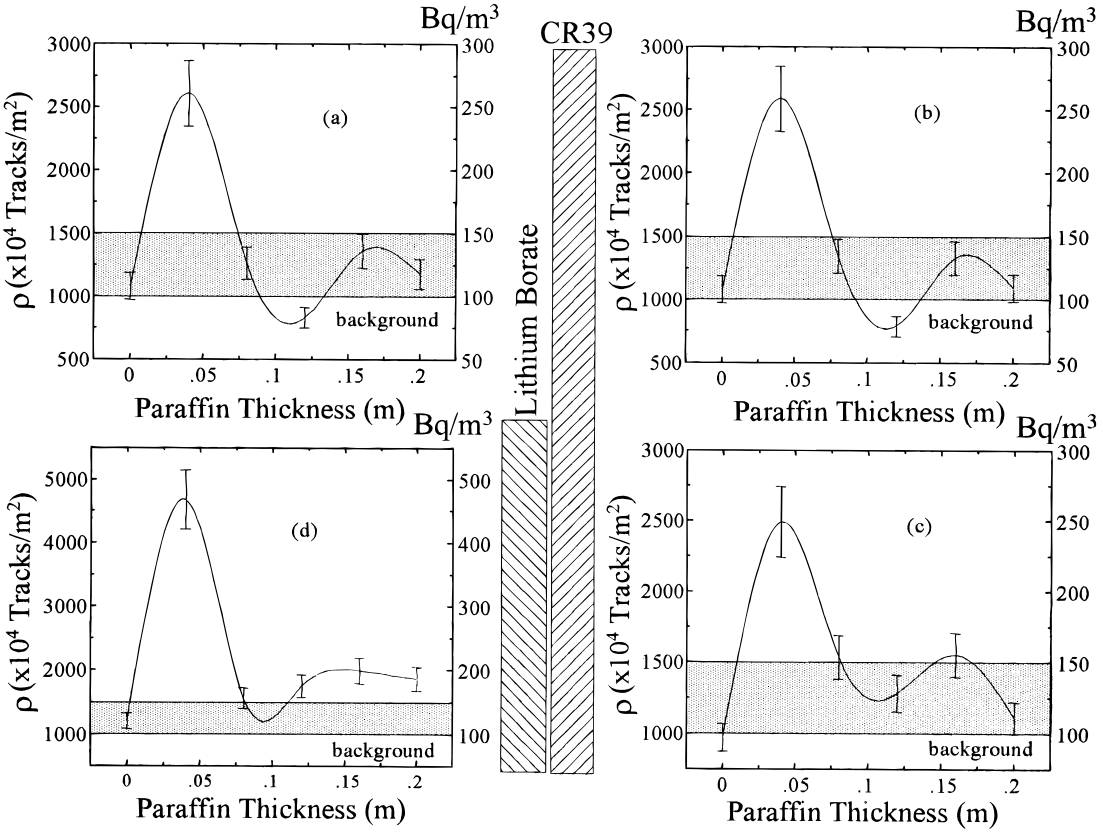

Fig. 7. Track number per square metre from the CR39 plastic detectors. The first three curves (a), (b), and (c) were obtained without the lithium borate layer. Curve (d) corresponds to the plastic area covered with a thin film of lithium borate; the peak observed does not overcome the background signal because of the environmental radon concentration present in the laboratory.

IV. CONCLUSIONS

Deuteration of titanium plates in the presence of electrical discharges has been systematically observed on an experimental assembly of massive electrodes (>2 kg in all) placed inside of a vacuum chamber.

As the chamber was cooled down with liquid air 1 min before the discharge, a decrease in the deuterium pressure inside the chamber, produced by the electrode discharge, was recorded. It is possible that a mechanism of forced deuteration was established through the electrical discharge among electrodes. On the other hand, when the discharge began without liquid air cooling, the pressure increased.

The temperatures registered on the electrode surfaces during the discharges were >300°C. These values decreased to 200°C ~1 min after the end of the electric discharge. An explanation for this event could be that the deuteration of metals such as titanium is an exothermic process.[11] The rapid reduction in temperature could entail an inverse deuteration mechanism. A pressure increment could also be involved in the latter phenomenon, although this was produced at a slower rate than the temperature variation.

The electronic detectors always registered neutron counts during the discharges between electrodes. It was found that these counts were induced partially by electromagnetic noise originated by the discharge itself. Because of this noise, it was not possible to register reliable neutron emission evidence (Figs. 5 and 6).

The CR39 plastic nuclear track detector used in this experiment is neither sensitive to the background produced by the gamma rays associated with a neutron emission nor to the electronic noise induced by the electric discharges. Background nuclear tracks in the CR39 plastic detectors are from environmental radon and its decay products. The radon background evaluated for 3 months from a set of plastics in the laboratory neighborhood was (125 ± 25) Bq/m^3.

The CR39 detectors permanently recorded as nuclear tracks the recoils produced by the interaction of neutrons and the hydrogen, carbon, and oxygen nuclei, which constitute the plastic structure. In this way nuclear tracks induced by neutron emission in all the experiments during a 3-month period are added in the plastic detectors.

A neutron energy of 2.5 MeV is expected from a cold fusion experiment; in such conditions oxygen and carbon recoils are hardly observable because their

corresponding track lengths in CR39 detectors are, at most, 1 to 2 μm. On the other hand, hydrogen recoils are the main neutron signal in CR39 in the energy interval of 100 keV to 2.5 MeV, with track lengths of 3 and 90 μm. Neutron probability interaction was increased by placing paraffin absorbers to slow down the neutron velocity, whereby taking advantage of the high neutron thermal cross section for both $^{10}B(n,\alpha)^{7}Li$ and $^{6}Li(n,\alpha)T$ reactions.

An anomalous peak well above the background was observed at a 0.04-m paraffin thickness. Curves obtained for detectors without the lithium borate converter foil show similar track densities, whereas the peak of the curve for the case with the foil is two times greater than the previous ones.

The explanation for the anomalous peaks may be nothing other than that they are produced by a neutron emission. More experiments are in progress to improve the neutron detection system.

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