MOTIVATION to use He

- **Edge and transport barriers** lead to better confinement of fusion-plasma in tokamaks

- **Lithium**-beam diagnostics is currently being successfully used to measure plasma-edge electron densities

- Advantage of helium over lithium: higher ionisation energy and thus deeper penetration into plasma; prospect of being able to measure electron temperature and density simultaneously
He experiment

ASDEX Upgrade

doped He-beam

- Inject neutral helium atoms into fusion-plasma and analyse emission spectra measured with spectrometers whose lines of sight are roughly perpendicular to the beam line

- Doping: Deuterium/hydrogen heating beams ‘doped’ with helium: parasitic experiments can be performed with little influence on the plasma or function of the heating beam
Active spectroscopy is used which has a higher spatial resolution than passive spectroscopy, especially if the lines of sight are roughly perpendicular to the beam line.

The NBI accelerates H/D/He ions, neutralises them, and deflects remnant ions.
He EXPERIMENT

\[ e^- + He \rightarrow e^- + He^* \rightarrow e^- + He + h\nu \]
\[ e^- + He \rightarrow 2 e^- + He^+ \]
\[ H^+ + He \rightarrow H^+ + He^* \rightarrow H^+ + He + h\nu \]
\[ H^+ + He \rightarrow H^* + He^+ \rightarrow H + He^+ + h\nu \]

- Excitation, de-excitation, ionisation, charge-exchange, electron/proton impact

- Constellation of the KS5-spectrometers (of octants 1 & 7) with respect to the pinis 6 & 7 of the NBI (of octant 8) at JET
He EXPERIMENT

- sweeping at JET across viewing lines
  - improved spatial resolution; used in case of small number of fibres
  - cross-calibration of neighbouring viewing channels.
He-BEAM MODELLING

Input from JET or ASDEX Upgrade:
1) exp. electron density & temperature profile (e.g. from LIDAR)
2) exp. Emission profiles of two wavelengths 667.8 nm & 587.6 nm

'scotty' & (1) > mod. emission profiles
'yttocs' & (2) > mod. elec. density & temp.

Comparison of experimental and modelling data
> re-evaluation of simulation techniques
He–BEAM MODELLING

- Collisional-radiative model used, relevant for plasma-densities $10^{17}$ to $10^{24}$ m$^{-3}$

- Competition between collisional processes and spontaneous emission
He-Beam Modelling

\[ vb \frac{dN_i}{dx} = - \sum_j C_{ij} N_j \]

- ‘scotty’ solves population-density balance equation iteratively using \( C \)
- The collisional-radiative model
- n=3 used (system in equilibrium with \( n>3 \)) \( \Rightarrow \)
  - 11 energy levels \( \Rightarrow \) 11x11 cr-matrix \( C(n_i, n_e, T_i, T_e, v_b) \)
- cr-matrix \( C \): cross-sections, rate-coefficients, and spontaneous emission coefficients from the ADAS-database and is generated by the ADAS311-software
- Processes: elec. & proton collisions, spontaneous emission, excitation, de-excitation, ionisation, charge-exchange. Recombination processes neglected
He-Beam Modelling

'yttocs' reversion code: (re-) calculates electron density & temperature from given emission intensities

- Subroutine loop first calculates emission profiles using 'scotty' from an intial 'guess' →

- Then minimizes difference between exp. & mod. emission profiles via variation method
He DATA ANALYSIS

- beam power changes only slightly due to ‘doping’
- radial position of outer plasma edge due to sweeping
- Some LIDAR experimental data which is used for comparison
- Visualisation of the 667.8 nm line using ‘show’ and it’s Doppler-shifted peak
**He DATA ANALYSIS**

- Helium-beam emission spectra are simple consisting only of the Doppler-shifted beam signal and the plasma emission. There’s no splitting of the peak nor are there impurity lines nearby.
He DATA ANALYSIS

- measured and modelled (grey) beam emission profiles

- Input: average temperature and density from JET.

- The black curve is an estimate of the calculation error

- Beam energy: 140 keV
He DATA ANALYSIS

- Cross sections for electron (o) and proton (\(\nabla\)) impact excitation from ground-state helium atoms into four low excited single states \((2^1S, 2^1P, 3^1S, 3^1P)\)

- Proton-helium impact becomes increasingly relevant at higher beam energies while that of electron-helium impact decreases.
MOTIVATION to use Na

Advantages of Na beams as compared to Li

- Higher PM quantum efficiency
- Na-beam (40 keV) 4 - 5 mA
- Higher Na⁺ current
- Lower Tₑmitter

Li-beam (35 keV) 1 - 2 mA

Higher CX-cross sections

Higher neutralization efficiency

35 channels Li-IXS

Separatrix

16 channels Li-CXS

Torus

Passive stabilizer loop

Plasma
MOTIVATION to use Na

- The neutralisation efficiency of the Na-vapour chamber is higher than in the case of Li.

- Hungarian colleagues of the KFKI-research institute are developing an Na-emitter that might be installed at ASDEX Upgrade: a higher ion intensity (3-4 x) than with Li is possible at the same beam energies. The new Na-emitter requires much lower temperatures than the Li-emitter.

- The CCD-cameras used are much more sensitive to the relevant Na wavelengths (589.5 nm) than to the relevant Li wavelengths.

- The intensity of the Na beam emission is significantly higher than that of Li.

- The lower lifespan of the relevant excited Na(3p) state as compared to the Li(2p) excited state in combination for the smaller velocities of the Na particles at the same beam energies implies a higher spatial resolution of the Na(3p-3s) profile and ultimately a more accurate reconstruction of the el. density profile.
comparison of Na and Li atomic data

**Li compared to Na**

\[
\begin{align*}
I_{Li} &= 5.4 \text{ eV} \\
\lambda_{Li(2p-2s)} &= 670.8 \text{ nm} \\
\tau_{Li(2p)} &= 27 \text{ ns}
\end{align*}
\]

\[
\begin{align*}
I_{Na} &= 5.1 \text{ eV} \\
\lambda_{Na(3p-3s)} &= 589.0 \text{ nm} / 589.6 \text{ nm} \\
\tau_{Na(3p)} &= 16 \text{ ns}
\end{align*}
\]
preliminary results
preliminary results
preliminary results

- using the Li emitter, emission from both thermal and accelerated Na could be detected by the spectrometers LIA and LIC at ASDEX Upgrade
- The Na stemmed from the Na-vapour chamber and diffused thermally in tow directions and was ionised in the same manner as the Li and then accelerated to 40 keV
- Despite the smaller ionisation energy of Na of 5.1 eV as compared to 5.4 eV for Li, the penetrations were practically equivalent
- as the new emitter being built by the KFKI allows much higher Na-beam energies than the current Li-emitter used at AUG, much deeper plasma penetrations are to be expected
- The Na-simula software (adapted from simula for Li) have, along with the current rudimentary data base, generated beam emissions that correspond well to the experimentally measured ones.
OUTLOOK

• Experiments performed at JET and ASDEX Upgrade

• Proof-of-principle has been shown that the electron temperature and density can be simulated using He-beam emission profiles

• It has been shown that Na is a promising candidate for beam diagnostics

He outlook:

• Error estimation and propagation

• Assessment of influence proton-impact, especially at higher beam energies

Na outlook:

• usage of new dedicated Na-emitter at higher energies
• compilation and extension of new data base
• usage of new DB to measure and calculate el. densities
• explore possible usage of CX-emission to measure ion temperatures
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