Experimental Test of the Polarization Persistence in Inertial Confinement Fusion

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Abstract. The complete deuteron and triton polarization in the DT fusion increases the reactivity by 50%. For Inertial Confinement Fusion (ICF), due to the dynamics of the fusion reaction process, the fusion rate could even be further increased. It has been argued that the polarization would survive as well in magnetic as in inertial confinements. Recently, we have proposed an experiment to test the persistence of the polarization in a fusion process, using a powerful laser hitting a polarized HD target. The polarized deuterons heated in the plasma induced by the laser can fuse. The corresponding reaction is: $\text{D} + \text{D} \rightarrow ^3\text{He} + \text{n}$. The angular distribution of the emitted neutrons and the change in the corresponding total cross section are signatures to estimate the polarization persistency. A proposal to test the persistence of the polarization in ICF has been accepted at ILE: the POLAF project (POlarization in LAser Fusion Process). It uses the polarized HD targets produced at RCNP and the powerful ILE lasers, as well as the neutron detectors existing there. Both institutions are on the same campus at Osaka University. The description of the POLAF experiment and of the corresponding set-up is given.

1. Introduction

The polarization of D and T nuclei increases the reactivity when they are used as fuel material in fusion processes induced either by magnetic or by inertial confinement. The fusion reaction:

$$\text{D} + \text{T} \rightarrow \alpha + \text{n} + 17.6 \text{ MeV}$$

(1)

goese mainly through the excitation of an $^5\text{He}$ $3/2^+$ intermediate state, resulting from the coupling of the spins 1 and 1/2 of the D and T nuclei to a total spin $S = 3/2$. Without polarization of D and T, the
The statistical distribution of the six possible states gives four $S = 3/2$ and two $S = 1/2$ states. Only the $3/2$ states can produce the intermediate $3/2$ resonance. With 100% parallel polarization of D and T, all states would contribute to the fusion, increasing the reactivity by 50%. In addition, the polarization allows the control of the direction in which the reaction products are emitted, the neutron having a $\sin^2 \theta$ distribution, as compared to the polarization axis. This can be very useful to reduce damage or activation of costly equipment. Theoretical considerations indicate that the polarization should persist as well in MCF (Magnetic Confinement Fusion) [1] as in ICF [2]. Recent realistic simulations show that for ICF, the required hot-spot temperature and areal density can be reduced by about 15% for fully polarized nuclear fuel. Moreover, numerical simulations of a directly driven capsule show that the required laser power and energy to achieve high gain are significantly reduced, while the maximum achievable energy gain scales roughly as the fusion cross section [3]. It is found that for an invested energy of 1 MJ, the estimated gains are $G_A (1 \text{MJ}) = 130$ while $G_B (1 \text{MJ}) = 300$ for un-polarized and polarized DT fuel respectively. For a detailed discussion, see Ref. [3] and [4].

2. Experimental set-up

We have proposed to investigate the polarization persistency using the reaction:

$$D + D \rightarrow ^3\text{He} + n + 3.3 \text{ MeV}$$

induced by the fusion of polarized deuterons heated in a plasma. It is anticipated that the angular distributions of the neutrons as well as significant changes in the fusion rates can be measured and related to the persistence of the polarization. Details on the set-up and the experiment features are given in Ref. [5]. Here, we show only a sketch of the experiment.

![Figure 1. Tentative set-up showing a polarized HD target in a cryostat (temperature 1 K, holding field 1 Tesla). The target is struck by a terawatt laser producing a localized plasma. Neutrons are generated by fusion reactions between polarized deuterons.](image)
The above described experiment uses only existing equipment: polarized HD targets are currently produced by static polarization [6] and the polarization can be accurately measured [7], on the other hand terawatt lasers and neutron detectors are easily available. A signal of 10-20% on the neutron yield due to the persistence of the polarization should be measurable. Precise data in this energy range will come from a Russian-German group which performs precise measurements of all the observables of the double polarized fusion reaction (2) at the PNPI laboratory in Gatchina [8].

3. Neutron detection

On the other hand, the laser fusion investigation is underway: a proposal has been made at the Institute for Laser Engineering (ILE) in Osaka, Japan and has been accepted as the POLAF project (Polarization in Laser Fusion) [9]. The experiment is planned using the ILE equipment, in particular the MANDALA neutron multi-detector as shown below.

![Figure 2. Picture showing the neutron detection set-up MANDALA at ILE.](image)

The MANDALA neutron detection equipment comprises 422 BC-408 scintillator cylinders (ϕ =10 cm x 10 cm) located in the present configuration 13.42 m away from the target center, providing an energy resolution of 28 keV for the 2.45 MeV neutrons produced by the DD fusion. Scintillators are viewed by photomultipliers which can be switched off during the flash light induced by the EM particles produced by the short laser pulse interacting with the target, so that heavy shielding of the neutron detectors is not necessary. This neutron detection method is feasible, due to the relatively
long delay between the impacts of the EM particles (electrons and gamma rays) and those of the slow neutrons coming from the DD fusion. The real difficulty is to bring the polarized HD target and its cryogenic support in the center of the laser target chamber. However, the complex handling of polarized HD targets for nuclear physics experiments requires various transfer and in-beam cryostats [10] which can be “easily” modified to match the ILE environment.

It should be mentioned that the present arrangement of the ILE MANDALA detector could be used to measure the Radiation Pressure Acceleration (RPA) of deuterons by lasers, at least their maximum energy, by measuring the maximum energy of emitted neutrons. Little is known concerning RPA as compared to Target Normal Sheath Acceleration (TNSA) [11]. This could be done with un-polarized D₂ and would be an excellent preparation towards runs with polarized HD targets.

4. Conclusion

A considerable effort is under way to produce energy using controlled fusion either by MCF or ICF. Polarized fusion fuel is of great interest, both to increase the fuel reactivity and to control the direction in which reaction products are emitted. The question to know if the polarization will persist in a fusion process can be answered using existing experimental equipment, and neutron detection. The corresponding investigation is underway at ILE (Osaka), through the POLAF project. The ongoing measurements at Gatchina for the double polarized DD fusion at low energy will provide the necessary experimental data to analyze the Osaka results. Finally, the investigation at ILE of the RPA by lasers using the un-polarized DD fusion neutrons to identify this acceleration mechanism as compared to TNSA, would be an excellent preparation to the future POLAF experiment.

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