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Publication Date
1987-07-01
Presented at the IAEA Topical Committee Meeting on Negative Ion Beam Heating, Abingdon, England, July 15-17, 1987

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July 1987
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Fusion Diagnostics with Neutral Atomic Beams*

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View-Graph Summary

Presented at the
IAEA Technical Committee Meeting on
Negative Ion Beam Heating

* This work was supported by the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.
Fusion Diagnostics with Neutral Atomic Beams*

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Information about the behavior and slowing down of alpha particles created by the d-t reaction is crucial for understanding of an ignited fusion plasma, such as that in the proposed CIT (Compact Ignition Tokamak). Although a variety of diagnostic methods for fast confined alpha particles has been proposed, e.g., microwave, laser, and nuclear-reaction techniques, the use of an energetic neutral atomic beam is particularly promising. Considerations for production of an intense energetic neutral beam are similar for diagnostic, heating, or current-drive applications.

Alpha particles produced by the d-t reaction are born at an energy of 3.5 MeV, or 880 keV/nucleon (velocity of $1.3 \times 10^9$ cm/s). They are trapped by the magnetic field of the tokamak, and slow down by collisions in the plasma, thus heating the plasma. An ideal diagnostic would provide a measurement of the spatial, temporal, and velocity distribution of these fast confined alpha particles.

Two methods for alpha-particle diagnostics using neutral beams have been proposed, as described in publications\textsuperscript{1} by Doug Post and Larry Grisham and their colleagues at Princeton Plasma Physics Laboratory. Both methods use an energetic neutral atomic beam injected into the plasma as a "target beam" for electron capture. The methods are:

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Single-electron capture

$$\text{He}^{2+} + X \rightarrow \text{He}^+^*(n\ell) + [X^+] \rightarrow \text{He}^+ + h\nu + [X^+]$$

Two-electron capture

$$\text{He}^{2+} + X \rightarrow \text{He}^0 + [X^{2+}]$$

where $X$ is a target beam; the brackets on the target beam after the collision indicate that its state is not determined. The photon produced by decay of the excited $\text{He}^+$ is detected outside the plasma in the single-electron-capture method; the fast $\text{He}^0$ (neutralized alpha particle) is detected by re-ionization outside the plasma in the two-electron-capture method.

Electron-capture cross sections are large only when the projectile velocity is similar to the velocity of the electron(s) to be captured. The velocity of the target beam must be similar to that of the alpha particles to be detected, so that the relative velocity is small, and thus the cross section for electron capture is large. Since a specific energy of the order of 880 keV/nucleon is required for the target beam in order to detect alpha particles at birth, a light species is a likely choice, to minimize the energy required, and thus to minimize the cost of the accelerator. A high intensity is required (0.1-1 ampere) to achieve a reasonable signal level, and, to achieve reasonable penetration of the target beam into the plasma, the atom beam must be primarily in the ground state.

A likely candidate for a target beam for the one-electron-capture method is $\text{H}^0$, as considerable effort is being expended to develop appropriate sources of $\text{H}^-$, accelerators, and neutralizers. An energy of up to 880 keV is required. A beam of fast ground-state $\text{He}^0$ at an energy of 3-4 MeV would be an excellent candidate as a target beam for two-electron capture. Unfortunately, the $\text{He}^-$ ion exists only in a quartet metastable state, which collisionally detaches primarily to the triplet metastable state of $\text{He}^0$, which will not penetrate efficiently into a dense plasma. Novel methods of producing fast ground-state $\text{He}^0$ are required. The next lighter species for a candidate as a target beam for two-electron capture is lithium. The negative ion $\text{Li}^-$ can be created by charge
transfer, surface, or volume production, and, at an energy of 6-7 MeV, can be efficiently neutralized. Penetration of Li\(^0\) into a dense plasma is not known.

An energetic neutral atom beam is thus a likely method as a diagnostic for fast, confined alpha particles in an ignited plasma. Many issues related to negative-ion-beam production, acceleration, and neutralization remain to be addressed, along with topics of signal detection. This research is intimately related to production of neutral beams for plasma heating and for current drive.

References
