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AN INVESTIGATION OF THE MECHANISMS FOR DIFFERENTIAL POLOIDAL ROTATION OF PROTON AND IMPURITIES IN THE TJ-II STELLARATOR

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INTRODUCTION. We have previously reported the differing behavior of proton and impurity poloidal rotation in the TJ-II stellarator plasmas for a few selected cases [1]. Presently, this difference in rotation velocities is unexplained, so a model similar to that developed for tokamaks [2] needs to be developed to explain the data. The goal of the present work is to understand, from an empirical point of view, the difference between the strength and direction of both species rotation based on an ample data set covering different operational regimes of TJ-II. For this purpose, we have pursued a systematic campaign to measure C^{4+} and proton poloidal rotation in TJ-II discharges with either ECRH or NBI heating and with either hydrogen or helium as the working gas. To gain insight into which poloidal rotation mechanisms could be responsible for the observed behavior, we will focus mainly on discharges created by ECRH with additional heating by one or two NBI injectors. The additional NBI heating enables us to achieve discharges with maximum line-average electron densities closed to $5\text{x}10^{19}$ m^{-3}.

The paper is organized as follows: first, an overview of the experiments is given; and second, the poloidal rotation results for C^{4+} and protons, obtained in hydrogen and helium as a function of density are presented. The plasma conditions where discrepancies exist in the rotation of the two species are discussed.

EXPERIMENTAL. The measurements reported here have been carried out with an experimental and analysis method [3], which was already used to study the impurity rotation in different TJ-II scenarios [4]. The analysis of the proton rotation is carried out by decomposing the H_α line into three Gaussian components, as was explained in Ref. [5]. The intermediate component, which is dominated by charge-exchange, is interpreted as being associated with the thermal protons; the temperature of this component agrees with that of the charge-exchange neutral particle analyzer. The line shift of this intermediate component is used to obtain the chord-average rotation of thermal protons. Impurity lines are analyzed by fitting the impurity line shape with a single Gaussian function. Although our data analysis procedure has the capability of simulating local rotation profiles, we will compare only chord-averaged data here to show that the behavior of impurity and proton rotation can be significantly different, even considering the uncertainties and limitations due to spatial averaging effects.

The TJ-II flexible heliac, where this experiment was performed, was operated during these measurements at maximum ECRH power (600 kW), either tuned on axis or off axis. The highest densities, those beyond 1.5x10^{19} m^{-3}, were achieved by injecting one or two NBI with 250 kW per injector. The main plasma parameters, which were varied to perform this investigation, were plasma density and working gas, as well as the injected power. We must highlight that the TJ-II chamber was coated by a layer of lithium before the start of this experimental campaign. This has achieved an improved control of electron density during the NBI phase.

RESULTS AND DISCUSSION. We first present results obtained by operating the TJ-II plasma with hydrogen. In Figs. 1 a) and b) we present poloidal rotation data of C^{4+} and protons in a series of discharges performed in hydrogen with ECRH and NBI heating. Fig. 1 a) corresponds to data along an upper half chord, whereas Fig. 1b) are data from lower half chord.

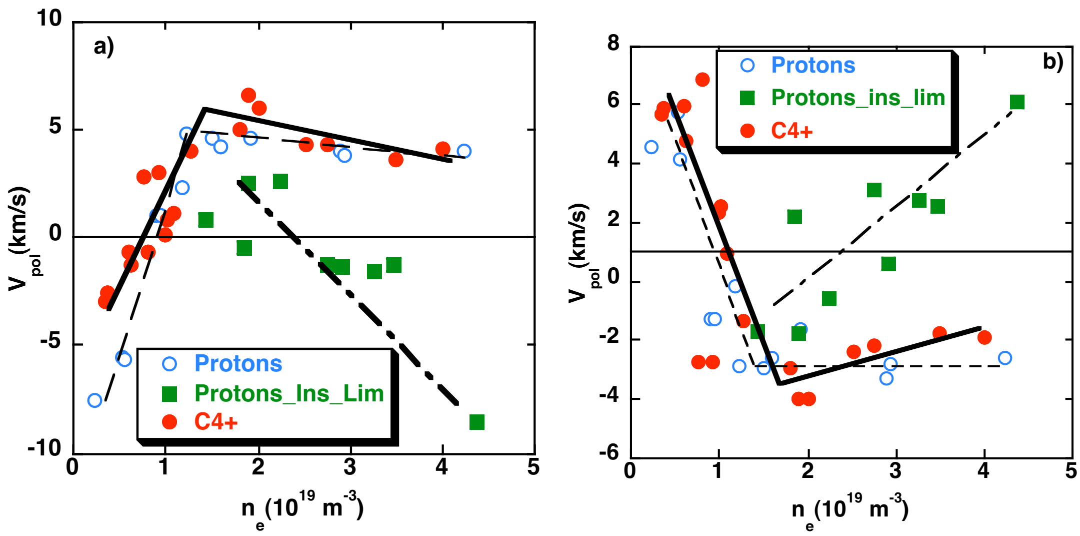

Fig. 1. Plots of C^{4+} and proton poloidal rotation versus the line average electron density: a) for an upper half chord and in b) for a lower half chord. Solid lines show C^{4+} rotation, dashed lines show H^+ rotation which follows the C^{4+} rotation, and dash-dot lines show shot where H^+ rotation deviates from C^{4+} rotation.

Taking data from those two chords, we observe a similar rotation of C^{4+} and H^+ for some discharges. What is worth emphasizing here is the following: the standard trend of C^{4+} rotation (full red points), similar to previously published C^{4+} results [4], is approximately followed by the protons (open blue circles) for some shots, as indicated by a dash line; the clear observation of sign change for proton rotation, for several discharges, is a peculiar property of lithium conditioned plasmas. However, for some shots, the proton rotation deviates from the standard trend. These shots are indicated by green full square symbols and guided by a dash-dot line. Studying the conditions of these discharges, with this anomalous behavior, we have realized that most of them correspond to discharges where both, or at least one of the limiters, were introduced slightly beyond the last flux surface, in order to observe the plasma edge with fast cameras. This results in a rise of neutral density, and consequently, could be the direct or indirect cause of the observed effect on proton rotation.

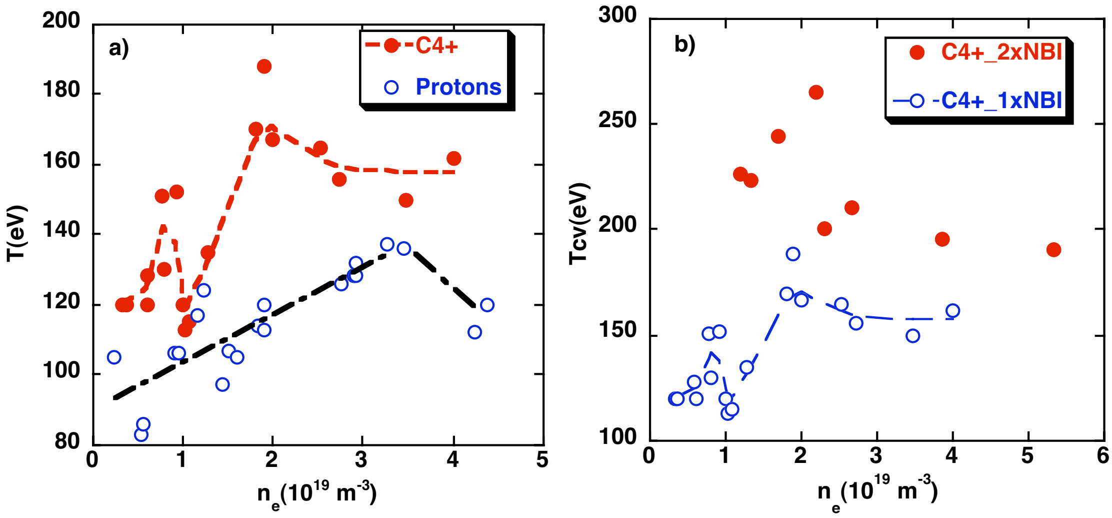

Fig. 2. Comparison of apparent chord averaged ion temperatures for: a) C^{4+} and protons and b) for C^{4+} in discharges with 2 NBI injectors versus discharges solely heated by the co-injected NBI.

We plot, in Fig. 2 a), the maximum chord averaged temperatures that correspond to the rotation data depicted in Figs. 1a) and b). Although a comparison of local values will be done in the next future, it is clear that the trend and absolute values exhibited by C^{4+} ions is significant different from that of protons and the most reasonable explanation was discussed in a previous paper [6]. In Fig. 2 b) we plot the maximum chord averaged C^{4+} temperature for plasmas with one NBI injector and with two. The difference clearly observed in C^{4+} is not seen clearly in proton temperature (not shown here) measured either by the spectral method or by the charge-exchange neutral particle analyzer.

In the case of operating the TJ-II with helium, the poloidal rotation results are depicted in Figs. 3 a) and b). The rotation plotted for He discharges is the angular rotation of the central core since the C^{4+} rotation profiles seems to be more asymmetric than in hydrogen discharges. In Fig. 3 b) the proton and C^{4+} temperatures are depicted for the same set of discharges. We must highlight the observed differences between both species rotation, in particular at the highest densities, where they rotate in opposite directions. Conclusions beyond these obvious considerations should wait until a more detailed analysis be performed, where local rotation profiles are considered. Additionally, a more global analysis of the discharges including particle and energy confinement could shed some light on the effects reported here.

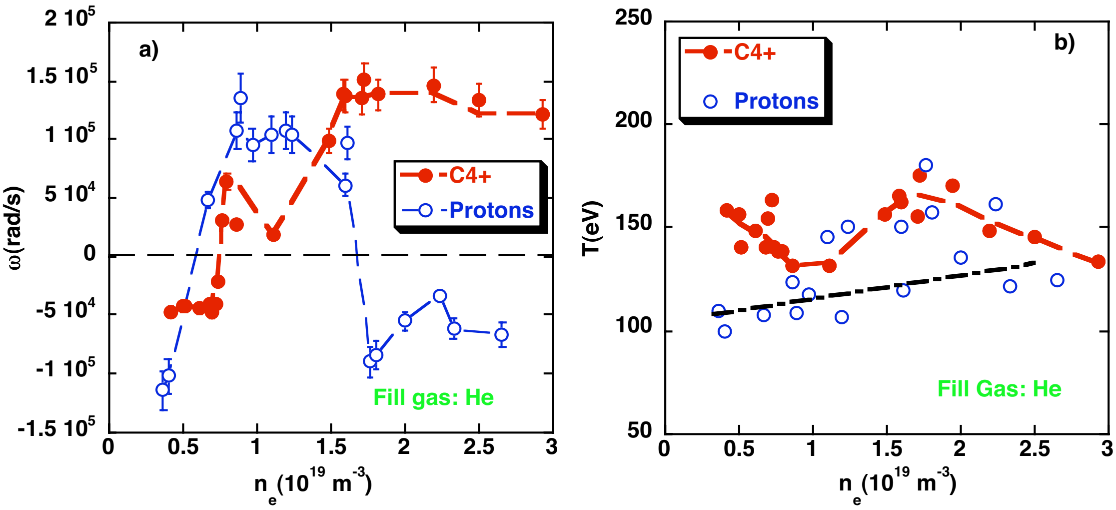

Fig. 3. Comparison of C^{4+} and proton data for TJ-II discharges in He: a) poloidal angular velocity of C^{4+} and protons; and b) C^{4+} and proton temperatures in the same set of discharges.

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