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Molecular (H/D/T) sources in JET

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Abstract

Molecular Fulcher-α spectroscopy is used for the investigation of the HD and DT molecule formation in JET during H_2 and T_2 puffs, respectively. In the hydrogen case, the HD fraction in the outer divertor was about 10% of the molecular D_2 flux, resulting in a 1% contribution of H_2 to the D_2 flux using the law of mass action which is a very sensitive means to measure low quantities of H_2 or T_2 respectively via the detection of the isotopomeres HD and DT. Since the puffed tritium was about one order of magnitude smaller than the H flux introduced, a DT-flux of only ~1% is expected, resulting in a T_2 flux of 0.1%. Evidence will be presented that similar levels have indeed been detected, although the signals were near the detection limit, demonstrating that this type of spectroscopy offers an interesting potential tool as a fuelling and recycling rate diagnostic.

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Keywords: JET; Hydrogen; Deuterium inventory; Tritium; Molecular effects

1. Introduction

Both tritium and deuterium will be used in equal measure as fuel species in future fusion reactors. A number of separate experiments have been conducted at JET over the years [1,2] in which tritium has been introduced in various quantities relative to the deuterium content. The most recent was the 'trace tritium' campaign in 2003, in which tritium has been puffed both from the wall and injected via the neutral beam heating line [3]. Since gas puffed tritium is introduced as a molecule via the nozzle and recycles mainly in the form of hydrogen isotopomeres, it is of interest to investigate the formation, particularly of DT molecules, with regard to the total fuelling of T achieved in the discharge. This contribution describes the use of molecular spectroscopy, employed in a similar way to that reported in [5], to investigate DT and T_2 molecule formation for the first time in JET. Tests with H_2 injections have been carried out beforehand and will

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[1] See the Appendix of J. Pamela et al., Fusion Energy 2004 (Proc. 20th Int.Conf. Vilamoura, 2004) IAEA, Vienna, 2004.

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also be described in this paper. This method provides a very sensitive way to detect a low minority (hydrogen or tritium) concentration versus a high deuterium background level. Simultaneously it offers a unique possibility, never previously performed, to record and study molecular spectra of both tritium and tritiated hydrogen isotopes in a fusion boundary plasma environment. In addition the full potential of molecular hydrogen spectroscopy developed for the determination of the molecular fluxes on TEXTOR [4] and on JET [5] can be employed.

2. Experiment and spectroscopic background

In these experiments tritium has been introduced into the JET tokamak by short, 80 ms T_2 gas puffs of up to 5 mg using a piezo-crystal valve (GIM 15) [6] located in the neutral beam injection line in Octant 6. The quantity of injected tritium was maintained at very low levels (less than 1% of D) in order to keep the DT fusion rate low and the decontamination time of the vessel short. The amount that is puffed is measured by the pressure drop in the reservoir of the valve and can be monitored by either Balmer spectroscopy of hydrogen isotope atoms or deuterium and tritium molecules. In [7] it was demonstrated that a low hydrogen content in the presence of deuterium saturated walls and its behaviour during the isotope exchange could be determined by spectroscopy of molecular HD. The background for this is illustrated in detail in Fig. 1 for the case of TD. One can see that from the measurement of the heteronuclear isotope (DT) a much smaller fraction of the homonuclear (T_2) species can be detected, e.g. from a flux ratio $\Gamma_{DT}/\Gamma_{D_2} = 10^{-1}$ a value for $\Gamma_{T_2}/\Gamma_{D_2} = 10^{-3}$ can be derived. The reason for this is that every T-atom will recombine with a D-atom on the wall, whereas a recombination with another T is highly unlikely. As the molecular to atom flux ratio can be up to nearly 100% [5], this technique is a well suited method for hydrogen isotope ratio measurements near surfaces. Moreover, it is superior to atomic (Balmer) line measurements, since the latter can show a complicated Zeeman pattern due to the magnetic field which practically hardly affect the molecular emission.

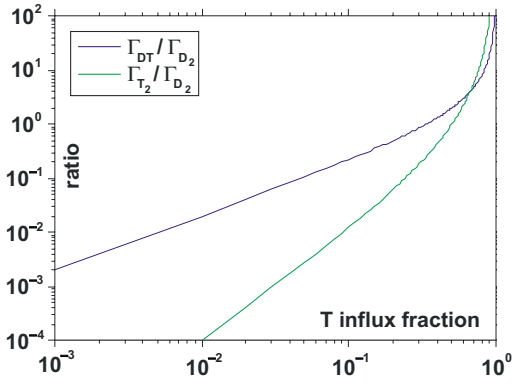

Fig. 1. Molecular flux ratios versus surface concentration derived from the law of mass action.

For the observation of the molecular spectra two high resolution spectrometers have been used with a resolution of 20 000 (KS3B at the injection port in Octant 6 and in the divertor of Octant 1) and 10 000 (KT3B for the outer divertor in Octant 8). In [5] the discharge conditions and the observation geometry used for the detection of the hydrogen isotopomeres formed in the outer divertor is described in detail. The same paper shows how the molecular flux may be determined from the observation of the molecular Fulcher-α band emission ($3p^3\Pi_u \rightarrow 2s^3\Sigma_g$) in the relatively unperturbed red spectral wavelength range around 610 nm. For the experiments described in this paper the separatrix outer strike point position was fixed on the lower horizontal target plate (Base – position a in [5]). JET was operated under the following discharge conditions: $I_p = 2$ MA, $B_t = 2.25$ T, NBI-heating powers of 3 MW and 12 MW.

3. Results

3.1. Hydrogen puff experiments

Before tritium puffs were applied in JET this method could be tested in the same way by injecting H_2 through GIM 15. Fig. 2 displays the results of the *hydrogen puff* experiments. Four identical puffs at 17, 19, 22 and 24 s of 50 mbar l for 100 ms each (green[2] traces: H_α) were injected through GIM 15 into the L-mode phase of discharge #61021 leading to a global density increase of about 6% (Fig. 2(a)). The hydrogen to deuterium ratio at the location of injection was monitored by spectroscopy of D_α and H_α and amounted to about 7 (Fig. 2(b)). In Octant 8 the simultaneous release of HD in the outer divertor could be observed in the Fulcher

[2] For interpretation of color in Figs. 1, 2 and 3, the reader is referred to the web version of this article.

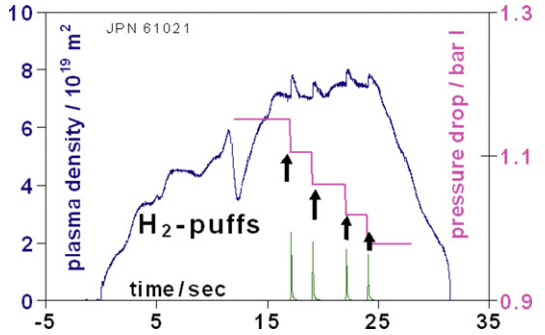

Fig. 2(a). Hydrogen puffs into a D-plasma at 17, 19 and 22, 24 into the L-mode and H-mode phases of the JET discharge #61021.

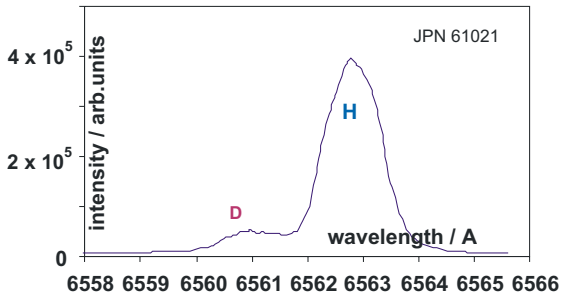

Fig. 2(b). H and D Balmer-α lines near their injection port GIM 15 at Octant 6.

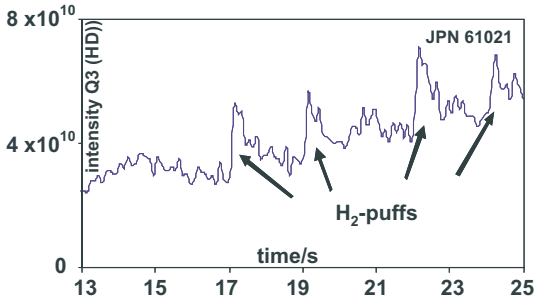

Fig. 2(c). HD release from the intensity of the Q3-line versus time in the outer divertor during the injections shown in (a).

spectrum (Fig. 2(c)). The Q3 line of the 0–0 transition has been chosen as representative indicated in the extended reduced spectrum (Fig. 2(d)). It should be mentioned that the heteronuclear HD molecule displays no intensity alternation between odd and even Q-lines (see [7]). From Fig. 2(d) one can deduce by comparison that the number of HD molecules amounts to about 10% of the D_2 molecules which then results in a 0.2% contribution of H_2 to the D_2 flux (see Fig. 1). Similarly we find that the H-

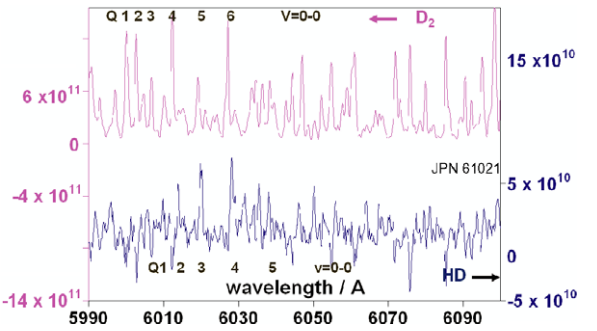

Fig. 2(d). D_2 spectra before and HD spectra from the 2. line of sight of KT3B during H_2 puffs. The HD spectra are averaged over all puffs in (a).

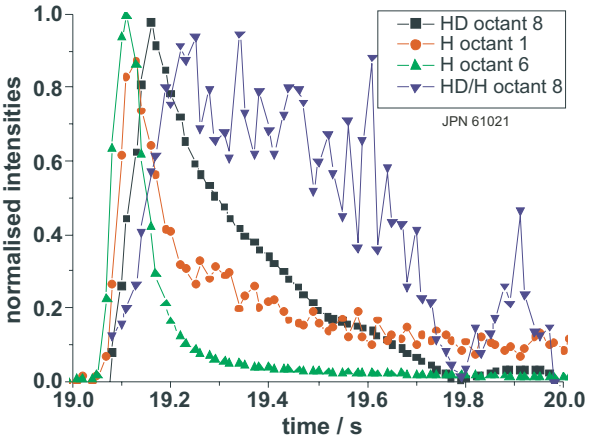

Fig. 2(e). The H_2 puff at 19 s and the respective responses of the hydrogen atoms and HD molecules in the outer divertor during the L-mode as well as the resulting HD/H intensity ratio.

atoms from molecules represent 5% of the total molecular influx in this case.

The local isotope exchange in the outer divertor can be followed in detail through the temporal development of the atomic H and molecular HD lines. Fig. 2(e) shows the gas puff and the resulting responses of the hydrogen atoms and HD molecules in the outer divertor during the L-mode. In order to be independent of the source function, the intensity ratio of molecules to atoms is also shown. From this a time to reach an equilibrium of 200 ms and a subsequent decay time of 400 ms can be derived.

3.2. Tritium puff experiments

Fig. 3 displays the results of the *tritium puff* experiments. In the L-mode phase of JPN#61384 a single tritium pulse of 25 mbar l for 80 ms was

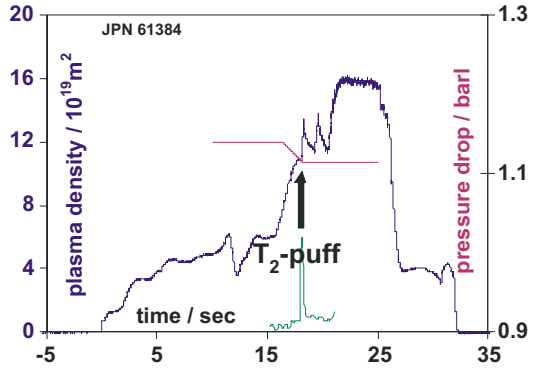

Fig. 3(a). A tritium puff into a D-plasma during the L-mode phase of JPN 61384.

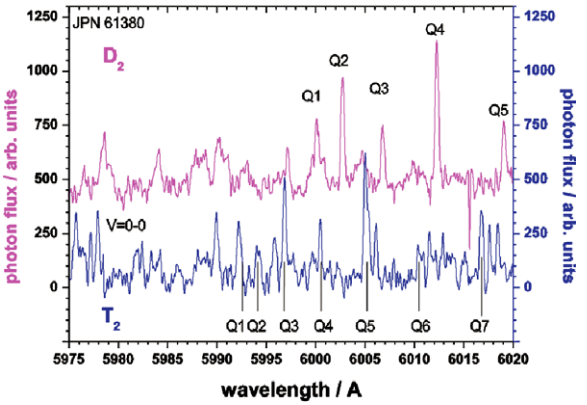

Fig. 3(b). D_2 before and T_2 spectra during a T_2 puff into the H-mode phase of JPN 61830.

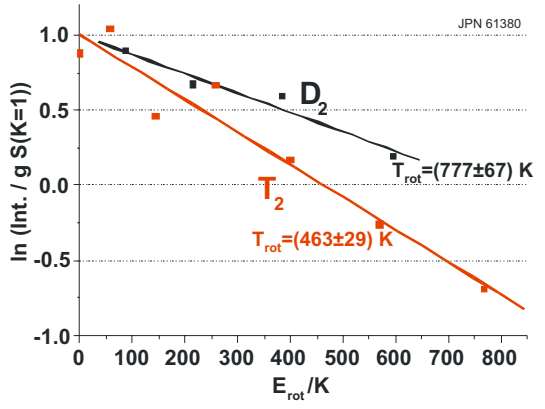

Fig. 3(c). Plot of the rotational intensity distributions versus their level energies for D_2 and T_2 shown in (a).

injected (green[2] trace: Q3 from 0–0, see Fig. 3(b)). Simultaneously a global density increase of about

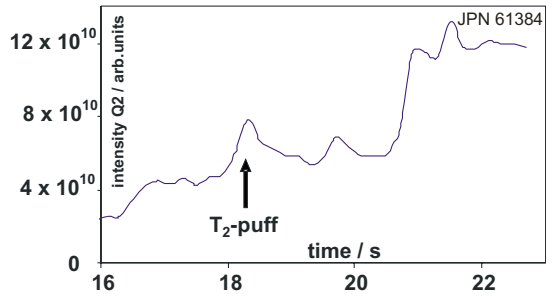

Fig. 3(d). TD release from the intensity of the Q2-line versus time in the outer divertor during the injection shown in (a).

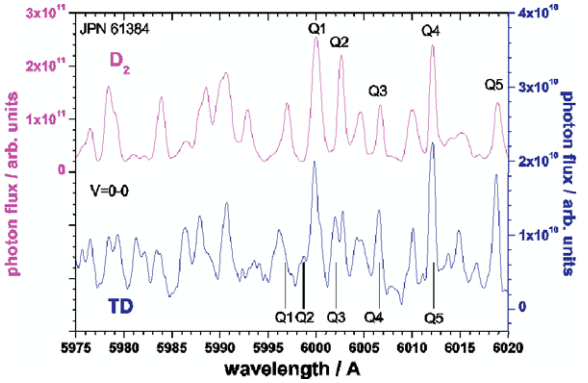

Fig. 3(e). D_2 spectra before and TD spectra from the 2. line of sight of KT3B during the T_2 puff shown in (a).

6% is seen, though, it is not clear if this is solely due to the puff or to a short transition of the discharge into an H-mode (Fig. 3(a)). The Fulcher-α spectrum of T_2 can been clearly identified at the location of the gas puff (Fig. 3(b)). This tritium data are the first known to have been obtained under fusion edge plasma conditions and complement now laboratory molecular T_2 spectra published more than 50 years ago but produced under the very different plasma conditions of a discharge tube [8]. The T/D ratio was found to be only two, which might partly explain the lower TD level detected (as shown below). From Fig. 3(b) the rotational population of the D- and T-molecules at the injection port may be derived. Fig. 3(c) displays the respective plots, from which $T_{\mathrm{rot}} = (777 \pm 67)$ K for D_2 and $T_{\mathrm{rot}} = (463 \pm 29)$ K for T_2 can be found. The lower value for T_2 is in good agreement with the difference of the molecular constants for these two molecules. As described in [9] it is possible to derive the electron density from the rotational temperature. In the case of D_2, T_{rot} above corresponds to $n_e = 8 \times 10^{18}$ m^{-3}, which is a reasonable number

for the electron density in the scrape off layer. The corresponding value for D_2 in the outer divertor near the strike point amounts to about 1×10^{19} m^{-3}, which agrees well with the values given in [5].

An attempt was made to detect the simultaneous release of TD in the outer divertor in the Fulcher spectrum in Octant 8 (Fig. 3(d)). It is difficult to find spectral ranges which display isolated TD lines without a higher resolving power than available with the diagnostics used here. This is because of higher masses the levels and, hence, the transition ranges shrink, which make it more likely that intensities blends from D_2 bands will occur. The Q2 line of the 0–0 transition seems to be a more isolated one and is indicated in the extended reduced spectrum. The whole Q-branch of the 0–0 transition is only marginally visible and should again obey no intensity alteration similar to HD (Fig. 3(d)). In Fig. 3(e) one can estimate from Q2 that the number of TD molecules amounts to about 3% of the D_2 molecules – resulting in a 0.02% contribution of T_2 to the D_2 flux (see Fig. 1). The T-atoms from molecules represent in this case 1.5% of the total molecular influx, i.e. in both cases the H and T in the heteronuclear molecules carry practically all the minority influx. A similar, but less sensitive approach has been performed in [10] using tritiated hydrocarbon radicals.

4. Conclusions

Molecular hydrogen spectroscopy has proven to be a sensitive means by which very low amounts of the recycling flux can be detected without difficult deconvolution procedures necessary in the case of atomic species in magnetic fields. Moreover, the origin of the particle sources and the nature of particle release can be studied in detail via the rovibrational level population. This allows also the determination of plasma parameters like local electron densities which are otherwise not accessible via conventional methods.

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