Research of Diagnostic Techniques on a Nonneutral Plasma
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II. Motivation

**Thermodynamic Equilibrium (TE)**

TE - when every process is in equilibrium with its converse

- \( a + e \leftrightarrow a^* + e \)
- \( a + e \leftrightarrow i + e + e \)
- \( a + hv \leftrightarrow a^* \)
- \( a + hv \leftrightarrow i + e \)
- Saha equation
- Boltzmann equation

**Nonneutral Plasma**

- electron density \( \sim 10^{14} \) 1/m³
- minimum density (He, \( T = 100 \text{eV} \)):
  \[
  n_e \geq 9 \cdot 10^{23} \left( \frac{E_2}{E_H} \right)^3 \sqrt{\frac{kT}{E_H}} \frac{1}{m^3}
  \]
  \[
  n_e \geq 9,78 \cdot 10^{23} \frac{1}{m^3} \text{(Griem)}
  \]
- ion loss, no 3-body recombination
- ion loss, no radiative recombination

**Corona-/Collisional Radiative-Model**

**Thermalisation**
Thermalisation

- homogeneous electron density distribution
- equality of longitudinal and radial average kinetic energy

average kinetic energy of electrons by optical diagnosis

calculated average kinetic energy of electrons

cyclotron frequency

ExB rotation
I. Experimental Setup

Determination of the plasma parameters dependence on external fields:

- optical methods e.g. CCD and monochromator exposure of the light emitted by residual gas
- momentum spectroscopy of the residual gas ions
I. Experimental Setup

- CCD + Spectrometer
- Three-Segmented-Gabor-Lens
- Faraday Cup
- Momentum Spectrometer
Confinement

The NNP is assumed to be thermalized with similar strengths in longitudinal & radial confinement.

Confinement Condition: \[ \Phi_A = \frac{e r_{\text{anode}}^2 B_z^2}{8 m_e} \]

1. radius
2. residual gas pressure
The residual gas pressure affects the rate ion production \( R_c \).

\[
R_c = n_e \nu_{iz} = n_e n_R \left( \frac{2}{m_e} \right)^{\frac{1}{2}} \int_0^{\infty} \frac{2E}{\pi^2 (T_e)^2} \sigma_{iz} e^{-\frac{E}{T_e}} dE
\]

It depends on the neutral number density as well as electron temperature.
Pressure Ranges

Better confinement at low pressure ranges:

![Graph showing pressure ranges and voltage relationship](image-url)
The work function of the Gabor lens changes with external parameters:
Symmetry of Plasma Column

Symmetry as evidence of thermalisation of the plasma column.
The continuous ion current indicates that the sojourn time of electrons within the Gabor lens is long enough for thermalisation.
Far from the optimum parameter range a variety of plasma instabilities can be observed.
Conditioning of the Three-Segmented-Gabor-Lens

non reproducible measured data: 

reproducible measured data:

![Graph 1](image1)

![Graph 2](image2)
Density Measurement

Elektronendichte: \( n_e \approx 1 \cdot 10^{14} \frac{1}{m^3} \)
Temperature Measurement

Für LTE Plasma:

\[ k_b T_e = \frac{E' - E}{\ln \left( \frac{I \lambda^3 g' f'}{I' \lambda^3 g f} \right)} \]
Broadening Mechanisms

• Stark Broadening

broadening of spectral lines due to the interaction of electric field near the radiator.

This mechanism doesn't occur in the NNP with densities about $\sim 10^{14} \text{ 1/m}^3$

Estimation by semi empirical formula: $n_e = 1,03 \cdot 10^{16} (\Delta \lambda)^{3/2} \frac{1}{cm^3}$, $\Delta \lambda$ in nm

• Doppler Broadening

broadening of spectral lines due to the Doppler effect in which the thermal movement of atoms or molecules shifts the apparent frequency of each emitter:

$$\Delta \lambda_{1/2} = \left( \frac{2kT \ln 2}{Mc^2} \right)^{1/2} \lambda_0 \text{nm}$$

A spectral resolution of 1,24 pm would be needed to observe the doppler broadening for a residual gas with temperature about 300K.
Doppler Shift of Emitted Ions

He II; 656,01nm

Comparison:

$$\Delta \lambda = \lambda_{\text{Lit, HeII}} - \lambda_{\text{Gauss}}$$
HF Probe

- For $p = 1.5 \times 10^{-5}$, $U = 4120\,\text{V}$, and $B = 2.8 \times 0.0038\,\text{T}$.
- For $p = 1.5 \times 10^{-5}$, $U = 3940\,\text{V}$, and $B = 2.8 \times 0.0038$.
- For $p = 1.5 \times 10^{-5}$, $U = 3830\,\text{V}$, and $B = 2.8 \times 0.0038\,\text{T}$. 
Diagnostic Techniques

non interceptive:
- CCD-Camera
- Monochromator
- HF-Probe
- LASER
  (Thomson-Scattering)

interceptive:
- Momentum Spectrometer
- Faraday Cup
- EMI
Outlook

• evaluation of electron temperature
• numerical calculated electron temperature and density compared to measurement
• analyses of different diagnostic techniques
Temperature Measurement

\[
\frac{I_{z-1, l_l'}}{I_{z, k_k'}} = \frac{A_{ll'} V_{ll'} g_{z+1,1} g_{z-1,l}}{A_{kk'} V_{kk'} g_{z,1} g_{z,k}} e^{-\frac{\Delta E_{z,k} - \Delta E_{z-1,l}}{kT_e}} F
\]