*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-4.141 (2005)*

Observation of "pure" (neutronless) reaction $^{11}B + p$ in picosecond laser plasma

V.S.Belyaev[1], A.P.Matafonov[1], V.I.Vinogradov[1], A.S.Roussetski[2],V.S.Lisitsa[3],V.P.Krainov[4]

[1] *Central Research Institute of Machine Building, Korolev, Russia*

[2] *P.N. Lebedev Physical Institute of Russian Academy of Sciences, Moscow, Russia*

[3] *Russian Research Centre Kurchatov Institute, Moscow, Russia*

[4] *Moscow Physicotechnical Institute, Dolgoprudnyi, Russia*

The investigation of neutron-less fusion reactions in plasmas presents the important problem with respect to peaceful applications of nuclear energy. The analysis of these reactions for systems with magnetic confinement requires very hard conditions upon plasma parameters due to high values of ionic temperature which are needed for initiation of these nuclear reactions. Oppositely, high kinetic energies of atomic ions can be simply obtained in plasmas produced by intense ultra-short laser pulses. Therefore it is interesting directly to check the generation of neutron-less fusion reaction in plasmas produced by ultra-short laser pulses. In this paper we present results of the experiments in which the initiation of the neutron-less fusion reaction $^{11}B + p$ has been observed in picosecond laser plasmas. These results were obtained on the 10 TW laser facility "NEODYM".

The laser setup has the parameters: the pulse energy up to 15 J, the wavelength of 1.055 μm, and the pulse duration of 1.5 ps. The focusing system provides the concentration of 40 % of laser energy into the spot with the diameter of 15 μm; the peak laser intensity on the target surface is equal to 2×10^{18} W/cm^2.

The experimental device is presented in Fig. 1. The laser beam is focused by the off-axis parabolic mirror with the focusing length of 20 cm into the solid target T at the angle of 40° to the normal to the target.

The composite targets $^{11}B + (CH_2)_n$ with the thickness of 300 and 500 μm containing 50% (weight) of ^{11}B atoms had been studied in our experiments. Targets from the polyethylene $(CH_2)_n$ with the thickness of 400 μm were used for control experiments. Track detectors CR-39 covered by aluminum foil with the thickness of 6, 11 and 22 μm were applied for registration of alpha-particles produced in the nuclear reaction

$$p + {}^{11}B \rightarrow 3\,{}^{4}He + 8.7\ \text{MeV}. \qquad (1)$$

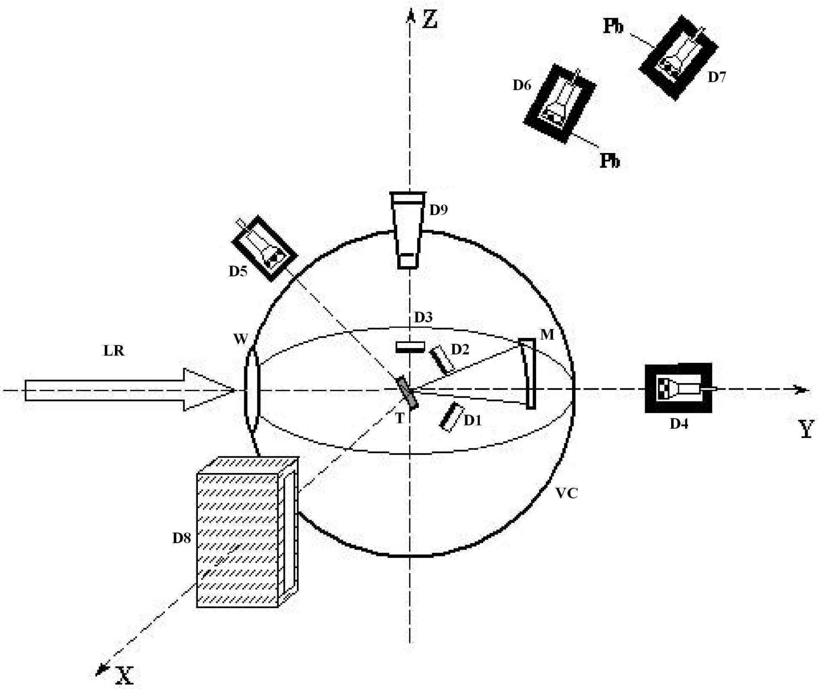

Fig. 1. A schematic of the experimental laser setup is shown. The various aspects are as follows: T - target, M - off-axis parabolic mirror, W - the window of the vacuum chamber, LR - laser radiation, VC - vacuum chamber, D1 - D3 - track detectors CR-39, D4 -D7 - scintillation detectors of γ radiation, D8 - detector of neutrons on helium counters, D9 - obscure chamber with the recording matrix.

Detectors were placed in vacuum chamber on various angles (0°, 45°, 85°) to the normal of the target and at various distances from target (1.8 and 2.4 cm) . The pressure of the rest gas was less than 10^{-3} Torr. Using of detectors with different covers allows to determine the type of the particles, while measurements at various angles allow to estimate their angular distribution.

The calibration of detectors CR-39 has been made using proton beams from Van-de-Graaf accelerator (E_p = 0.75 – 3.0 MeV) and also using standard α-sources (E_α = 0.4 – 7.7 MeV), and cyclotron α sources (E_α = 8 - 30 MeV).

In this experiment we should choose tracks of α particles among the background of tracks of other atomic ions ejected from target during the laser pulse. The following experimental method was used. According to the calibration data α particles with energies of 2 - 8 MeV have tracks with the diameters of 7.8 - 12 μm; an effect can be observed for these track diameters. This range was divided into two ranges: 7.8 - 10 μm and 10.2 – 12.0 μm. The estimate of yields of α particles is based on subtraction of track densities for $^{11}B + (CH_2)_n$ target and pure $(CH_2)_n$ target. Then this quantity was multiplied by the efficiency of measurements which is determined by the geometric factor (i.e., by the distance between the detector and target).

The scintillation plastic and stilbene detectors had been used for observations of hard X-ray. The detector of neutrons containing helium counters had been used for observation of neutron emission.

Two types of experiments had been carried out. First, detectors CR-39 were exposured after a single irradiation of the target; then these detectors were exposured after the multiply irradiation.

Estimations of the yield of α particles for detectors covered by 11 and 22 μm Al are given in Table 1. The maximum effect was observed for diameters of 7.8 - 10 μm (the ratio of effect/background is equal to 4 - 11 for various detectors). The average yield of α particles into 4π solid angle for this range of track diameters is estimated as $\langle N_\alpha \rangle = 1.77\times10^3$. Some effect (the ratio of effect/background is equal to 2) is observed also for track diameters of 10.2 – 12.0 μm. In this case the average yield of α particles is $\langle N_\alpha \rangle = 1.2\times10^3$.

Table 1. Estimations of yields of α particles in the reaction, Eq. (1).

Position of detector, R(cm)/φ^o	Burst the amount	Detector covering, Al	N_α (7.8-10 μm) in 4π Sr.	N_α (10.2-12.0 μm) in 4π Sr.
1.8 / 85	1	11 μm	1.6×10^3	-
2.4 / 0	1	11 μm	1.8×10^3	10^3
2.4 / 45	1	11 μm	1.9×10^3	1.4×10^3
1.8 / 85	3	11 μm	1.1×10^3	8×10^2
2.4 / 0	3	11 μm	2.4×10^3	-
2.4 / 45	3	11 μm	10^4	2×10^4
1.8 / 85	2	22 μm	5×10^2	1.6×10^3
2.4 / 0	2	22 μm	3×10^2	1.4×10^3
1.8 / 85	2	22 μm	5.5×10^2	-

A hyphen in Table 1 means that the effect does not exceed the background.

At the multiply irradiation the average yields of α particles per one burst for detectors covered by 11 μm Al, are equal to 1.5×10^3 and 2.3×10^3 for track diameters in the ranges 7.8 - 10 and 10.2 - 12 μm, respectively (into the solid angle 4π-Sr). For detectors covered by 22 μm Al, these yields are equal to 2.3×10^2 and 3×10^2, respectively.

The resulting distribution of track diameters based on measurements of six pairs of detectors covered by the Al foil with the thickness of 11 μm is shown in Fig. 2. Peaks with d = 7.8 ÷ 8.6 μm (E_α ~6 - 8 MeV) and with d = 9.8 ÷ 10.0 μm (E_α ~ 4 MeV) are observed. The broad maximum is observed also for d = 10.8 ÷ 12 μm (E_α ~ 1 - 3 MeV). These peaks demonstrate the possibility for emission of mono-energetic α particles with the kinetic energy of

E_α > 3 MeV which are produced in the reaction ^{11}B + p via different states of the intermediate nucleus ^{8}Be.

More exact measurements of the α particle energy were carried out taking into account the data for detectors covered by 22 μm Al (see the distribution in Fig. 3). Only one small maximum occurs at d = 7.8 μm (E_α ~ 7.5 MeV). The initial energy of α particles which takes into account the energy losses in 22 μm Al can be estimated as E_α ~ 10 MeV. Some excess above the background is observed also at d = 10 - 11 μm (E_α ~ 2.5 - 3 MeV). The initial energy of α particles in this case is equal to 5.5 - 5.7 MeV. Disappearance of maxima which were observed in Fig. 2, demonstrates that they correspond to α particles with energies of 3 - 5 MeV.

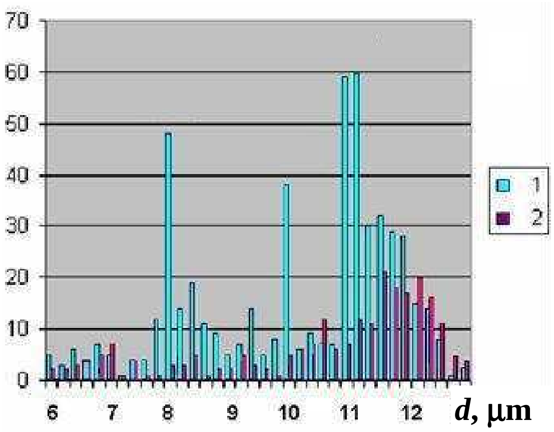

Fig. 2. The total distributions of track diameters (number of tracks) for detectors covered with 11 μm Al. The detector's area is 3 cm^2; (1) target ^{11}B + $(CH_2)_n$, (2) target $(CH_2)_n$.

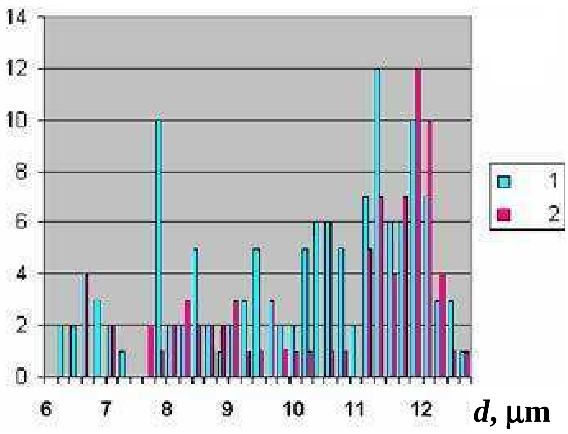

Fig. 3. The same as in Fig. 2, but with 22 μm Al. The detector's area is 1.5 cm^2; (1) target ^{11}B + $(CH_2)_n$, (2) target $(CH_2)_n$.

Thus, the conclusion can be made that α particles with initial kinetic energies about of 3.4±0:4; 4.0±0.4; 5.6±0.3 and 10±1 MeV were observed in our experiments. The main part of the radiated α particles (up to 90%) have the energy less than 5 MeV. The detector using helium counters did not show registration of the neutron emission in these experiments.

In conclusion, the possibility of initiation of neutrons-less fusion reaction in plasma of picosecond laser pulses has been demonstrated for the first time. The yield of the order of 10^3 α particles in 4π Sr per one laser pulse in the fusion reaction ^{11}B + p has been measured at the peak laser intensity of 2×10^{18} W/cm^2. Simultaneous measurements of neutrons result in zero yield that proofs the observation of the neutron-less fusion reactions in our experiments.

This work was supported by the International Science and Technology Center (project N 2155), by RFBR (project N 05-02-16551a).