Spectroscopy of Neutrons Generated Through Nuclear Reactions in Short-Pulse Laser Experiments

C. Stoeckl
University of Rochester
Laboratory for Laser Energetics

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Summary

A nuclear physics platform using laser-generated light ions is being developed at the Laboratory for Laser Energetics (LLE)

- An energetic deuteron flow ($E_k = 2$ to $5$ MeV) is created off the back surface of a primary target irradiated by a short-pulse laser ($E = 1.25$ keV, $\tau = 10$ ps)

- Studies of d–d fusion, d–$^9$Be fusion processes show the expected neutron spectra

- First experiments looking at the $^9$Be(d, t) $^8$Be neutron pickup reaction show no signature of triton production
Collaborators

C. J. Forrest, V. Yu. Glebov, and T. C. Sangster
University of Rochester
Laboratory for Laser Energetics

W. U. Schröder and E. Henry
University of Rochester
Department of Chemistry
The nSpec Laboratory Basic Science (LBS) proposal studies neutron production in laser-driven, light-ion reactions

- CD, Be, and layered CD/Be secondary targets were used to study these reactions:
  1. Be$^9$ (d, t) $^8$Be neutron pickup
  2. Be$^9$ (d, n) $^{10}$B fusion/neutron stripping
  3. d (d, $^3$He) n fusion
  4. d (t, $\alpha$) n fusion as secondary reaction to process 1

The short-pulse laser generates high-energy protons and deuterons off the primary target; nuclear reactions create neutrons in the secondary target.
The cross sections for the deuteron reactions are comparable in the >1-MeV energy range

- The Be$^9$ (d, t) $^8$Be reaction has a positive Q value of ~4.5 MeV
- The Be$^9$ (d, n) $^{10}$B reaction has a positive Q value of ~4.3 MeV
- The d (d, $^3$He) n reaction has a positive Q value of ~3.3 MeV
- The d (t, $\alpha$) n reaction has a positive Q value of ~17.6 MeV
Three neutron time-of-flight (nTOF) detectors are installed on OMEGA EP at different angles to the laser direction.
Two different secondary targets, a CD cylinder, and a stack of alternating CD and Be foils, were used

- A small (100-J) UV pulse fired 0.5 ns before the short pulse was used to suppress p–n reactions off the front side of the target
- The calculated range of an ~5-MeV deuteron is ~100 μm in beryllium
- The Be and CD foils in the stack had a thickness of 25 μm
The spectrum of the ion flow off the backside of the primary target was measured using an ion spectrometer.

- The high-energy end point of the ion spectrum is a strong function of the laser intensity.
- The laser intensity was varied by up to a factor of 10 during the experiments.
The nTOF spectrum changes significantly with the different secondary targets.

**OMEGA EP nTOF 73 scintillator signal**

- **Shot 19247**
  - CD primary target
  - Video: 0.0 - 0.1
  - Laser: 10 ps, 1250 J
  - 100- to 140-µm focus
  - ~10^{18} W/cm^2

- **Shot 19273**
  - Various secondaries
  - Video: 0.2 - 0.4
  - 50 µm Be

- **Shot 21756**
  - Laser: 10 ps, 1250 J
  - 100- to 140-µm focus
  - Video: 0.2 - 0.6
  - 25 µm CD + 25 µm Be

**Time (ns)**

- 0
- 200
- 400
- 600
- 800

**OMEGA EP nTOF 73 scintillator signal**
The neutron spectrum from the 25-μm CD/25-μm Be layered target shows DD and dBe neutrons

- The kinematic shift of the DD neutrons indicate a deuteron energy of ~2 to 4 MeV; the shifts of the DBe neutrons are consistent with a deuteron energy of 1 to 2 MeV
- No secondary DT fusion neutrons are seen from the Be⁹ (d, t) Be⁸ neutron pickup reaction
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