T_e and n_e Measurements in Edge Turbulence Plasmas by Helium Spectroscopy

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Outline

The T_e measurements using the He I line intensity ratios was first proposed by Cunningham (1955) and has been applied with various improvements.

Cunningham method based on the corona model, however cannot be applied for fusion edge plasmas with $n_e > 10^{11} cm^{-3}$, since it only includes the direct excitations from the ground state and the radiative deexitations and neglects electron impact on the exited states. The frequent electron impacts in a high n_e plasma enhance the ionization and deexitation from the exited states, resulting in strong n_e dependences of line emission rate coefficients.

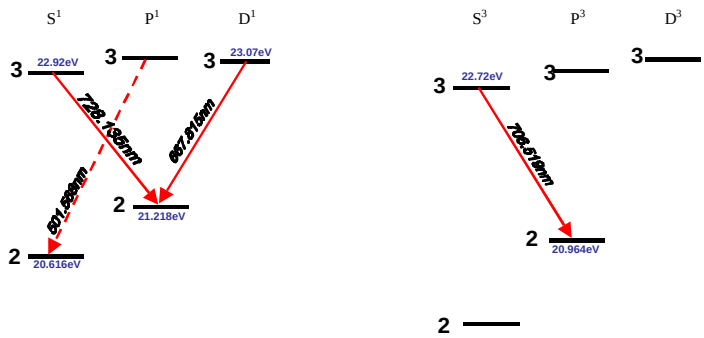
Consequently, in tokamak studies, the collision radiative model, which includes electron impacts on the various exited states, has been applied for the investigation of the population dynamics of helium atoms. So far, the T_e and n_e measurements based on the collisional radiative model has been utilized and successfully used on several devices such as TEXTOR, Start and Alcator C Mod.

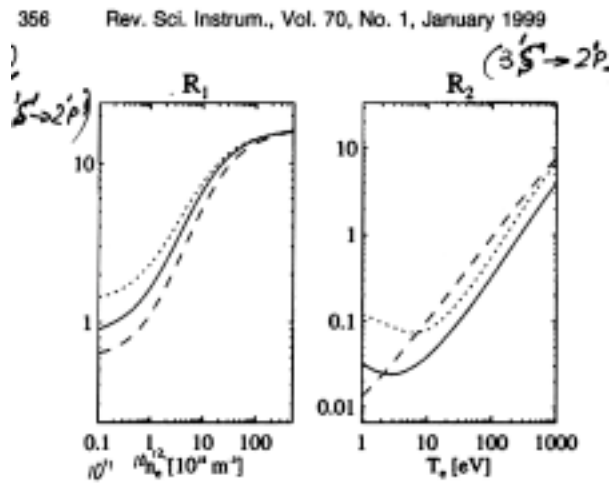
The emissivity per unit volume and solid angle is expressed as

$$B = \frac{1}{4\pi} n_e \cdot n_{He} \cdot C_{em}(\lambda_{ik})$$

where C_{em} is the emission rate coefficient derived from well developed numerical codes

Reduced level diagram of Helium atom





Intensity ratios $R_1(n_e)$ and $R_2(T_e)$ obtained from ratios of effective excitation coefficients. Data corresponding to various values of T_e (30,100 and 300eV) and n_e (10^{18},10^{19} and $10^{20}m^{-3}$) are shown as dotted, solid and dashed lines, respectively

The ratio $R_1 = \frac{C_{em}(\lambda_{D\Rightarrow P}^{Singlet})}{C_{em}(\lambda_{S\Rightarrow P}^{Singlet})}$ for singlet transitions demonstrate the strongly pronounced density dependence in the range $n_e=10^{11}$-10^{13} cm^{-3}, showing the moderate dependence on T_e

At the same time the cross-ratio $R_2 = \frac{C_{em}(\lambda_{S\Rightarrow P}^{Singlet})}{C_{em}(\lambda_{S\Rightarrow P}^{Triplet})}$ of singlet to triplet transition is strongly temperature sensitive in the range from 10eV up to several hundred eV, showing a weak dependence on n_e

Objective

- Surveying the edge turbulence to gain access to: anomalous transport, H-mode physics, transport outside last close flux surface, diffusion of toroidal current from edge to core, etc.
- Monitoring the electron temperature and density profiles of edge turbulence plasmas require good spatial (~1cm) and temporal (~10μsec) resolution.

Approach

- Measure visible emission from plasma edge
  - $\mathbf{n_e}$ is obtained from the singlet-singlet line pairs (**667.8nm/728.1nm**)
  - $\mathbf{T_e}$ is obtained from the singlet-triplet line pairs (**728.1nm/706.5nm**)

  Margins
  - Since excitation rate coefficients from ground state rapidly decrease with $\mathbf{T_e}$ below excitation energy (~20eV), a small amount of hot electrons have a large influence on the line emissions give rise to a substantial modification of the line intensity ratio when $\mathbf{T_e}$<10eV. For n_e measurements, the effect of hot electrons can be neglected because of the weak T_e dependences of the singlet-singlet line intensity ratio

- Use localized, controlled gas puffs to overcome the "halo" emission from plasma edge
- Use the line of gas puff view along B field line
- Use routine Thomson filter polychromator for simultaneous monitoring of edge plasma events in the light of He I lines
- Use detector based on Avalanche PD routinely in service on Thomson scattering diagnostic for edge turbulence frequency spectrum monitoring with temporal resolution a few μsec
- A future possibility of this method could be 2D imaging of $\mathbf{T_e}$ and $\mathbf{n_e}$ in the plasma boundary with good temporal resolution for edge turbulence cross-field scale-length monitoring.
  - Spatial resolution Δx is dominated by the requirement for slowest level to equilibrate the local plasma condition $\Delta x=\tau_{equilibrium}\ V_{thermal}$. For a gas jet at 300K it means $n_e\ \Delta x \cong 5\ 10^{11} cm^{-2}$ so a resolution of less than 1cm is achievable at $\mathbf{n_e}>10^{12} cm^{-3}$

Sensitivity Estimate

In general, the need to obtain the sufficient signal for analysis is the limiting factor of a real time spectroscopy diagnostics. It is common in tokamak studies to interpret the emission from impurities in terms of ionization model. Using the data on ionization events per photon $\frac{<\sigma_{emission} v_e>}{<\sigma_{ionization} v_e>}$ the line radiance ($\frac{photon}{cm^2 \cdot sr \cdot s}$) is estimated by Eq(1) increasing with the shallow view of emitting layer

$$B \geq \frac{\Gamma}{4\pi \frac{<\sigma_{ionization} v_e>}{<\sigma_{emission} v_e>}} \qquad (1)$$

where Γ ($\frac{atoms}{cm^2 \cdot sr \cdot s}$)-Helium atoms local influx at plasma boundary

Given the gas puffing is about $10^{19} \frac{atoms}{s}$ spread over $10^2 cm^2$ cross-section of plasma boundary and allowing for the ratio $\frac{<\sigma_{emission} v_e>}{<\sigma_{ionization} v_e>}$ to be approximated according to Fig.1 the line radiances for the transition of interest would be no less than

$$B = \frac{10^{19}}{4\pi \cdot 10^2 \cdot 600} \approx 10^{13} \frac{photons}{cm^2 \cdot sr \cdot s}$$

That looks satisfactory to provide the signal to noise ratio of nearly 100.

The interference by the continuum radiation could be estimated using the emission intensity for the Bremsstrahlung. With keeping the edge plasma parameters at T_e=100eV, n=$10^{13} cm^{-3}$ the Bremsstrahlung radiance within a spectrum band of 10nm has got approximately 10^{-2} of the line emission. The low Z impurity multiplets may be an issue giving rise to a background enhancement by up to orders of magnitude. Thus it stands to reason to use the more selective spectrum channels of ~1nm resolved band.

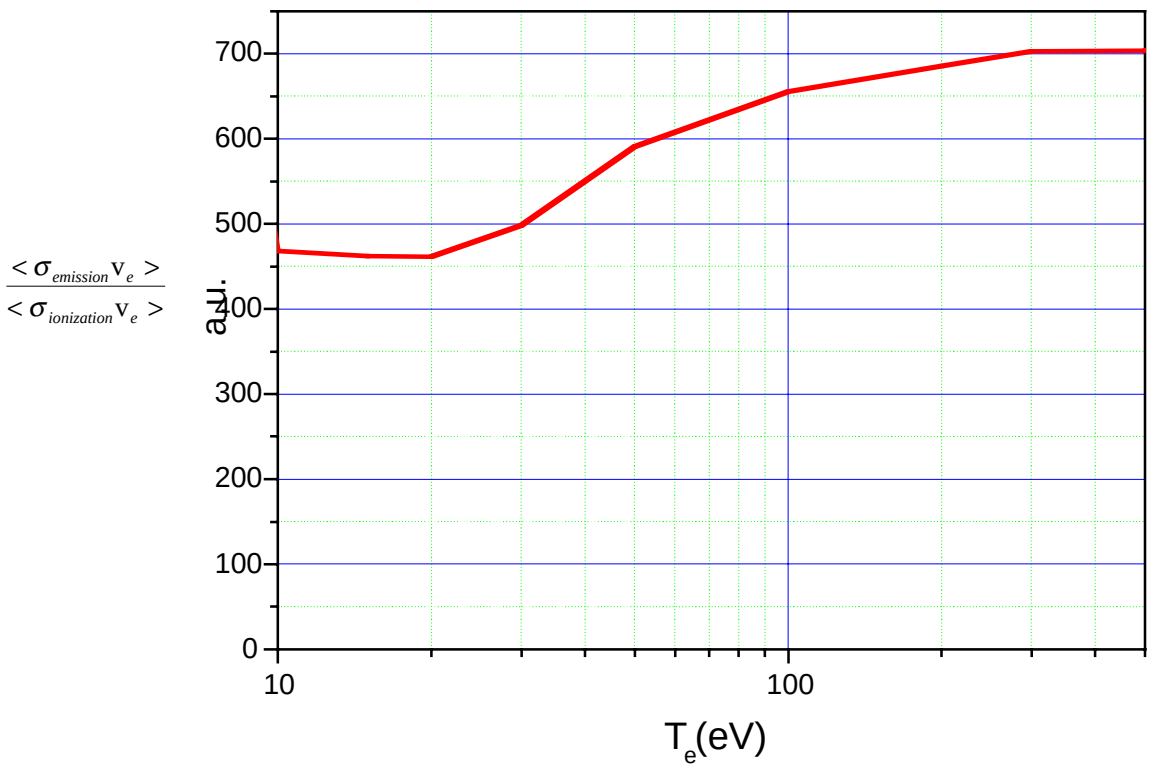


Fig.1 Number of ionizations per emitted photon for typical singlet-singlet transition line λ=501.6nm.

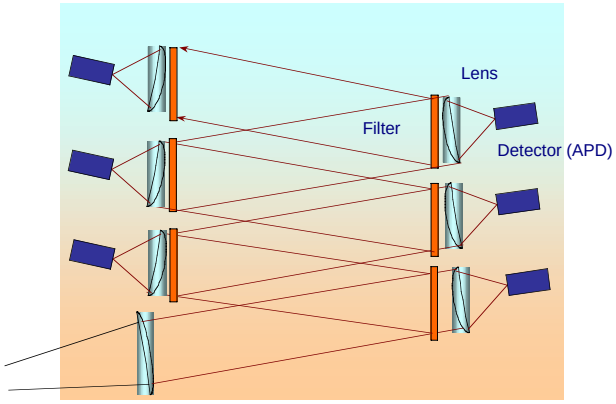
Experimental Setup

Optical scheme principles

first stage of experiment

frequency spectrum monitoring

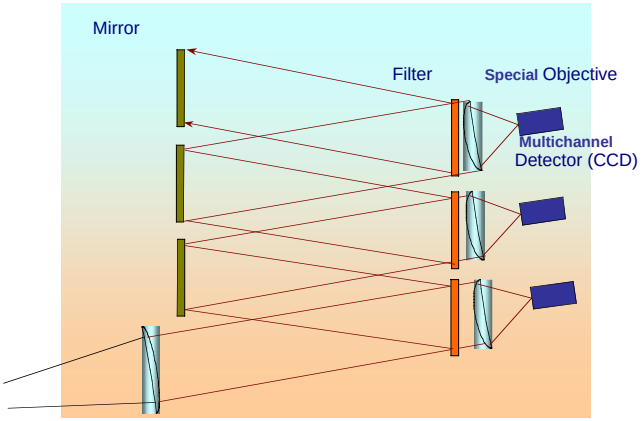
Standart filter polykhromator



second stage of experiment

cross-field scale-length monitoring

Reconstructed polychromator



Quick reference data on demanded filter set

Filter set	$3S^1$-$2P^1$	728.1nm*
	$3D^3$-$2P^3$	706.5nm*
	$3D^1$-$2P^1$	667.8nm*
(reference line)	$3P^1$-$2S^1$	501.6nm*
(background)		720nm

* all filters should be ordered taking into account wavelength shift over 4 Deg inclination