First Demonstration of a Triton Beam Using Target Normal Sheath Acceleration

A. K. Schwemmlein,[1,2] C. Stoeckl,[1] C. J. Forrest,[1] W. T. Shmayda,[1] S. P. Regan,[1] and W. U. Schröder[1,2]

[1]Laboratory for Laser Energetics, University of Rochester
[2]Departments of Physics and Chemistry, University of Rochester

Triton beams provide unique experimental opportunities to study reactions between light nuclei. Of particular interest is the tritium–tritium reaction T(t, 2n)α, which may produce the exotic compound nucleus ^{6}He in an excited state. However, populating the excited state of ^{6}He closest to the entrance configuration of two tritons requires a bombarding energy of at least 2.3 MeV (Ref. 1), which has never been reached experimentally. The results will improve the understanding of both the structure of ^{6}He and the T–T reaction mechanism.

Triton beams up to energies of about 1 MeV have been generated from the 1950s to 1980s in accelerator facilities,[2–4] but tritium contamination of the exposed infrastructure led to a cessation of such experiments. Target normal sheath acceleration[5] (TNSA) isolates the necessary tritium in a small ($500 \times 500 \times 25$-μm^3) target. When exposed to a high-intensity (>10^{16} W/cm^2) laser beam, the target emits energetic (~1-MeV) electrons, which establish a strong (TV/m) electric field that accelerates ions from the target surface. Previous studies using deuterated targets on OMEGA EP[6] demonstrated that deuteron energies of up to 12 MeV are achievable with this technique.

For this study, titanium targets were exposed to approximately 1 bar of 99.97% pure tritium gas at 225°C for 2 h. Several targets were examined separately to determine their tritium content by a thermal desorption process,[7] revealing an activity of 500±10 μCi or approximately 10^{16} tritons. In a first experiment, one target was irradiated by a short (10-ps) OMEGA EP pulse (1.25-kJ, 30-μm focal-spot diameter). The spectra of the emitted ions were analyzed using Thomson parabola ion energy (TPIE[8]) to reveal the triton spectrum shown in Fig 1(a). The experimental data (blue circles) can be fitted reasonably well with a Maxwell–Boltzmann distribution (red curve) and an effective temperature of 1.4±0.1 MeV. This shape is typical for the TNSA process using planar targets. The total integrated yield of tritons was 3×10^{12}, corresponding to a laser-to-triton energy conversion efficiency of approximately 0.04%.

In a proof-of-principle nuclear reaction experiment, a secondary 100-μm-thick deuterated polyethylene (CD) target was arranged parallel to the tritiated target generating the triton beam 5 mm behind the CD target. A standard OMEGA neutron time-of-flight detector,[9] positioned 13.4 m away from the target at 79° to the target normal, was utilized to detect any deuterium–tritium (D–T) fusion neutrons. The neutron spectrum, corrected for instrument and attenuation effects, is shown in Fig. 1(b). The experimental data (blue circles) can be fitted well with a Gaussian (dashed red curve) with parameters 14.2±0.3 MeV (mean±stdev). A Geant4 (Ref. 10) simulation of the experiment is shown by the black curve and accounts for the energy loss of tritons in the CD target and applicable kinematics. The simulation reveals that scattering angles close to 90° greatly reduce the effect of the projectile energy since the momentum transfer from projectile to ejectile becomes very inefficient. In these cases, the Q value of the reaction dominates, and a narrow peak is generated. A total of approximately 10^8 neutrons were produced, in good agreement with predictions by Geant4.

Future experiments will catch the triton beam in a tritiated secondary target to induce T–T reactions at the high energies required to populate the mentioned excited state of ^{6}He. A rapid increase in cross section with triton energy is expected once the state can

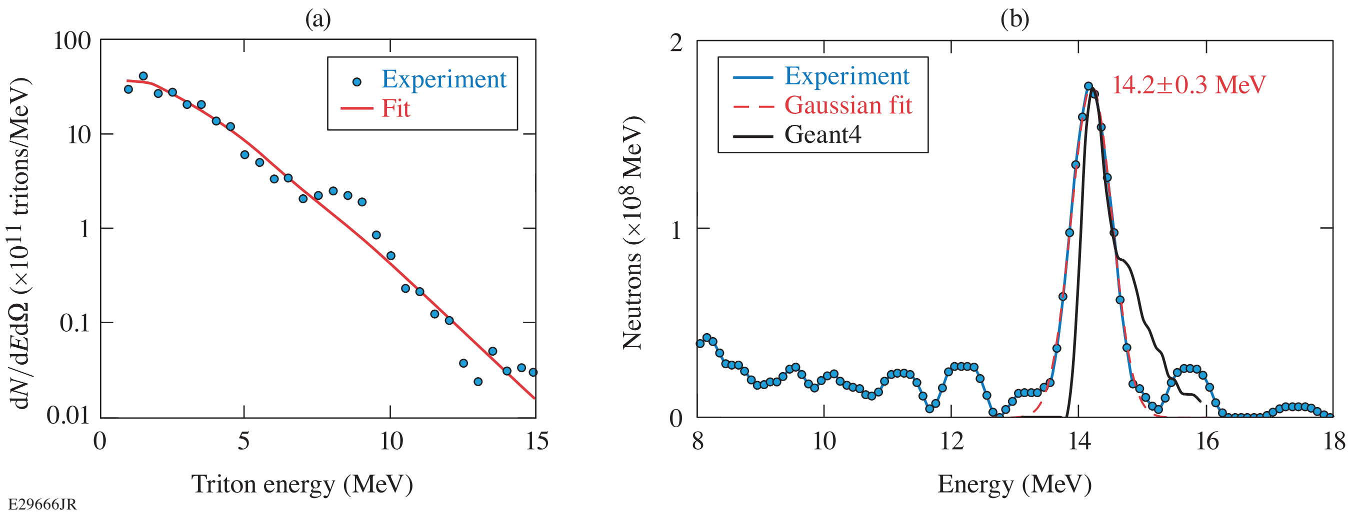

Figure 1
(a) The triton beam spectrum (blue circles) as delivered by TPIE, together with a fit (red curve) to a Maxwell–Boltzmann distribution. (b) The neutron spectrum produced by the D–T reaction experiment (blue circles), together with a Gaussian fit (dashed red curve) and a Geant4 simulation (solid black curve).

be populated, and the shape of the neutron spectrum will reveal details about the reaction mechanism.[11] Further experiments are planned with secondary lithium and beryllium targets to produce exotic, neutron-rich isotopes of these elements via di-neutron transfers. These isotopes are of interest to *ab initio* structure modeling[12,13] and reaction networks in stars.[14]

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