COMPARISON OF ICRH AND LH ACCELERATED HYDROGEN IONS IN NI HEATED ASDEX PLASMAS

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Introduction

In ASDEX, ICRH /1/ and LHH or LHCD /2/ have been applied separately to NI preheated plasmas in the L regime ($H^0 \rightarrow D^+$, energy E_B). The coupling of these waves to beam ions (H^+) have been studied with charge exchange diagnostics. Possible synergetic effects are discussed in /3/. Shots were made with E_B = 29 keV and E_B = 42 keV and in the latter case P_{NI} or P_{RF} were scanned.

1. Experimental set-up

Measurements were carried out with two neutral particle analysers. One "tangential" analyser (E = 0.1 - 55 keV) viewing opposite to the NI beam direction with the same tangency radius R_T at which the beam is injected (R_T = 145 cm R_0 = 165 cm) and with one "perpendicular" analyser (E = 0.5 - 200 keV) which can be scanned vertically. Perpendicular measurements detect only particles with $V_{\parallel}/V \simeq 0$. Near the edge, however, banana ions are seen at the orbit tips. The energy upshift can be better studied in the case E_B = 29 keV because of the upper energy limit of the tangential analyser. For the 29 keV shots a diagnostic beam of hydrogen atoms was injected vertically in the poloidal plane of the perpendiular analyser and crossed the line of sight of the tangential one in the plasma centre.

2. Results

a) ICRH

The following features are observed with the tangential analyser when ICRH is applied: flux increase for $E > E_B$, flux decrease for $E < E_B$ (Fig.1). Fast atoms are detected in the highest energy channel (47 keV for E_B = 29 keV, 55 keV for E_B = 42 keV, Fig. 2). This signal has a rise time and a decay time of 30 ms. The diagnostic beam has no effect on this signal. In the perpendicular direction the active fluxes show a tail of fast ions up to 60 keV (Fig.3) and passive flux decay time is 30 ms at 40 keV. Passive fluxes at the plasma edge (r=a=40 cm) with E_B = 42 keV increase with P_{RF}/P_{NI} (Fig.4).

b) LH

In the tangential direction, fluxes increase for $E > E_B$, fluxes remain constant or increase (10 - 20 %) for $E < E_B$ (Fig. 1). Fast ions in the 47 keV channel, (55 keV for E_B = 42 keV) are detected (Fig. 2). This flux is twice as large for $\langle N_{\parallel} \rangle = 4$ than for $\langle N_{\parallel} \rangle = 2$. The decay seems to consist of a fast part (few ms) and a longer one (100 ms). For the E_B = 42 keV case, only the fast decay is clearly visible. As for ICRH the active flux is not

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visible for $E > E_B$. In the perpendicular direction fluxes increase and ions are found till 60 keV. The 40 keV fluxes are twice as large for $<N_\parallel> = 4$ than for $<N_\parallel> = 2$ in the centre and equal at $r/a = 0.6$.

3. Discussion

Under our geometrical conditions ($R_T(NI) = R_T$ (Analyser) $= R_T$) and with NI alone, the tangential analyser receives only passing co-particles originating from the maximum of the ion distribution for each magnetic surface (Fig. 5). This is due to the relation, valid both for injection and detection: $R_T/R = v_\parallel/v$ (R is the radius where the C.X. collision happens, $V_\parallel$ the parallel velocity and v the total velocity). Then, for each position R, the ion distribution is peaked at the injection angle defined by $v_\parallel/v = R_T/R$ which is the condition which must be fulfilled to receive neutrals from the position R. If the waves add perpendicular energy to some of the ions, a part of the distribution function is shifted to higher perpendicular velocities and the parallel analyser does not receive any more fluxes from the maximum for each magnetic surface. If no compensations occur from other regions, the signal for $E < E_B$ should drop. On the other hand, ions with $E > E_B$ must be found. They can be detected after acceleration and collisions which place them onto the detection line of the analyser, both geometrically and in velocity space. Estimation of the main collision times is given for the ICRH and LH cases for 30 keV ions ($n_e = 5 \cdot 10^{13}$ cm^{-3}, $T_e = 1.5$ keV and $n_e = 1.5 \cdot 10^{13}$ cm^{-3}, $T_e = 1.5$ keV correspondingly):

	slowing down on e^-	90^0 scattering	charge exchange $n_o=10^7-10^8 cm^{-3}$)
ICRH	25 ms	50 ms	1s to 100 ms
LH	60 ms	115 ms	1s to 100 ms

These characteristic times as well as the confinement define the decay time of the signal after the RF turn off.
For the perpendicular analyser a general flux increase is expected. The experimental results show that both ICRH and LH waves add perpendicular energy to ions which are clearly accelerated to high energies and nevertheless remain confined as discussed in the following.

a) ICRH

Ions which fulfil the relation $\Omega_{ICRF}(R) - 2\Omega_{CH} = k_\parallel . v_\parallel$ can be accelerated in the perpendicular direction. It happens in the resonance layer ($R = R_o \pm 4$cm) if they have $v_\parallel \simeq 0$. Some of them can be banana ions having their orbit tips in the resonance layer /4,5/. Ions can be accelerated outside of the resonance layer if they have enough $v_\parallel$ to fulfil the relation given above. These are passing or banana particles with large $v_\parallel/v$. Taking into account the $k_\parallel$ spectrum of the wave, we calculate that acceleration is possible till $r \simeq 12$ cm for $E_\parallel = 29$ keV and till $r \simeq 18$ cm for $E_\parallel = 42$ keV. Therefore beam ions (passing particles) can be directly accelerated only outside of the resonance layer. Beam ions first scatter to larger $v_\perp/v_\parallel$ before they can be accelerated in the resonance layer. Experimentally it is shown by the absence of active flux ($v_\parallel = 0.85$ v) in the tangential analyser: ICRH does not affect passing ions in the centre but off-axis acceleration is found. On the other hand, observations made with the perpendicular analyser show that accelerated ions with large $v_\perp/v_\parallel$ are present in the plasma centre.

b) LH

The LH interaction is not well located but particles must have enough perpendicular energy $E_\perp$ to fulfil the relation: $N_\perp \simeq 700\ (A/E_\perp)^{1/2}$ ($[E_\perp]$ = keV, A = atomic number)

The perpendicular index $N_\perp$ of the wave is calculated by ray tracing /6/ and the next tables compare the lowest $N_\perp$ values necessary for the interaction and the highest $N_\perp$ values given by the ray tracing method for different $N_\parallel$ values:

	$\langle N_\parallel \rangle$	2	4	resonance	$E_\perp$	29 keV	42 keV
code	$N_\perp$	30-75	75-125	condition	$N_\perp$	130	108

It appears that the $N_\perp$ values given by the code are too small to allow for interaction with beam ions particularly for the $\langle N_\parallel \rangle = 2$ spectrum. This general problem for the LH experiments will not be discussed here. As for ICRH the absence of active fluxes in the tangential direction shows that the interacting and accelerated ions in the centre have too large $E_\perp/E$ to be detected. This is confirmed by the perpendicular measurements which show an active flux increase in the centre due to LH.

Off axis acceleration happens and is enfavoured by the geometrical effect which provides the outer surfaces with beam ions having more $E_\perp$ than in the centre. The contribution of the non-central part to the fluxes could be large due to the high value of the neutral density and explain the flux increase for $E < E_B$. The life time of the ions generated off-axis is shorter due to higher losses (charge exchange, confinement) and could account for the fast part of the decay time. The non central effects are more favourable in the E_B =42keV case which provides the plasma edge with faster ions. Moreover interaction is expected further outside at higher density values. Shots made at 3×10^{13} cm^{-3} show flux increase of a factor 2 in the parallel direction for $E < E_B$ and very fast rise time and decay time. The perpendicular observations show large off-axis fluxes, similar to observed without NI /7/.

Conclusion

It appears from this analysis that for both the ICRH and the LH waves give perpendicular energy to beam ions:

- in the centre, to beam ions which have made 90° pitch-angle scattering
- off-axis, to ions which come almost directly from the beam. This contribution to the fluxes seems to be larger for the LH case.

For ICRH in particular, these two populations are separated both geometrically and in velocity space and cannot mix strongly according to the collision times. The second population might improve somewhat the ICRH heating efficiency for NI preheated plasmas compared to that obtained in ohmic plasmas, nevertheless both for ICRH and LH the contribution of the accelerated ions to β is small /1,3/.

The clear patterns shown in Fig. 4 as a function of P_{RF}/P_{NI} (RF power per injected particle) indicate probably that the interaction occurs mainly with beam ions. They show the global increase of the perpendicular energy of the ion distribution. For ICRH the contribution of the fast ions to the impurity production is very probable as discussed in /8/.

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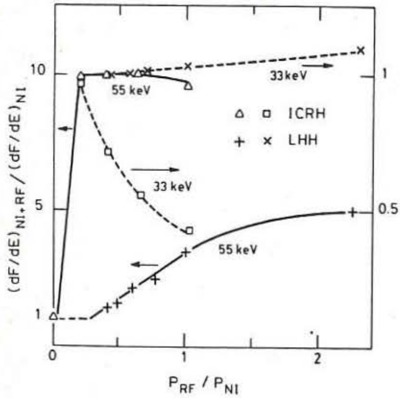

Fig. 1: H^o normalised fluxes for the tangential analyser versus P_{RF}/P_{NI} ($E_B = 42keV$).

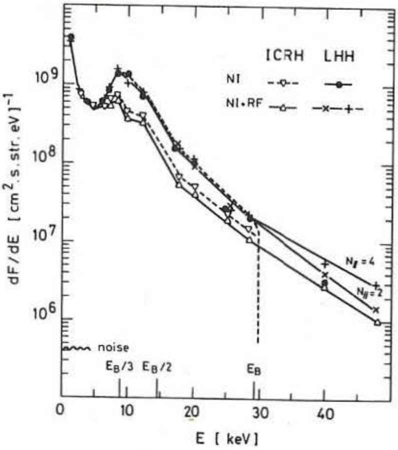

Fig.2: H^o energy spectra for the tangential analyser ($E_B = 29keV$).

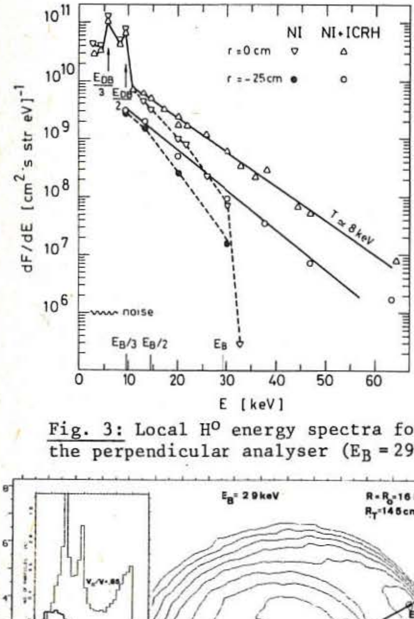

Fig. 3: Local H^O energy spectra for the perpendicular analyser ($E_B = 29keV$).

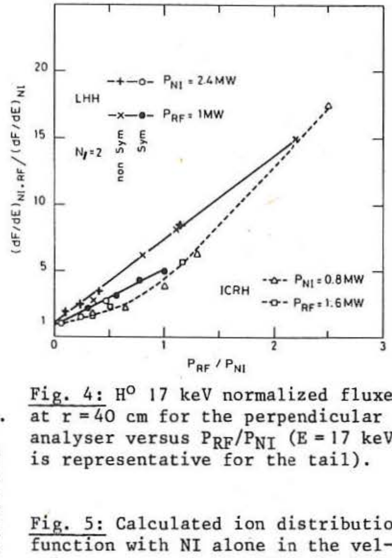

Fig. 4: H^O 17 keV normalized fluxes at $r = 40$ cm for the perpendicular analyser versus P_{RF}/P_{NI} ($E = 17$ keV is representative for the tail).

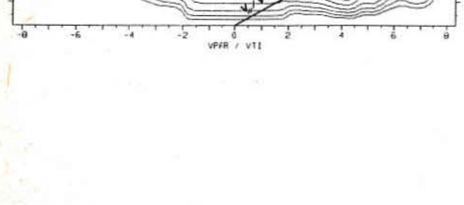

Fig. 5: Calculated ion distribution function with NI alone in the velocity space normalised to the thermal velocity. Energy spectra for two $v_{\parallel}/v$ values are enclosed.