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Evidence of Neutron Production by Nonthermal Effects in a Laserproduced Deuterium Plasma

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Abstract

The origin of fusion reactions observed in a laser produced deuterium plasma is investigated by various diagnostic methods. Surrounding the target by a low-pressure background gas results in a reduction of the neutron yield to zero. It is concluded that the observed fusion reactions are not of thermonuclear origin.

High power nanosecond [1,2] and picosecond [3,4] laser pulses have been used for plasma production from targets containing solid deuterium. Observation of neutrons from D-D fusion reactions in both these cases [1-4] has created renewed interest in these plasmas for the purpose of thermonuclear fusion. However, the experimental results so far reported are not sufficient to decide the important question whether the observed fusion reactions are of thermonuclear origin. The measurements reported in this letter concentrate on this question for the case of a pure deuterium plasma produced by nanosecond laser pulses from a neodymium glass laser.

Neutron emission from plasmas produced with our experimental device has already been reported [2]. In this paper as well a description of the experimental device and the applied diagnostics has been given. For our typical experimental conditions (laser energy 2o J, pulse duration 1o ns, laser intensity $1o^{13}$ W/cm^2) the plasma may be described by the following measured parameters: electron temperature T_e = 5oo eV, mean ion expansion energy on the laser axis E_i = 3 keV and total number of ions $N_i = 4 \cdot 1o^{16}$. These experimental results are in agreement with gasdynamical calculations performed for a plane [2] and a spherical geometry [5], the latter case being a more realistic description of the actual experimental situation. There are, however, other observations which are not described by a gasdynamical model. These observations concern the neutron and X-ray emission of the plasma and are, in particular, the following:

1. Whereas the gasdynamical calculations in spherical geometry yield otherwise correct values for the plasma parameters, the

computer code predicts that no fusion reactions in the plasma should occur (the total number of neutrons from fusion reactions is calculated to be less than $1o^{-2}$). However, in the experiment up to $1o^{3}$ neutrons per shot are emitted.

2. Excess deuteron emission from the plasma with energies up to 2o keV is observed. The appearance of these high energy deuterons is correlated with neutron emission.

3. The bremsstrahlung continuum of the plasma differs from that of a thermal plasma (for details of the applied absorbing foil method see [2]). Enhanced emission of hard X-rays is observed. As can be seen from fig. 2, for an absorbing foil with a cut-off energy of 3.6 keV, the intensity of the transmitted plasma radiation is about 5 times as high as that calculated for a thermal plasma with T_e = 42o eV. The measurements have recenty been extended up to a cut-off energy of 15 keV using aluminum absorber foils. At this energy the radiation intensity is enhanced by more than $1o^{5}$.

4. The intensity of the reflected laser light and the X-ray intensity and also the neutron yield of the plasma seem to be correlated. During the course of the laser pulse the reflection coefficient reaches values up to 3o %.

To investigate further this behaviour of the plasma, we repeated the experiments with the target sourrounded by a low density gas rather than by a high vacuum. Tests were made to ascertain that the background gas had no influence either on the laser beam by absorption or deflection, or on the target itself. With neutral gas added the plasma behaviour was influenced in two respects: Firstly, the number of neutrons produced is rapidly reduced to zero with increasing gas pressure, as shown in fig. 1. Secondly, the hard X-ray intensity decreases. Already at a pressure of $3 \cdot 10^{-2}$ torr the experimental points fit the calculated curve for a thermal plasma with $T_e = 420$ eV (see fig. 2). The measurements of fig. 1 and 2 were performed in helium, however, deuterium as a background gas gave essentially the same results.

The nature of the processes which under high vacuum conditions lead to enhanced X-ray and neutron emission, and which are heavily damped in the presence of a background gas is not yet understood. Nevertheless, it is possible to decide from these observations whether the observed fusion reactions are of thermonuclear origin or not.

From gasdynamic theory we expect thermal fusion reactions to occur in the high density region of the plasma where the density reaches its critical (or cut-off) value n_{crit} ($n_{crit} = 10^{21}$ cm^{-3} for a wavelength of $\lambda = 1$ μ) or even in the more dense interior of the plasma, which is heated by electronic heat conduction. It is hard to imagine that this high density region of the plasma is influenced by the applied low density background gas. This is confirmed by the fact that the following measured quantities remain essentially unaffected:

1. The total intensity of the low energy X-rays as measured with the thinnest absorber foil (see fig. 1).

2. The electron temperature or, more precisely, the mean energy of the bulk of the electrons. This follows from the fact that the slope of the measured curve is conserved for low energy X-rays (see fig. 1).

3. The total number and mean energy of the ions at least up to a gas pressure of 3×10^{-2} torr.

4. The reflection coefficient of the plasma for the incident laser light.

Therefore, the following conclusions can be drawn:
The number of thermal fusion reactions in the high density region of the plasma is undetectably small compared with the total number of fusion reactions observed. This is in agreement with numerical calculations, which do not predict a measurable amount of fusion reactions under our experimental conditions. Thus, for the laser intensities applied here thermonuclear conditions are not achieved. A number of observations indicate that the origin of the observed fusion reactions must be sought in the fact that the plasma is not in a purely thermal state.

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Figure Captions

Fig. 1 Mean number of neutrons per shot emitted into 4π as a function of helium background pressure. Mean laser energy 11 joule.

Fig. 2 X-ray intensity versus photon cut-off energy E_c of the beryllium absorber foils. □, high vacuum (10^{-5} torr). +, helium background pressure 3×10^{-2} torr. Lower curve is calculated for thermal bremsstrahlung emission with $T_e = 420$ eV. Mean laser energy 11 joule.

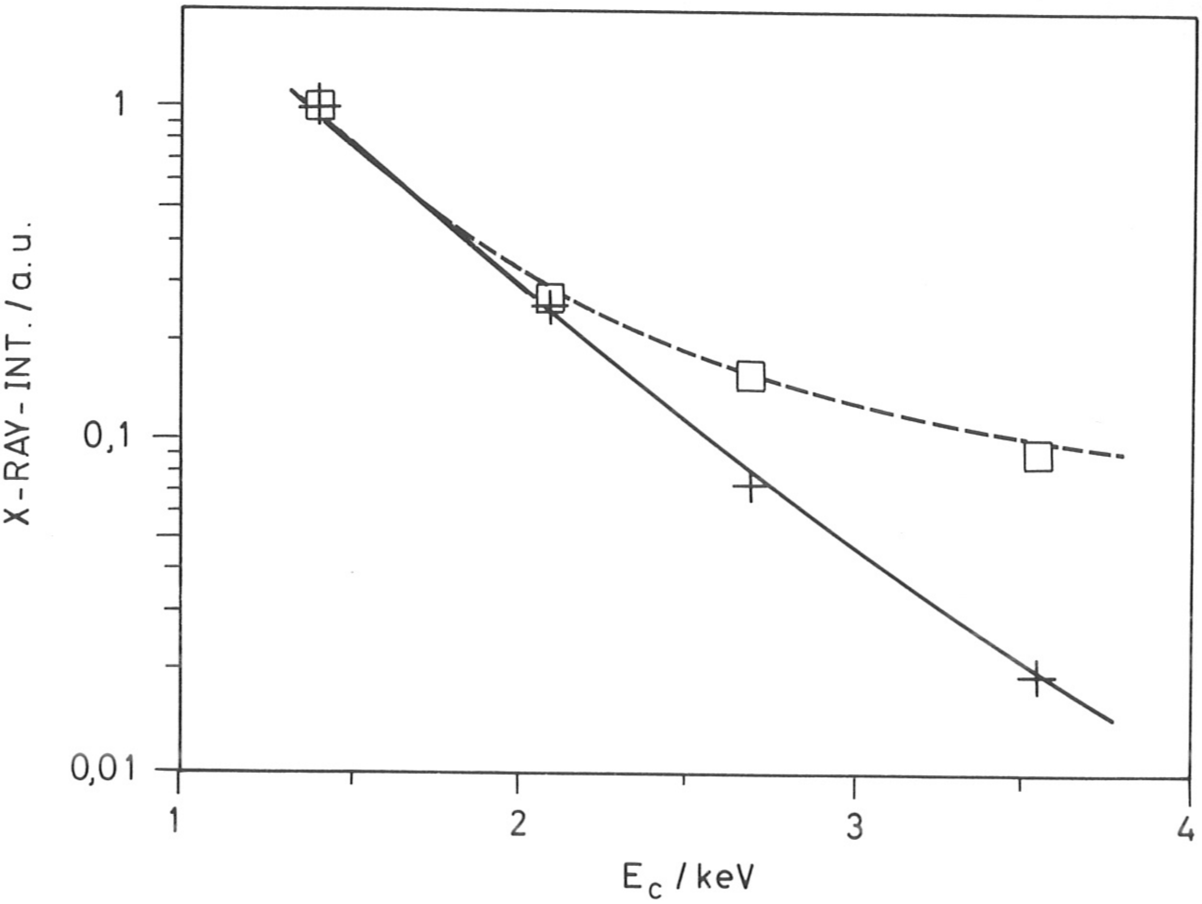
X-RAY-INT. /a.u.
1
0,1
0,01
1
2
3
4
E$_c$ / keV

Fig.1

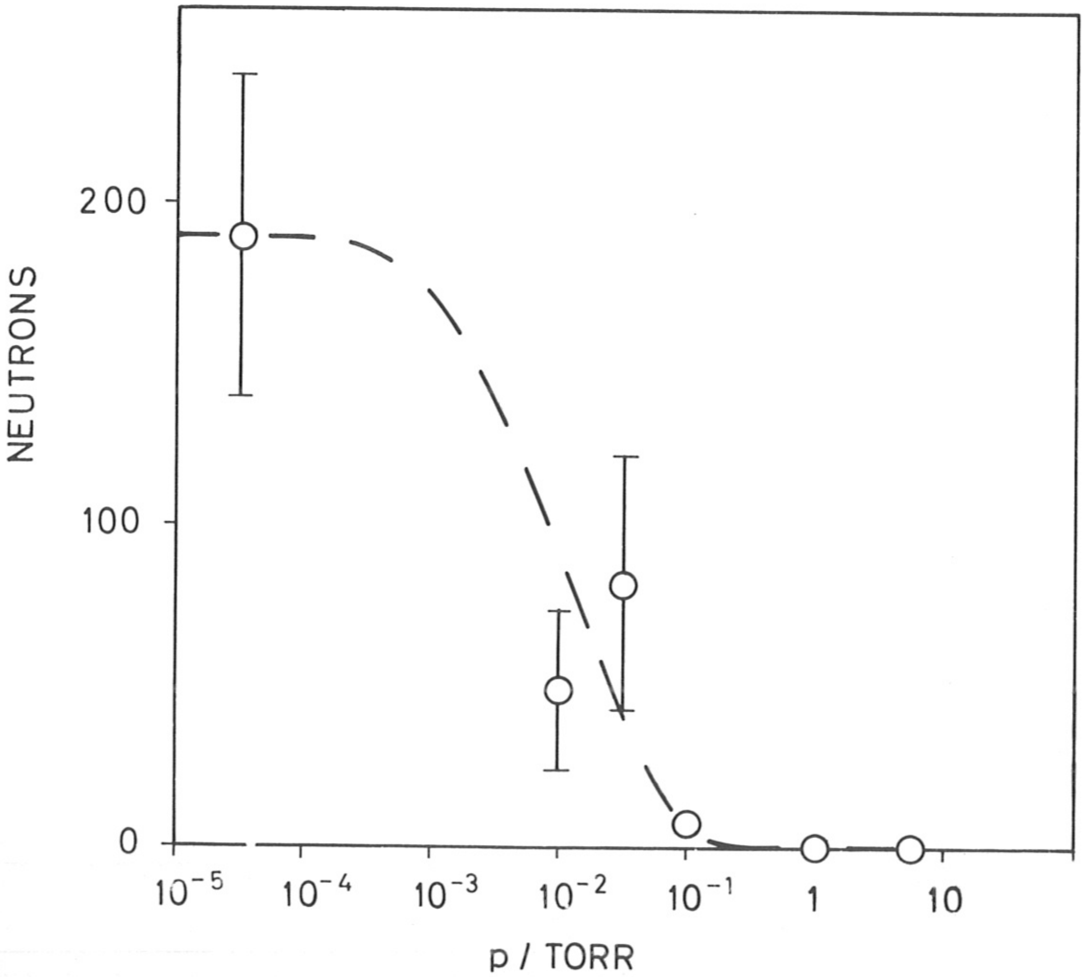
NEUTRONS
200
100
0
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
p / TORR

Fig.2