Observation of High Energy Protons Emitted in the TiD_x + D Reaction at E_d = 150 keV and Anomalous Concentration of ^3He

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Abstract

Energetic protons were observed up to ~ 17.5 MeV in the bombardment of 150-keV deuteron on highly deuterated Ti rods. It has been shown that these protons are originated from the D+^{3}He reaction. The observed spectrum can be explained very well by the sequential reaction process, except for the three cases which require anomalous concentration of ^{3}He in TiD_x. The concentration, which is severely limited at some particular places in TiD_x and seldom occurs, is considered to occur before the bombardment.

1. Introduction

Since a possibility of the so-called cold fusion was indicated by Fleischman and Pons[1] and Jones et al.[2], considerable efforts have been made to confirm their results, especially to clarify whether the nuclear reaction can really occur in the condensed matter at the room temperature. Up to the present, however, the situation is still unclear.[3] In this paper, we report on observation of energetic charged particles emitted in deuteron bombardment on highly deuterated Ti, because the analysis of the spectrum clearly shows anomalous concentration of ^{3}He in TiD_x, which is considered to have occurred before the bombardment.

2. Experiment

Target samples were prepared as follows. D_2 gas was absorbed into various Ti rods (10, 8, and 6 mm in diameter and 30 mm in length) and plates (10 mm x 30 mm x 2mm), which were manufactured by Nippon Mining Co., Ltd. A cylindrical vessel (16 mm in inner diameter and 10 cm in length) made of inconel metal was used for the gas absorption, and was set in an electric oven. The vacuum line, to which a high-pressure D_2 gas container, a 500-cm^3 reservoir, a vacuum gauge and a pressure gauge were connected, was made of stainless steel and was evacuated by a turbo molecular pump. Before admitting D_2 gas, a plate or a rod of Ti was loaded in the vessel and degassed by heating the vessel at around 800 °C in vacua of 10^{-5} Pa for at least 20 hours. After that, the temperature of the vessel was lowered to about 600 °C and then the vessel as well as the reservoir was filled with the D_2 gas of 3 atm. The absorption speed increased gradually; for example, for a rod of 10 mm in diameter and 30 mm in length, it took about 30 min. that the pressure decreased from 3 to 1 atm for the first fill but a few min. for the second fill. Then, it decreased rapidly after the third fill. The system was refilled with the gas again and again until the absorption was saturated; we usually took more than 24 hours to stop the gas loading. In our experience, the gas can be absorbed into a rod much more than into a plate, probably because the plate is easily bent due to the non-uniformly absorption and stops the absorption. Average atomic ratio D/Ti was obtained by weighing before and after the D_2 gas loading.

The bombardments have been performed with a deuteron beam obtained from a Cockcroft-Walton accelerator at Department of Chemistry at Tohoku University. Deuterons were ionized in an RF-type ion source and accelerated up to 150 keV. After passing through the acceleration tube, the beam was bent by 30 degree by a dipole magnet in order to select the D^+ beam. The targets were set at the center of a small chamber (10 cm in radius). The beam passed through a collimator of 3 mm in diameter, set at the entrance of the chamber. Since the beam is stopped in the target, the electric current from the target was monitored and integrated during the run. Typical intensity of the beam was about 2 μA.

3. Charged particle spectra

Charged particles emitted in the bombardment were detected with either a surface barrier Si detector of 2 mm in thickness and 25 mm^2 in area or a Li-drifted Si detector of 5 mm in thickness and 100 mm^2 in area, placed at a distance of 1.5 - 2 cm from the target and at angles of 110° and 135° in respect to the beam direction. Energy resolution of the detectors was checked with an ^{241}Am source and was about 30 keV for 5.48 MeV. A 15-μm thick Al foil was placed in front of the detector to prevent δ-electrons from hitting the detector.

Up to the present, more than 20 plates and 10 rods have been bombarded. The average atomic ratio D/Ti of them ranges from 0.3 to 1.9. In the bombardment on TiD_x with small x ($<$ 0.9), only protons from the D(d,p)T reaction were observed. To our surprise, however, very energetic charged particles were observed in the bombardment for larger x ($>$ 1.2). In Fig. 1(a) is shown such a spectrum measured at 135° in the bombardment on the rod A. A huge peak appearing at about 2.45 MeV, whose actual energy is 2.75 MeV, is attributed to protons emitted in the D(d,p)T reaction. Although a simple kinematical consideration requires a broader peak between 2.74 and 3.02 MeV, the observed peak is not broad because of the steep fall of the reaction cross section for lower incident energies. Events due to the double and the triple pileups of the protons are distributed up to about 4.9 and 7.5 MeV, respectively, where sharp edges are clearly seen in the spectrum.

In addition to these normal events, events up to about 17.5 MeV are also seen. They are neither pileups nor events produced in the detector as proved in Fig. 1(b), which shows the spectrum measured with the same condition but putting a 200-μm thick Al foil in front of the detector to stop protons from the D(d,p)T reaction. As seen, the huge proton peak and the pileups disappear, but still remain the similar structure at the high energy region. Observed energy difference for these spectra clearly indicates that these high energy particles are protons emitted in the target. The characteristics of the proton spectrum are a broad bump ranging from 12.5 to 16.5 MeV, and a sharp peak at E_p = 14.1 MeV. We have to add, furthermore, that the sharp peak at 14.1 MeV does not always appear; we have had only three cases which show the peak clearly, out of more than 50 bombardments on various places of the rods and plates. By contrast, the bump always appear in any measurements on TiD_x as far as $x > 1$.

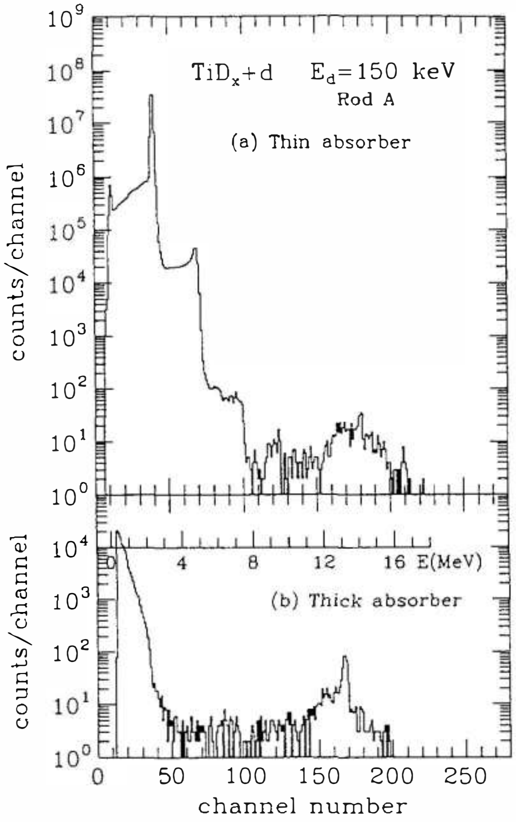

Fig. 1. Charged particle spectra obtained in 150-keV deuteron bombardment on TiD_x *(x=1.3) at* 135^o *with a 15-µm thick Al absorber (a) and a 200-µm thick Al absorber (b). The energy scale represents energy of charged particles after passing through the absorber.*

The origin of both the broad bump and the sharp peak has been considered to be the $D+^3He\text{->}p+^4He$ reaction, since no other reactions with deuterons can emit such high energy protons. For the broad peak, protons are interpreted to be emitted in the $D(^3He,p)^4He$ reaction which sequentially occurs following the primary $D(d,^3He)n$ reaction. In this case, the ejected ^3He particle reacts with deuterons at rest in the target, and thus the protons cannot make a sharp peak, because of the spread of energy and direction of the ejected ^{3}He. In order to verify this situation quantitatively, we have calculated the spectral shape of protons emitted in the sequential reaction. For the calculation, an excitation function of the cross section and angular distributions of the primary D(d,^{3}He)n reaction for $E_d < 150$ keV were taken from ref. 4. Angular distributions of the secondary D(^{3}He,p)^{4}He reaction were assumed to be isotropic in the CM frame for $E_{^3He} < 1.33$ MeV (the maximum incident energy for the secondary reaction), and cross sections were estimated from the differential cross sections[5] and reported S-factors[4]. Values of energy loss of deuteron and ^{3}He in Ti were taken from ref. 6. In Fig. 2, spectra measured at 110° and 135° are compared with the calculations. The calculations can explain the spectral shape very well for both angles. Therefore, we conclude that the broad bump is due to the sequential D(^{3}He,p)^{4}He reaction.

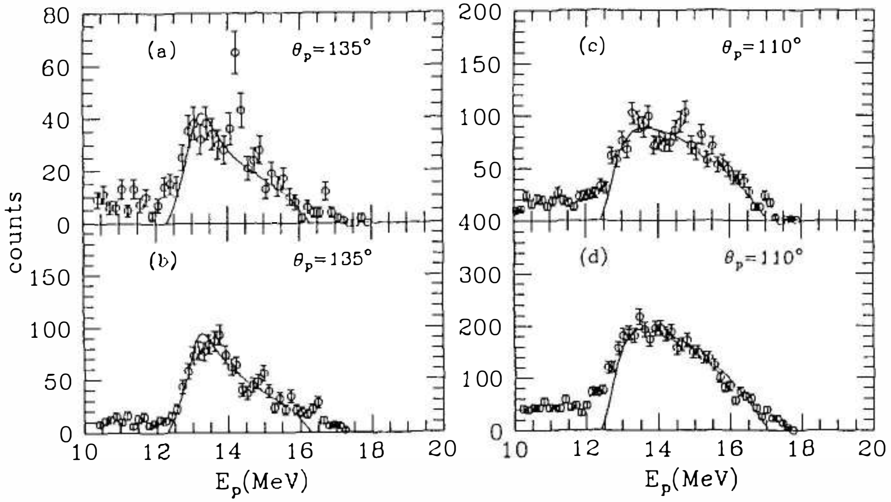

Fig. 2. Comparison of observed proton spectra with the calculations (solid lines) for the detection angles of 135° ((a) and (b)) and 110° ((c) and (d)). The sharp peak does not exisit in (b) and (d); it is seen unambiguously in (a), whereas ststistical fluctuations can also explain the structure in (c).

The yield of the sequential reaction is proportional to the square of deuteron density in the target; this explains why the bump was not observed for the targets with smaller D/Ti ratio (< 0.9). The value of D/Ti at the bombarded region of the target can be deduced accurately from the ratio of the yield of the broad peak to that of the peak of the D(d,p)T reaction; the ratio is proportional to D/Ti. For this purpose, the calculated ratio of the yield of the sequential reaction to that of the primary D(d,p)T reaction at the detected angles was compared with the measured one. The value of D/Ti mentioned below is the one deduced with this method, which generally agrees with the averaged one obtained by weighing.

The sharp peak at 14.1 MeV in the spectrum measured at 135° is naturally interpreted as the protons emitted in the ^{3}He(d,p)^{4}He reaction, where the deuteron beam directly interacts with ^{3}He at rest, since the peak energy exactly coincides with the kinematical prediction. However, up to the present, we have had only three rods (rod A, B and C) with which the peak was observed unambiguously; we could find only one place in each rod in random bombardments. The rod A is the first case; the spectra for the rod A are already shown in Fig. 1 (and also in Fig. 2(a) which shows the same one as in Fig. 1(a) but with the linear scale). The spectra were obtained in the bombardments on the same place but at different time; the spectrum in Fig. 1(a) was obtained at the bombardment 45 days after the one for Fig. 1(b). The yield ratio of the peak at $E_p = 14.1$ MeV to the one at $E_p = 2.75$ MeV is proportional to the atomic ratio of ^{3}He/D. It is 8.5×10^{-7} for Fig. 1(a) but 5×10^{-6} for Fig. 1(b). This decrease is probably due to diffusion of ^{3}He, which is much smaller than the usual one in Ti because of high density of deuteron. In the second and the third cases, we obtained the spectra with much larger peak. They are shown in Fig. 3 as for rod B and C whose D/Ti ratios are 1.7 and 1.9, respectively. The yield of the 14.1-MeV peak is quite large so that the bump underlying the peak is hardly seen in both spectra; ratios of the peak yield to that of 2.75-MeV peak are 4.5×10^{-5} and 8×10^{-5} for rod B and C, respectively. Values of the cross sections of the ^{3}He(d,p)^{4}He reaction are almost similar with those of the D(d,p)T reaction for $100 < Ed < 150$ keV[4]. This indicates that the atomic ratio of ^{3}He/D at the bombarded area is the order of 5×10^{-6} to 8×10^{-5}, and thus the atomic ratio of ^{3}He/Ti is 3.8×10^{-6} to 4.5×10^{-5}. In other words, the number of ^{3}He, at least in the volume of about 7 mm^2 x 0.2 μm (area of beam spot times effective depth), is the order of 5×10^{11} to 10^{13}.

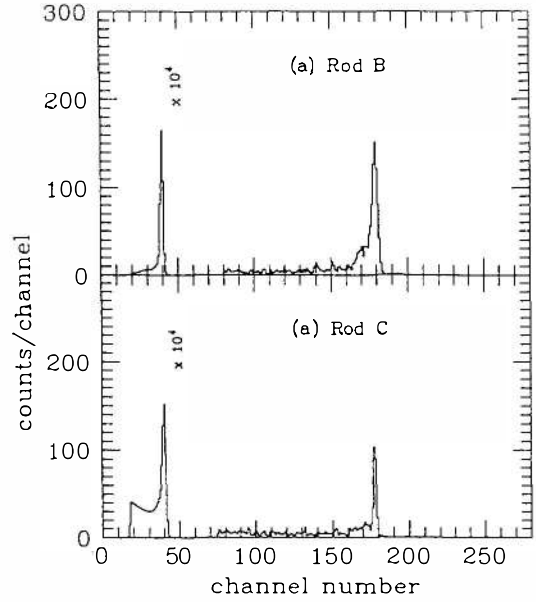

Fig. 3. Proton spectra measured at 135° for the rod B (a) and C (b). Only the sharp peak at $E_p = 14.1$ MeV is seen because of higher concentration of ^{3}He.

4. Discussion

The fact that the concentration of ^{3}He is severely limited to some particular places in the Ti rod is a characteristic of the observed anomalous phenomena and is quite difficult to understand. It is impossible to consider that ^{3}He was concentrated in the manufacturing process, for the following reasons. Natural abundance of ^{3}He is 1.3×10^{-6}. Therefore, if the observed concentration of ^{3}He is due to He bubbles which might be formed during a manufacturing process, the number of He required in the area of the beam spot is 3×10^{17} to 8×10^{18}. However, He gas was never used in the whole manufacturing process from rutile to Ti rods, at Nippon Mining Co., Ltd. How could it be happened that the He atoms in 5×10^4 cm^3 of air can be concentrated in the small region of the Ti rods ?

The effects of contamination of ^{3}He in D_2 gas should be considered, also. Since no information on the ^{3}He contamination in the D_2 gas was available, the upper limit of ^{3}He is assumed to be equal to the quantity of tritium; the T/D ratio in the D_2 gas was less than 10^{-14}. In the D_2 gas loading process, about 4000 cc of gas was absorbed into a Ti rod. The number of ^{3}He atoms in the gas is, then, less than 10^9, that is again far below the required number. The number of ^{3}He in the residual gas in the D_2 gas loading system after pumping is estimated, from the quantity of ^{3}He in air, to be less than 10^5 atoms.

^{3}He nuclei that are produced and stop in the target as the reaction residues of the D(d,n)^{3}He reaction cannot contribute to the yield of the sharp peak at all, since a dueteron bombardment of 10 mC in electric charge on the target with D/Ti=2 only produces 7×10^9 atoms of ^{3}He which is far below the required number of 10^{13}. In fact, we have lots of targets with which the 14.1-MeV peak cannot be seen at all.

Finally, we have inferred that the ^{3}He concentration was produced by nuclear transmutation during the D_2 gas loading, *i.e.*, by the so-called cold fusion, since, as discussed above, neither the normal production in the bombardment, nor the existence in D_2 gas and Ti can explain the ^{3}He concentration. The occurrence of cold fusion is not widely accepted, mainly because of the lack of reproducibility. In the present work, we found only three rods of TiD_x having particular spots of the dense ^{3}He area, out of 12 rods; this indicates again the poor reproducibility. Although we have not yet specified conditions under which ^{3}He is produced in Ti, the following is common to the three cases showing the sharp peak: (1) The TiD_x rod with $x > 1.3$ was bombarded. (2) A peripheral region of the split section of the rod was bombarded. (3) The peak disappeared when the beam position was changed to a central region of the split section.

5. Conclusion

In conclusion, the sharp proton peak, observed in the 150-keV deuteron bombardment on highly deutarated Ti, is attributed to anomalous ^{3}He concentration which is considered to be produced during the D_2 gas loading into Ti, *i.e.*, "cold fusion". The present observation shows that the concentration of ^{3}He is severely limited to some particular places and seldom occurs.

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