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Effect of Re-absorption on Neutral Helium Spectral Lines Useful for Plasma Diagnostic

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by

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Overview

1). Objective

2). Experimental Set Up

3). Model

4). Results

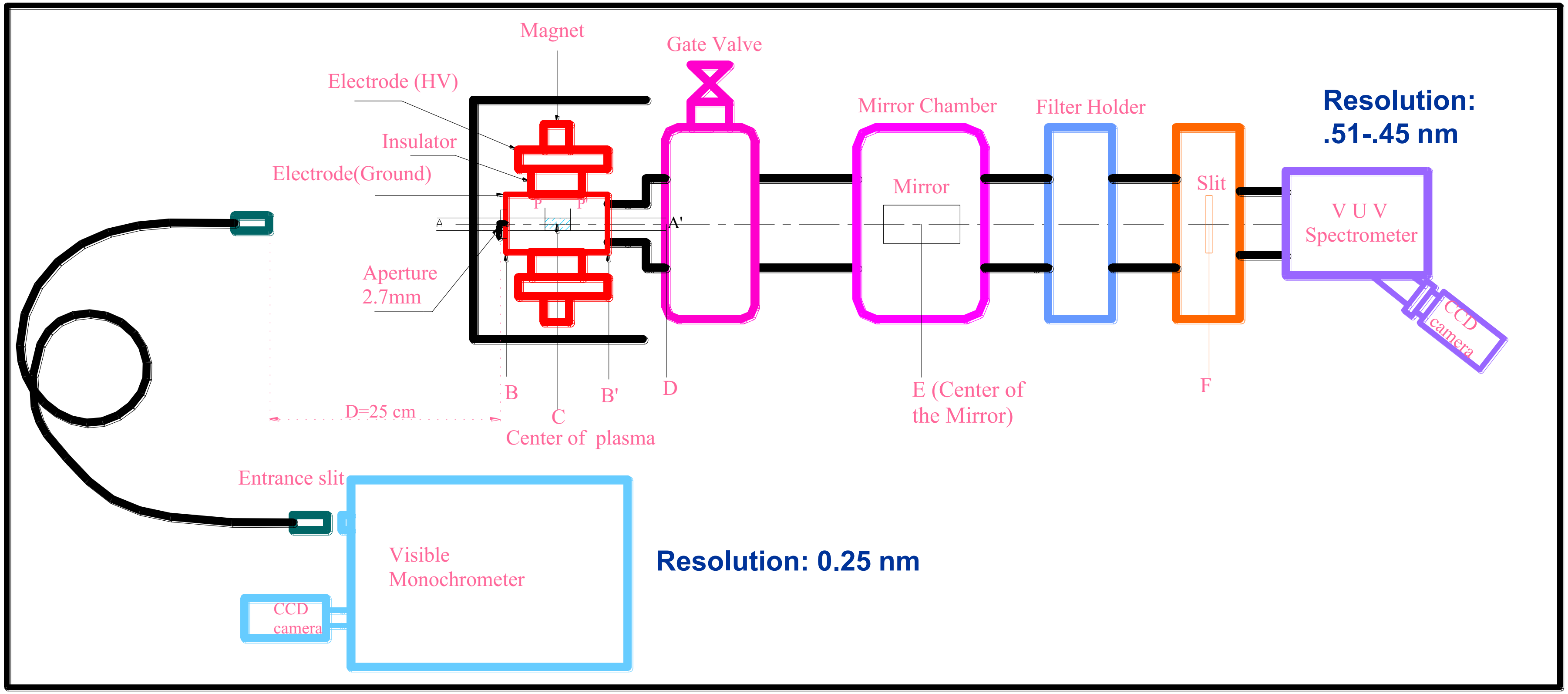
5). Opacity Analysis

Objectives

- To Characterize a standard penning plasma source using visible spectroscopy and full collisional-radiative (CR) model from the ADAS code.
- Consequently, develop a simple method to calibrate a VUV spectrometer-detector system using a standard penning discharge source.
- To include the effect of opacity to modify the developed model.

Experimental Set Up

We used a standard penning plasma source available for wavelength calibration i.e. from 15 nm to 170 nm in this study. We used Helium gas and the plasma was characterized using visible plasma spectroscopy for different fill pressures and discharge currents. The spectrum was recorded by both visible and VUV spectrometers simultaneously.



Spectral Lines

Visible		Vacuum Ultra Violet	
He I	He II	He I	He II
3889.7 A^0	4685 A^0	522.2 A^0	303.9 A^0
3965.7 A^0		537 A^0	
4714.8 A^0		584.4 A^0	
4923.2 A^0			
5049.0 A^0			
5877.5 A^0			
6680.0 A^0			
7067.6 A^0			
7283.3 A^0			

We use Collision-Radiative Model for our further analysis.

Model

- The Spectral line intensity of a particular transition can be written as

$$I = \frac{1}{4\pi}\left\{\overline{PEC}_{recombining} N_e \tilde{N}_i + \overline{PEC}_{excitation} N_e \tilde{N}_g + \overline{PEC}_{metastable} N_e \tilde{N}_M\right\}$$

- Here PECs are the effective photon emission coefficients (photons cm^3 sec^{-1}) for recombination, excitation processes and metastable contributions respectively in an average measurement.

- These PECs are the complicated function of Ne and Te and are be obtained from the ADAS data - base.

First Approach

- Grid of N_e ranges from 1×10^{10} to 1×10^{13} cm^{-3}
- Grid of T_e ranges from 1 to 100 eV and restricted for the positive values for N_g and $N_{m.}$
- Assuming Quasi-Neutrality i.e. $N_i \approx N_e$

$$\tilde{I}(7283.3)_{expt} = \frac{1}{4\pi}\left\{PE\overline{C}_{reco1}N_e\tilde{N}_i + PE\overline{C}_{excit1}N_e\tilde{N}_g + PE\overline{C}_{meta1}N_e\tilde{N}_M\right\}$$

$$\tilde{I}(7067.6)_{expt} = \frac{1}{4\pi}\left\{PE\overline{C}_{reco2}N_e\tilde{N}_i + PE\overline{C}_{excit2}N_e\tilde{N}_g + PE\overline{C}_{meta2}N_e\tilde{N}_M\right\}$$

L is 1 cm in our case

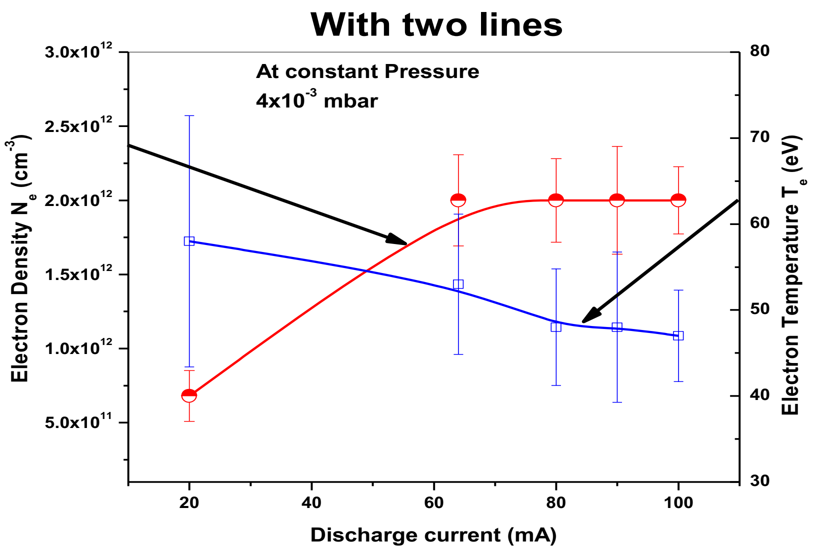
Define a mismatch parameter

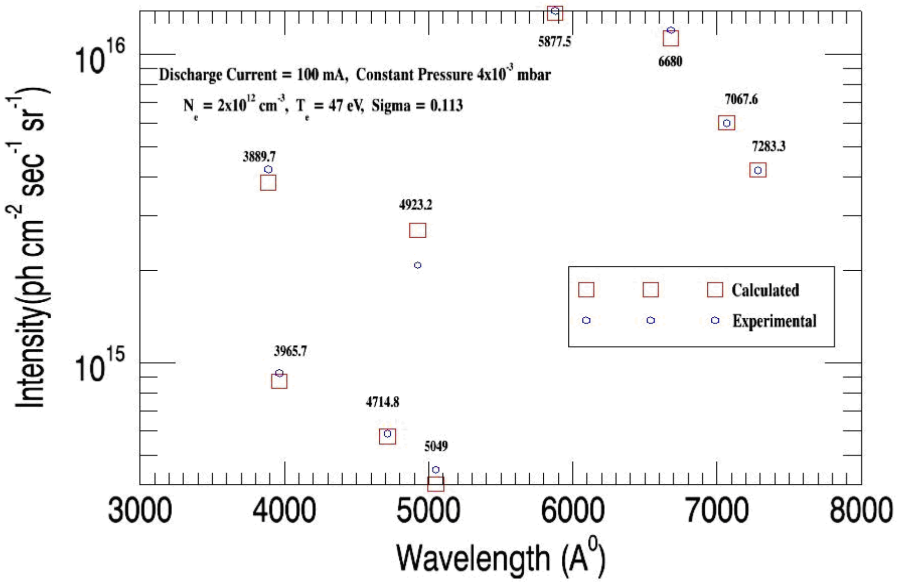
$$\sigma = \sqrt{\mathrm{Mean}\left(\frac{I_{exp} - I_{cal}}{I_{exp}}\right)^2}$$

We found all the aforesaid unknown parameters at minimum σ.

Problem with first approach:

- Getting higher temperature.
- Will not give the unique solution.





Second Approach:

Which processes are responsible for emissivity?

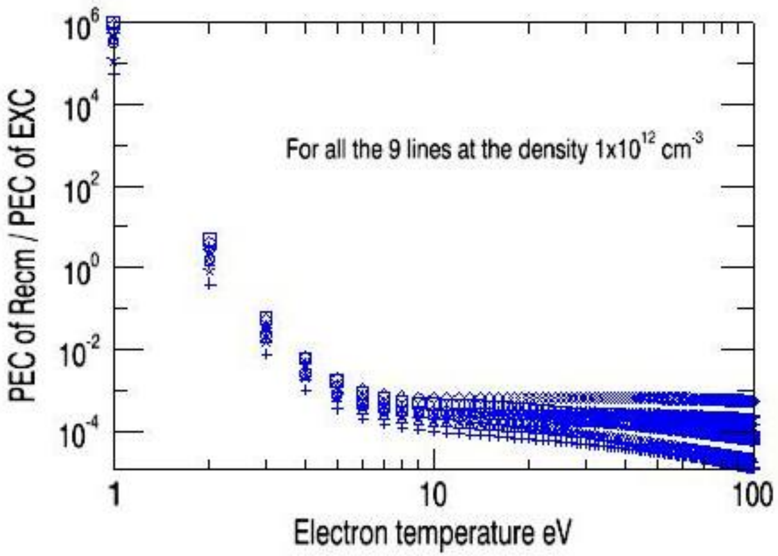
- Grid of N_e from $1x10^{10} – 9x10^{12}$ cm^{-3}.
- Grid of T_e from 1 – 100 eV.
- Take the ratio for all the lines.

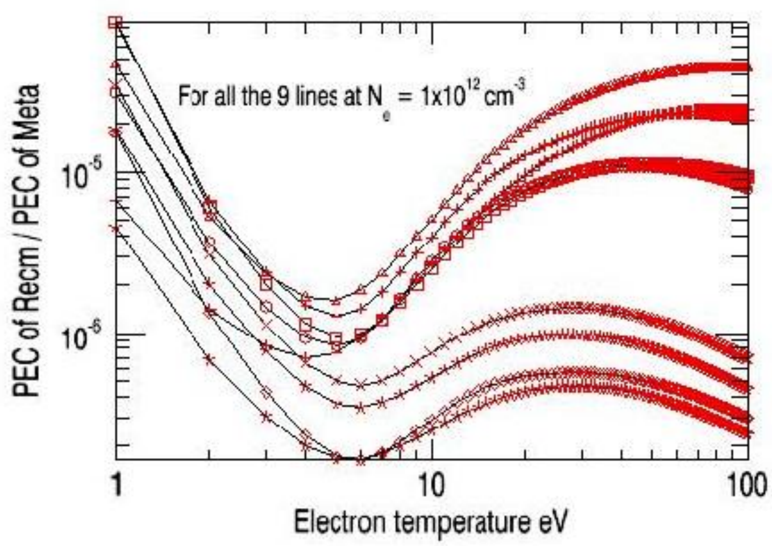
Assumption:

- $N_g > N_i$ and $N_g > N_m$

$$R1 = \frac{PEC_{Reco}}{PEC_{Exc}} \approx 10^{-4}, \quad R2 = \frac{PEC_{Reco}}{PEC_{Meta}} \approx 10^{-5}$$

⇨ Recombination process can be neglected for all the lines above 3 eV and it is a good approximation for plasma to be taken purely ionizing.

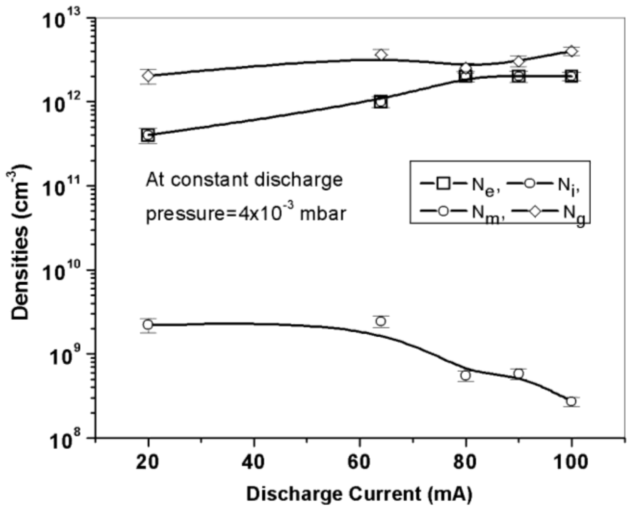


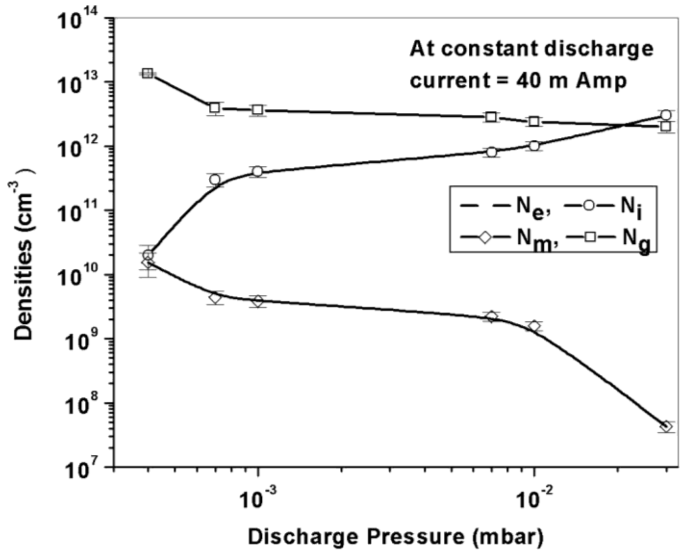


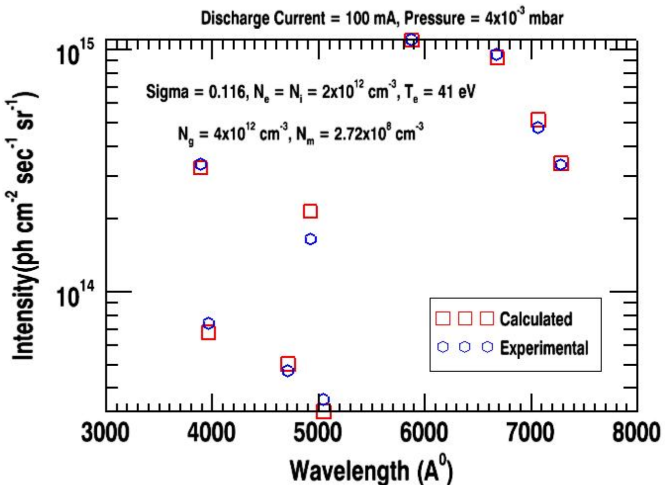
Second Approach Cont.

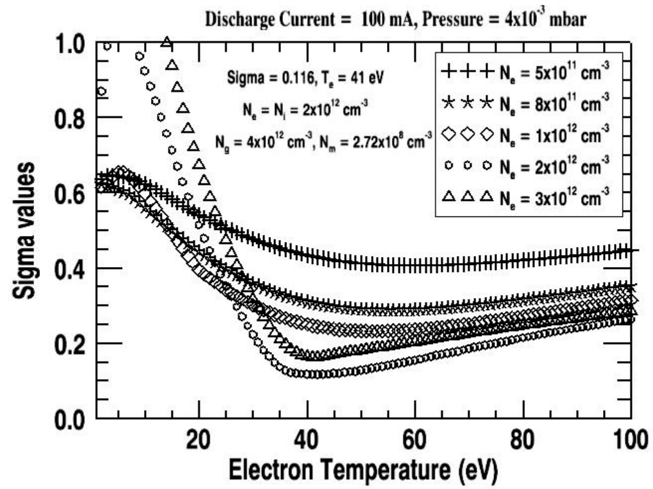
- ➢ Use of Singular Value Decomposition (SVD) technique.

- ➢ SVD is useful for the over determinant problems, i.e. number of equations is greater than the number of unknowns.









Flow chart of calculations

Write the spectral line intensity using full collisional-radiative model with $N_e \approx N_i$

↓

Drive PECs values for the given values of N_e and T_e

↓

Calculate the values of N_g and N_m using SVD technique.

↓

Calculate the intensities at each value of N_g and N_m

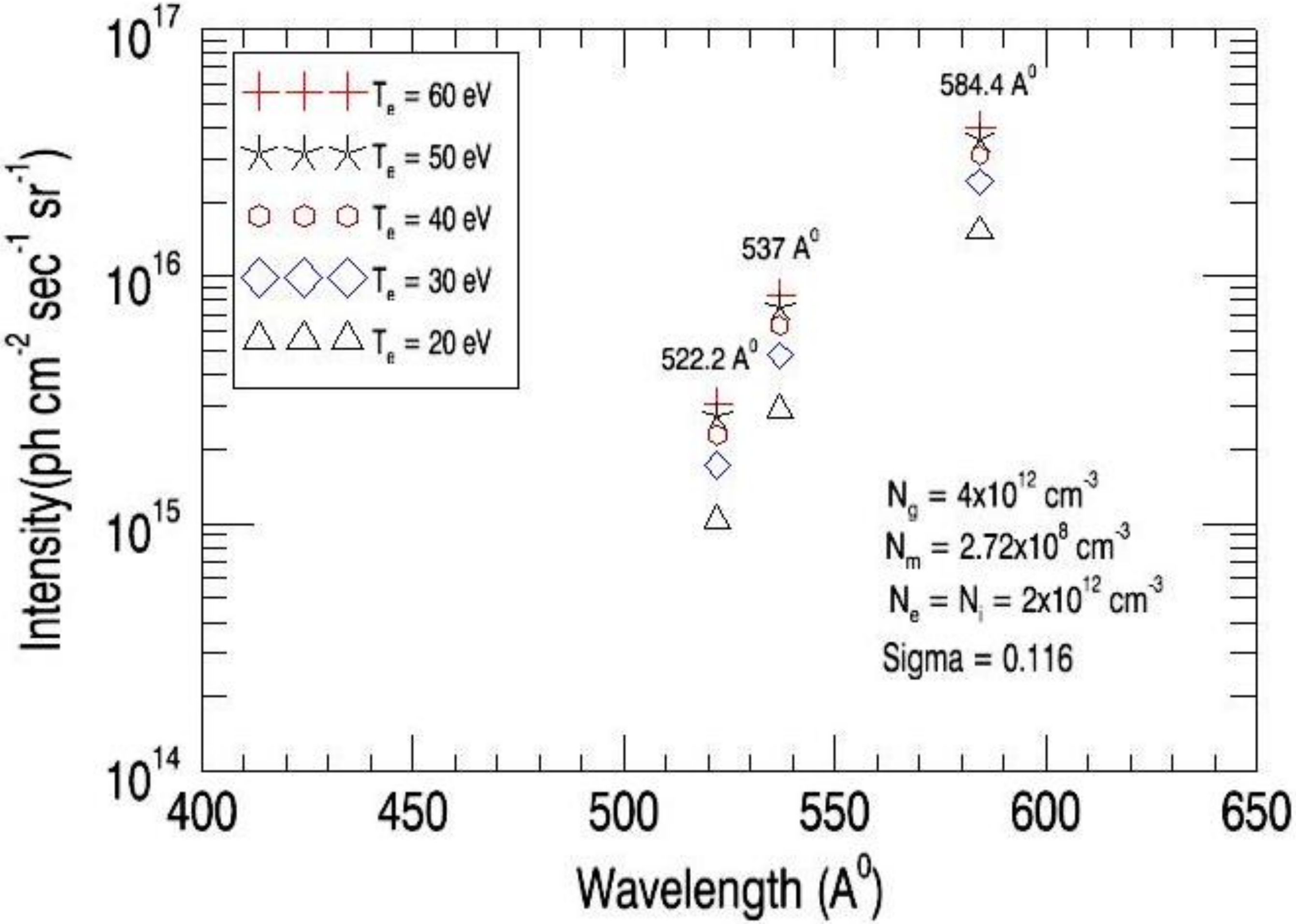
↓

Define a mismatch parameter

↓

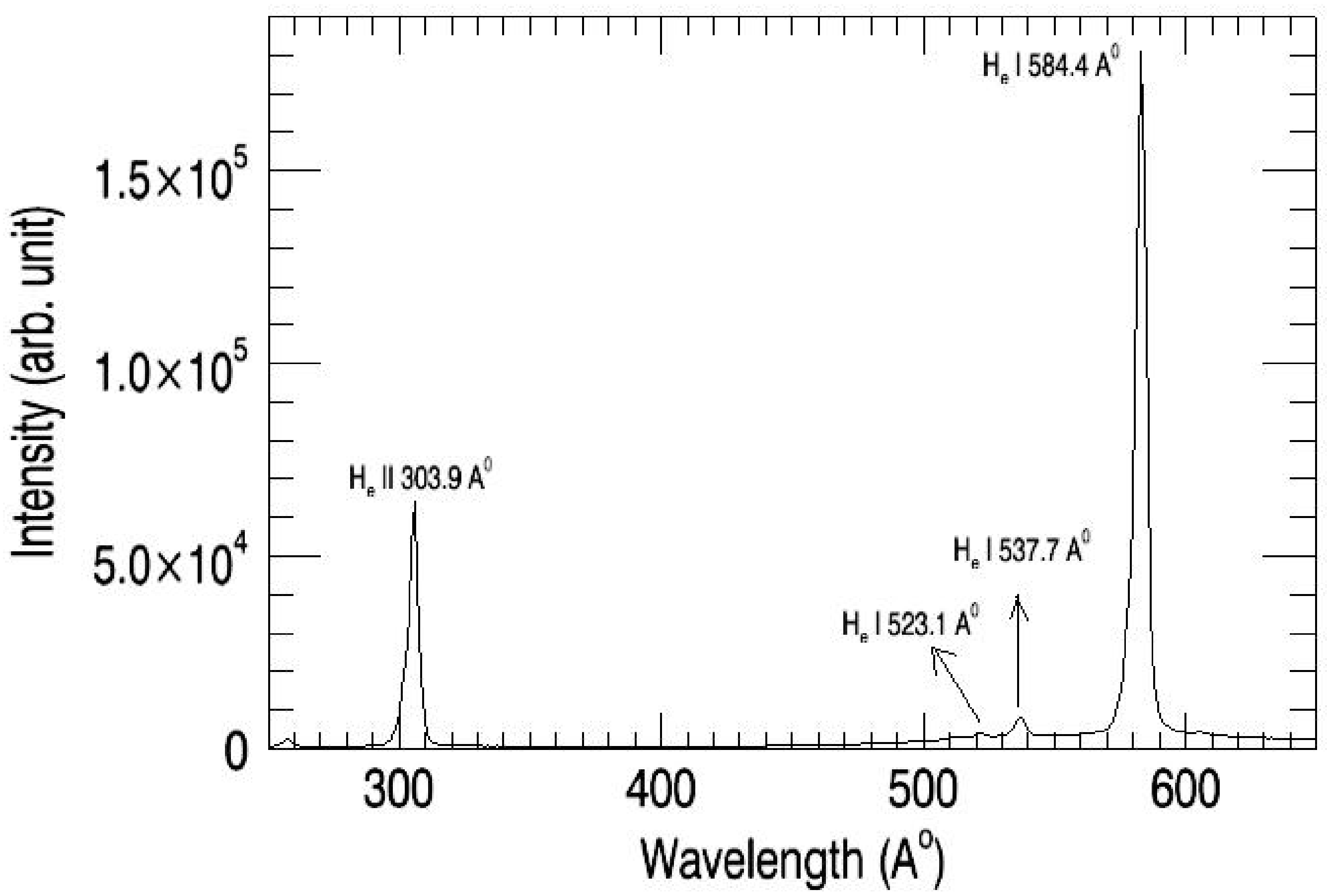
Print the unknown parameters at minimum mismatch parameter

Temperature Dependency of calculated VUV intensities.

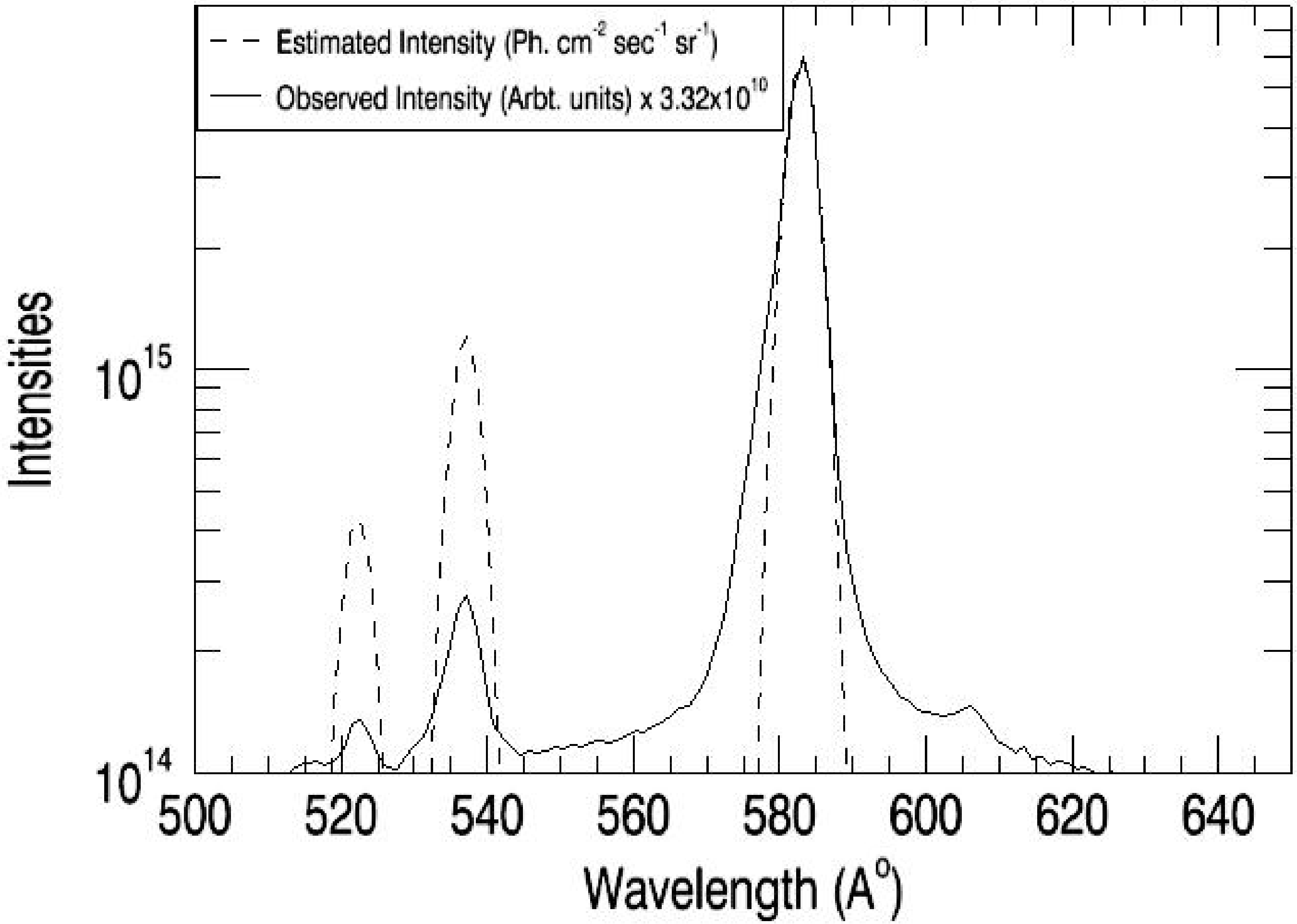


VUV calibration scheme

Observed VUV spectra

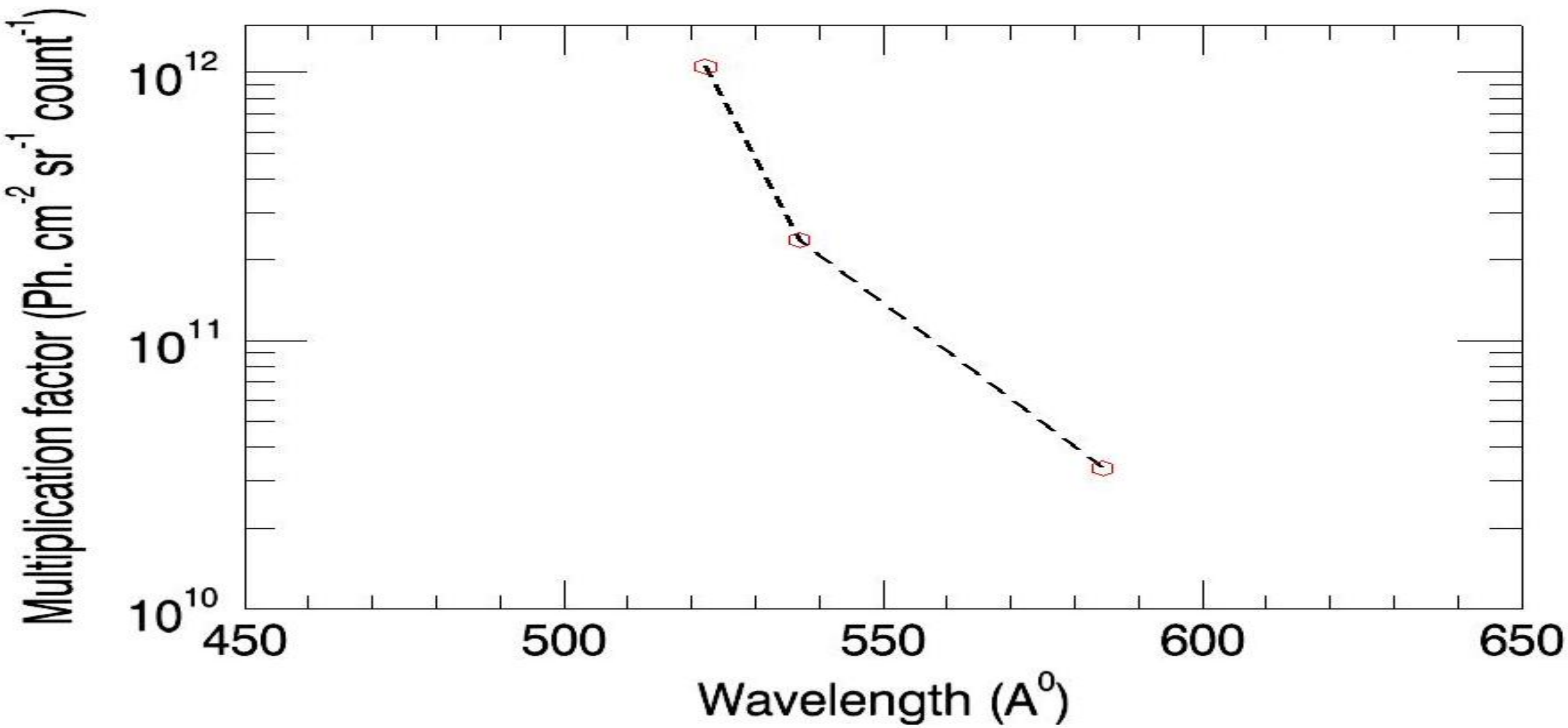


Determination of Multiplication factors



$M_{522.2} \sim 1x10^{12}$, $M_{537} \sim 2x10^{11}$, $M_{584.4} \sim 3x10^{10}$

The calibration curve for VUV spectrometer



Results

- The PD plasma source was operated at various fill pressures and discharge currents.

- The best fit values of σ for fill pressures $3x10^{-2}$ mbar, $1x10^{-2}$ mbar, $7x10^{-3}$ mbar, $4x10^{-3}$ mbar, $1x10^{-3}$ mbar and $4x10^{-4}$ mbar (at constant discharge current 40 mA) are 0.20, 0.16, 0.14, 0.20, 0.23, and 0.41 respectively.

- The best fit values of σ for different discharge currents 20 mA, 50 mA, 64 mA, 80 mA, 90 mA and 100 mA (at constant fill pressure $4x10^{-3}$ mbar) are 0.20, 0.23, 0.15, 0.14, 0.15, and 0.116.

- The values of N_e and N_m are similar to results obtained in other studies [1-2]. The values of T_e are rather high (T_e ~ 41 eV) .

J. Phys. B: At. Mol. And Opt. Phys. 43 (2010) 144012 (5pp)

[1]. Anduczyk D, Feng P X, James B W and Howard J 2002 *Plasma Sources Sci. Technol. 11 426–30.*

[2]. Feng P X and Weiner B 2004 *J. Phys. B: At. Mol. Opt. Phys.* 37 3265–9

- The higher temperature indicates that there is some thing missing in the model. It may be diffusion processes or it may be opacity effect or it may be both the processes which should be taken into account in the model. Let us first consider opacity effects in plasmas.

- We are looking for the opacity effects on different lines and some of the results are given on next slides.

Third Approach: Opacity Modeling

- The radiation emitted from a region in plasma may absorbed at some other places in plasmas and this re-absorption will change the population of excited states and results a net change in effective rate coefficients (PECs).

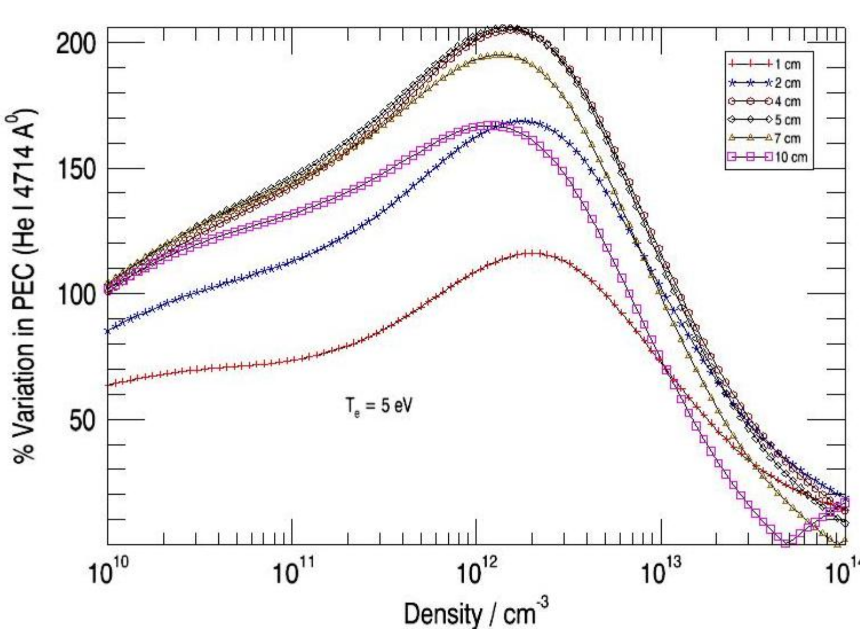
- This change in effective rate coefficients may change the obtained plasma parameters.

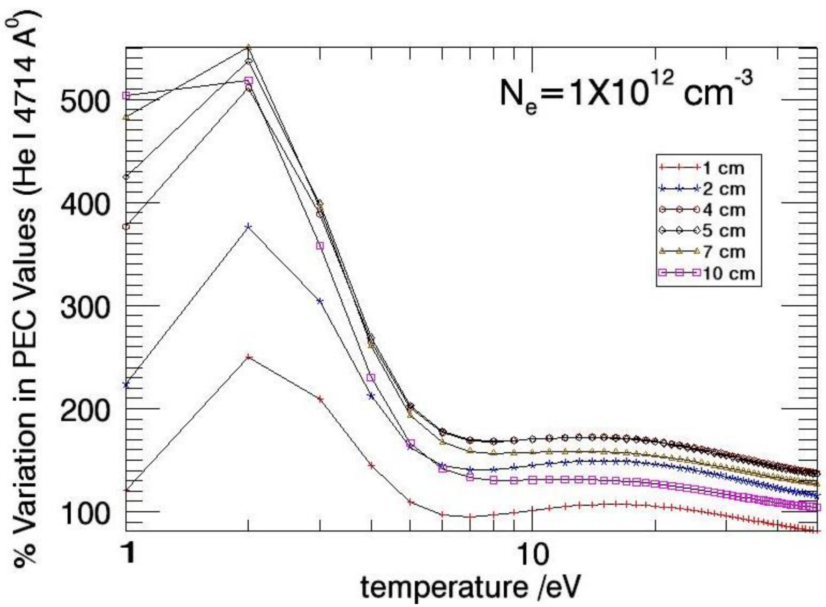
- We used escape factor method using ADAS code to see the effect of opacity in plasma.

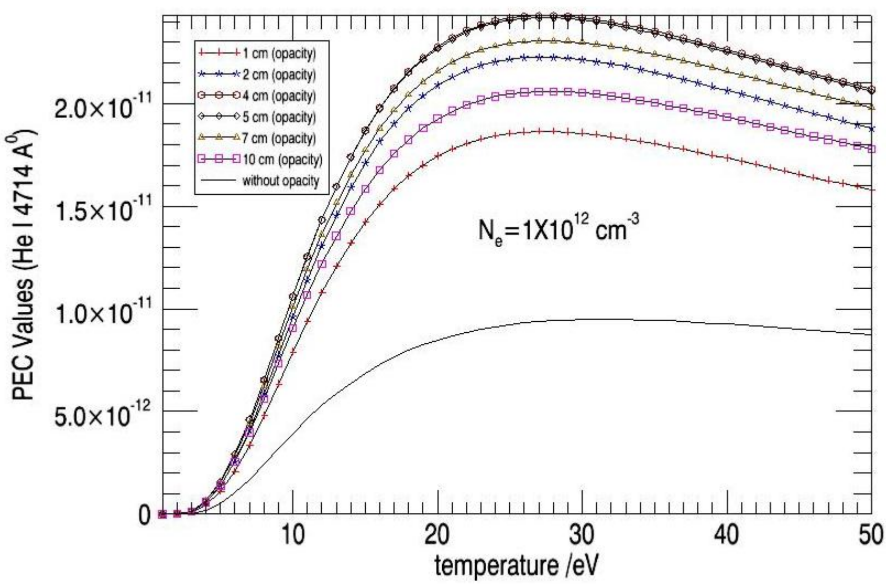
- The population escape factors are obtained. The following input parameters are used: atomic mass number, electron temperature (this is only used to calculate the Boltzmann density distribution i.e. ~8 eV), gas temperature (~600 ^{0}K), neutral density (~10^{13}), length of plasma *b* (1-10 cm), aspect ratio (0.5), plasma geometry (cylindrical), line profile (Doppler) and type of density distribution across plasma (parabolic).

- Some of the results of the opacity affected PECs are as follows.

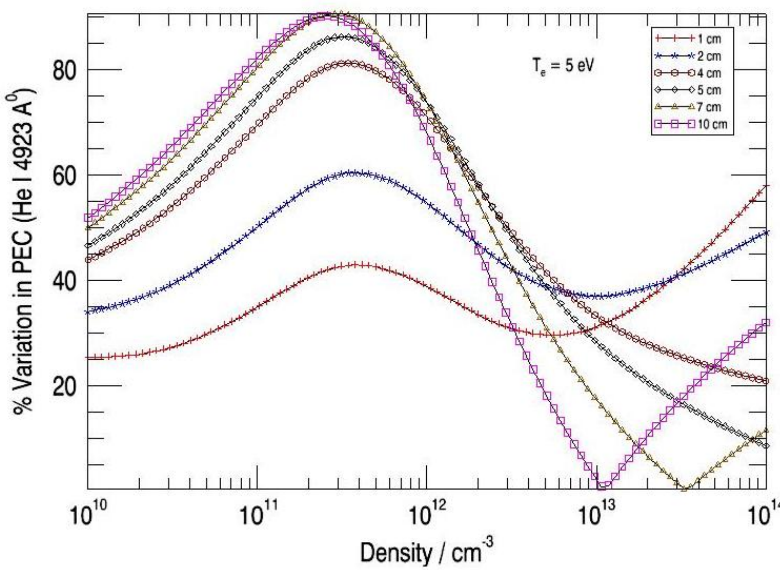
Opacity effect on the line 4714 Å (Excitation case)

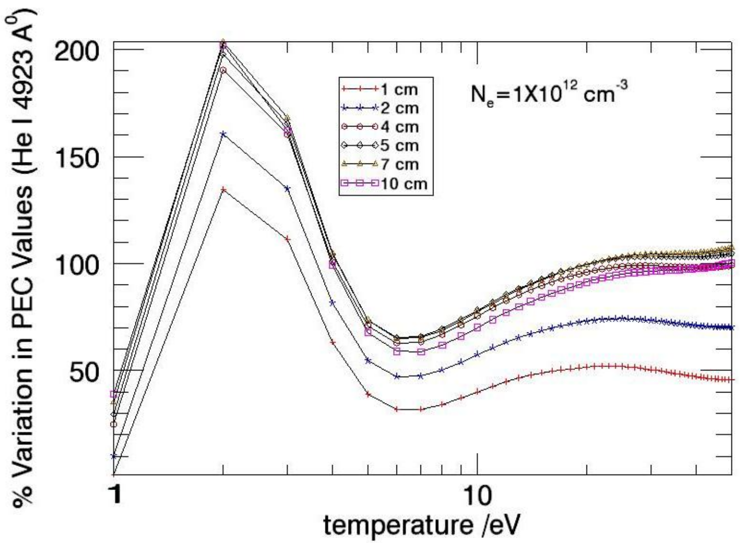


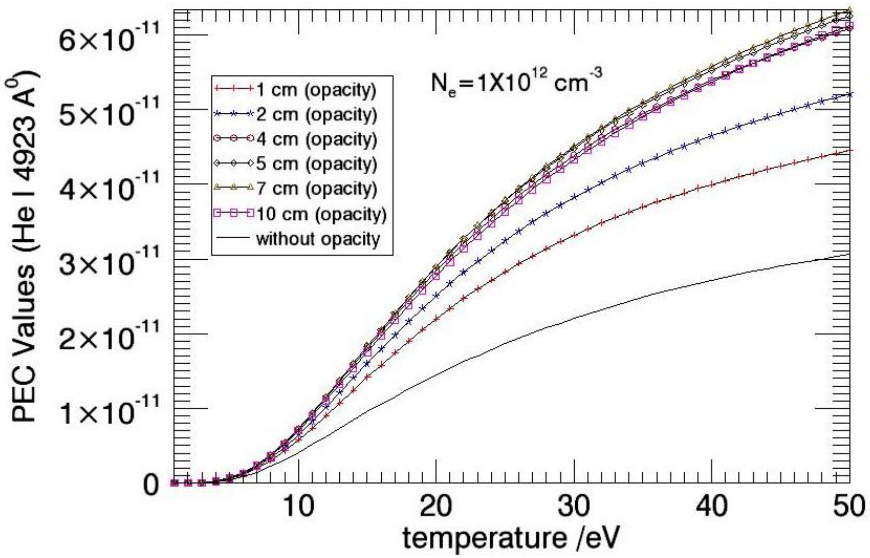




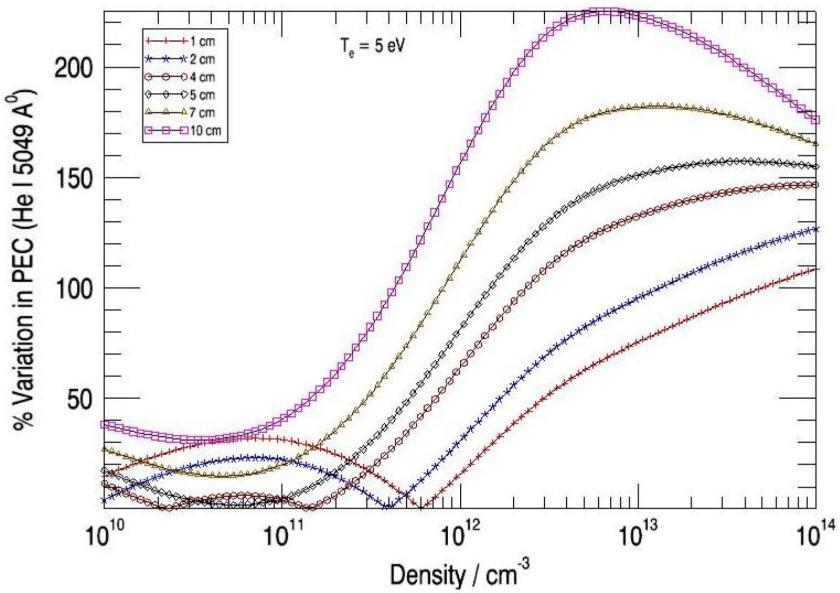
Opacity effect on the line 4923 Å (Excitation case)

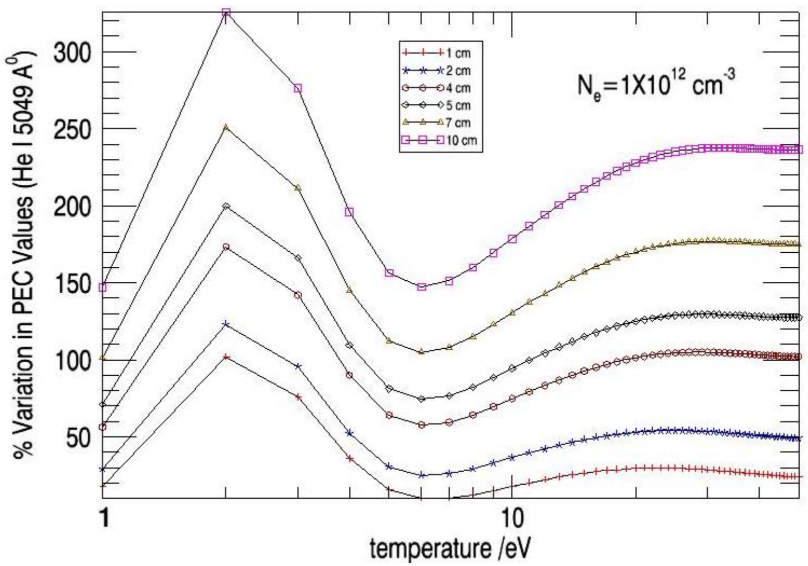


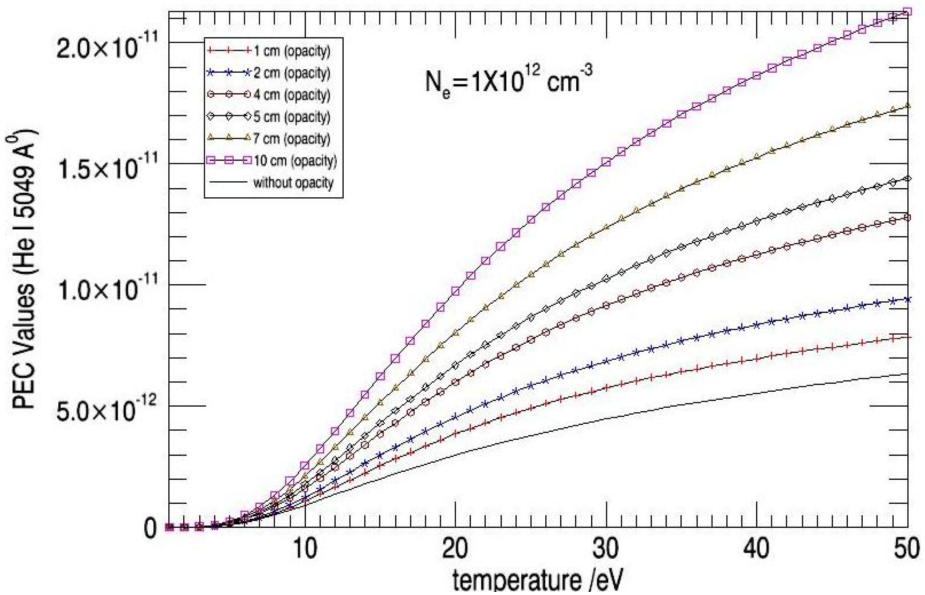




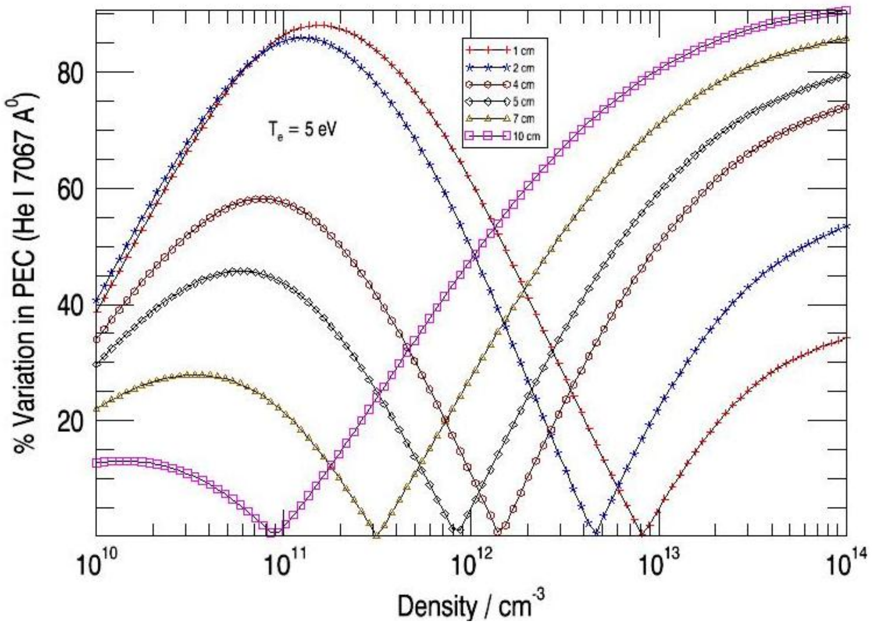
Opacity effect on the line 5049 Å (Excitation case)

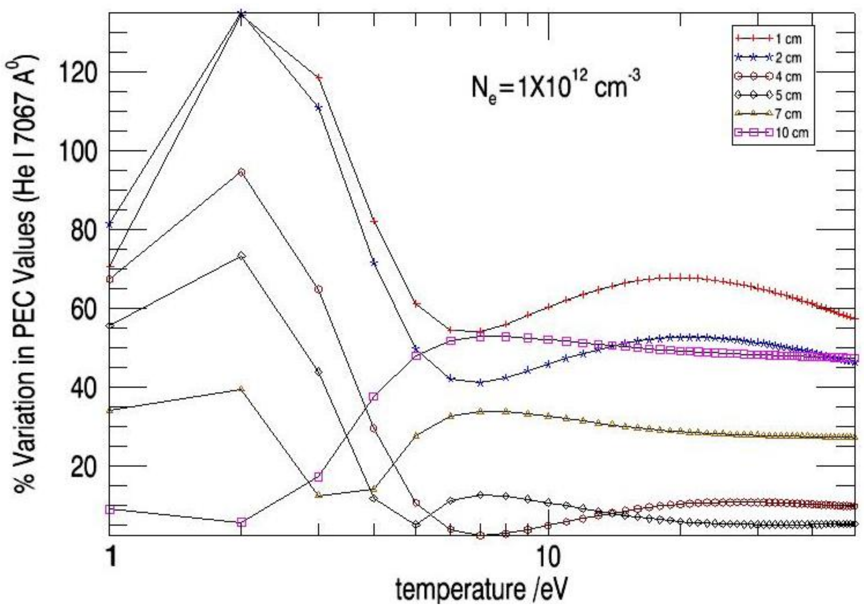


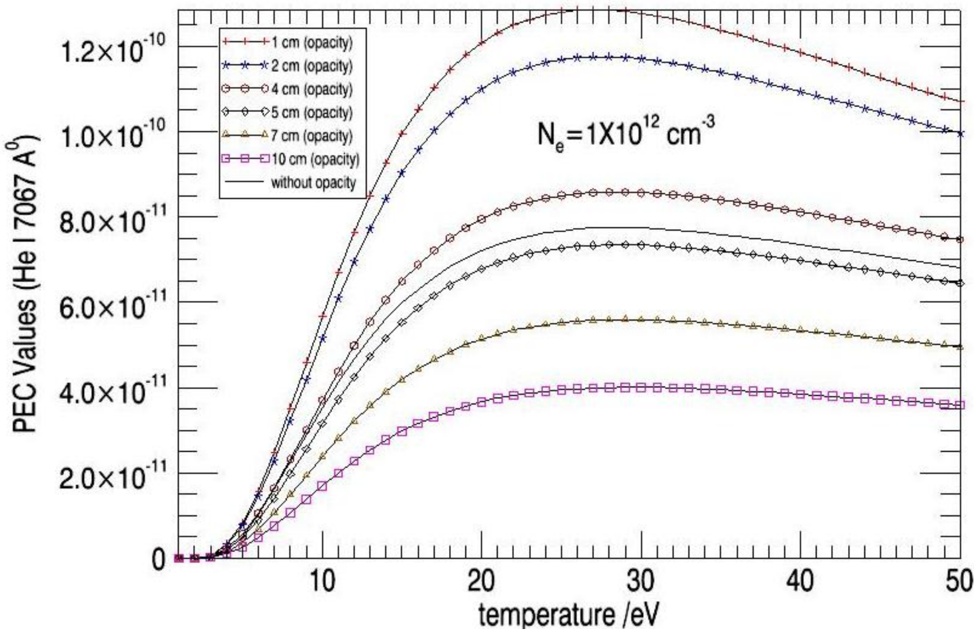




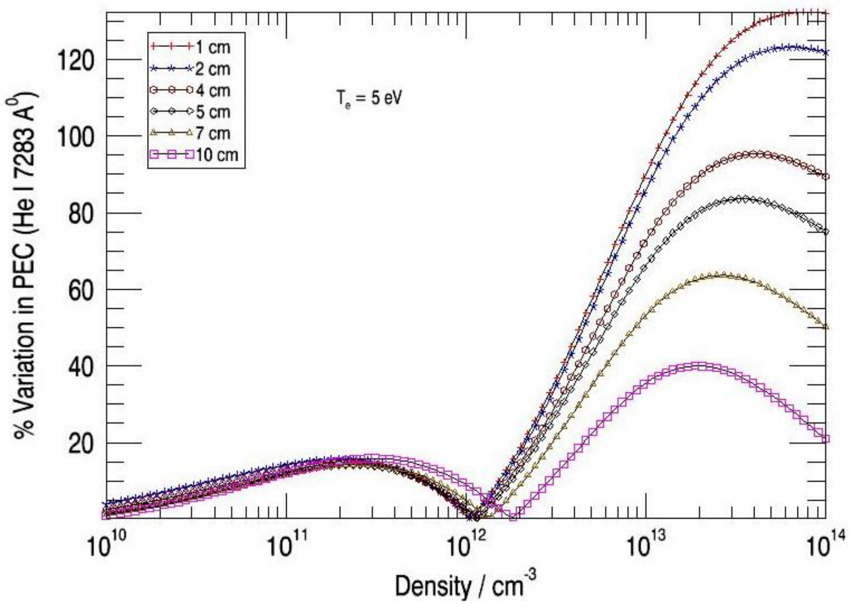
Opacity effect on the line 7067 (Excitation case)

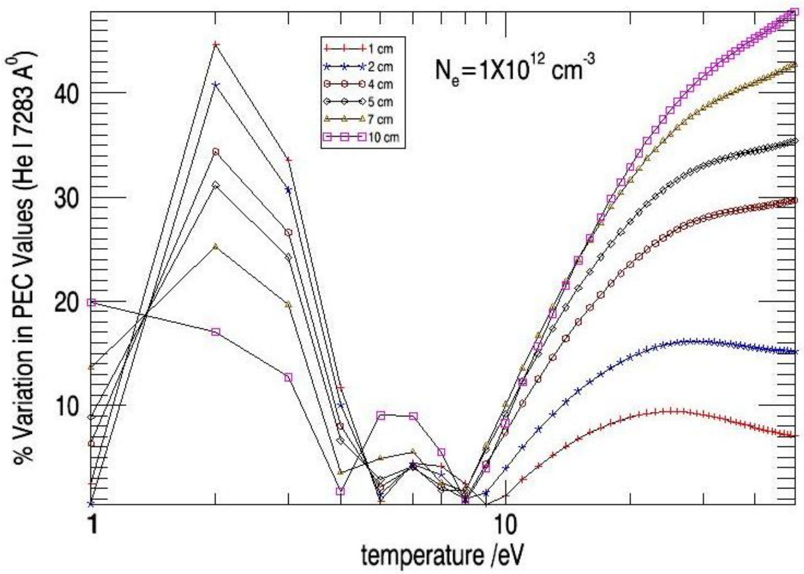


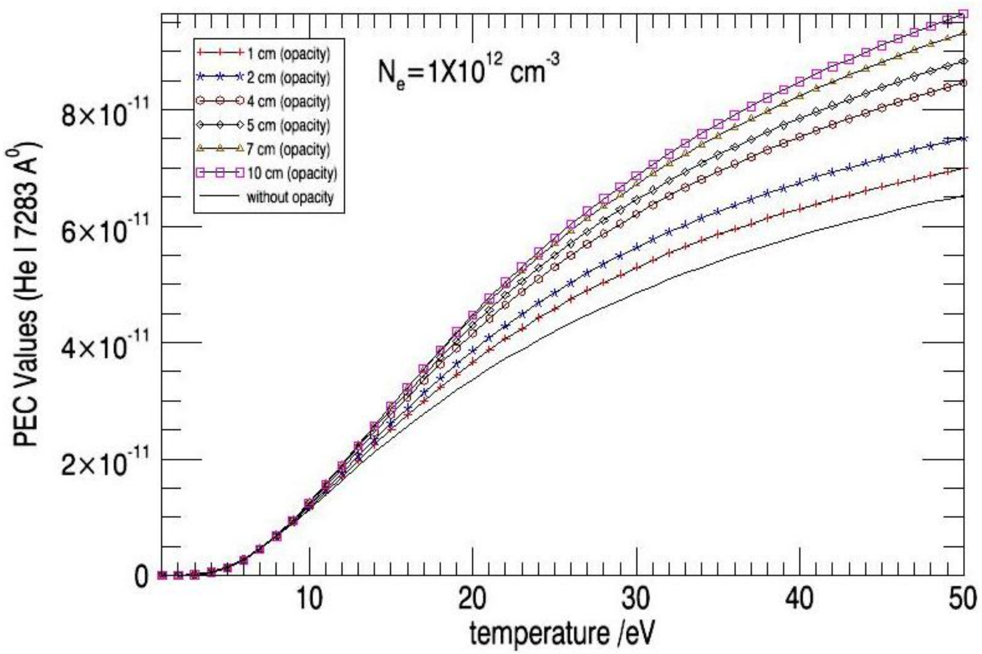




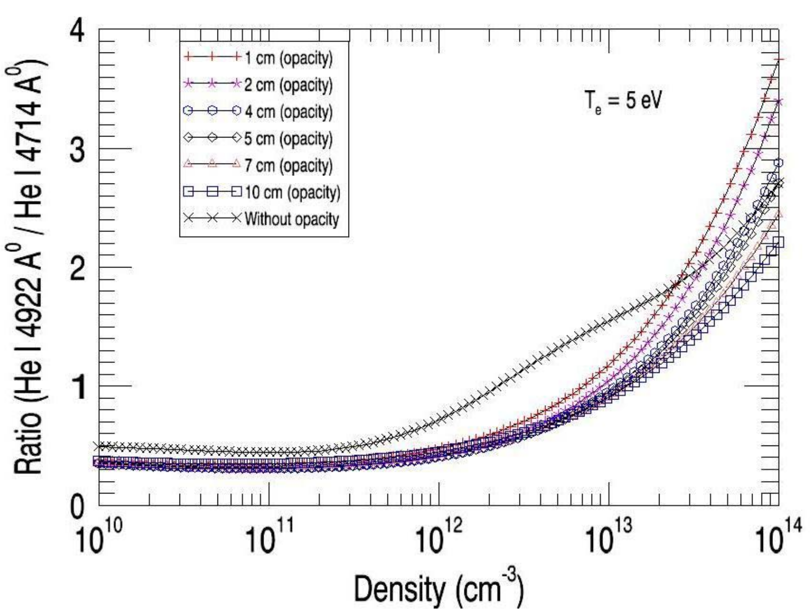
Opacity effect on the line 7283 Å (Excitation case)

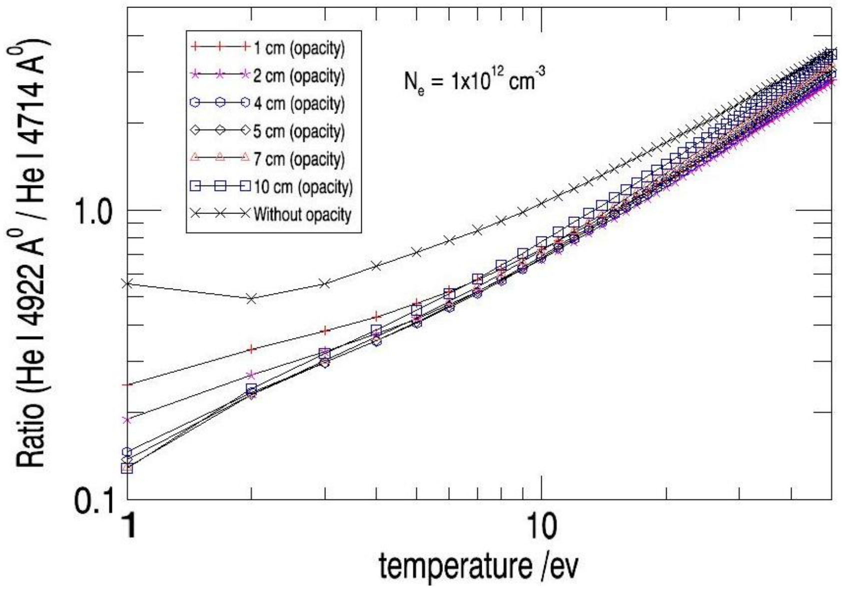


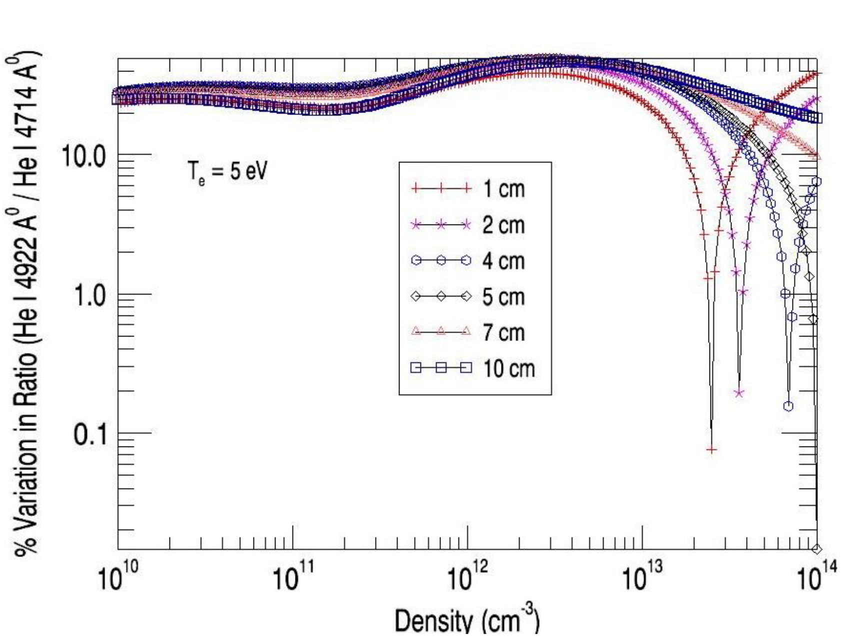


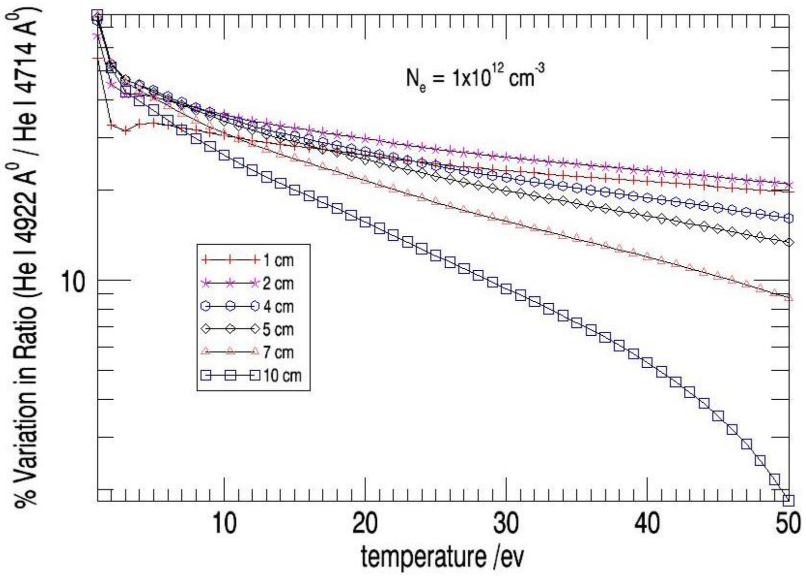


Opacity Effect on the ratio 4922/4714

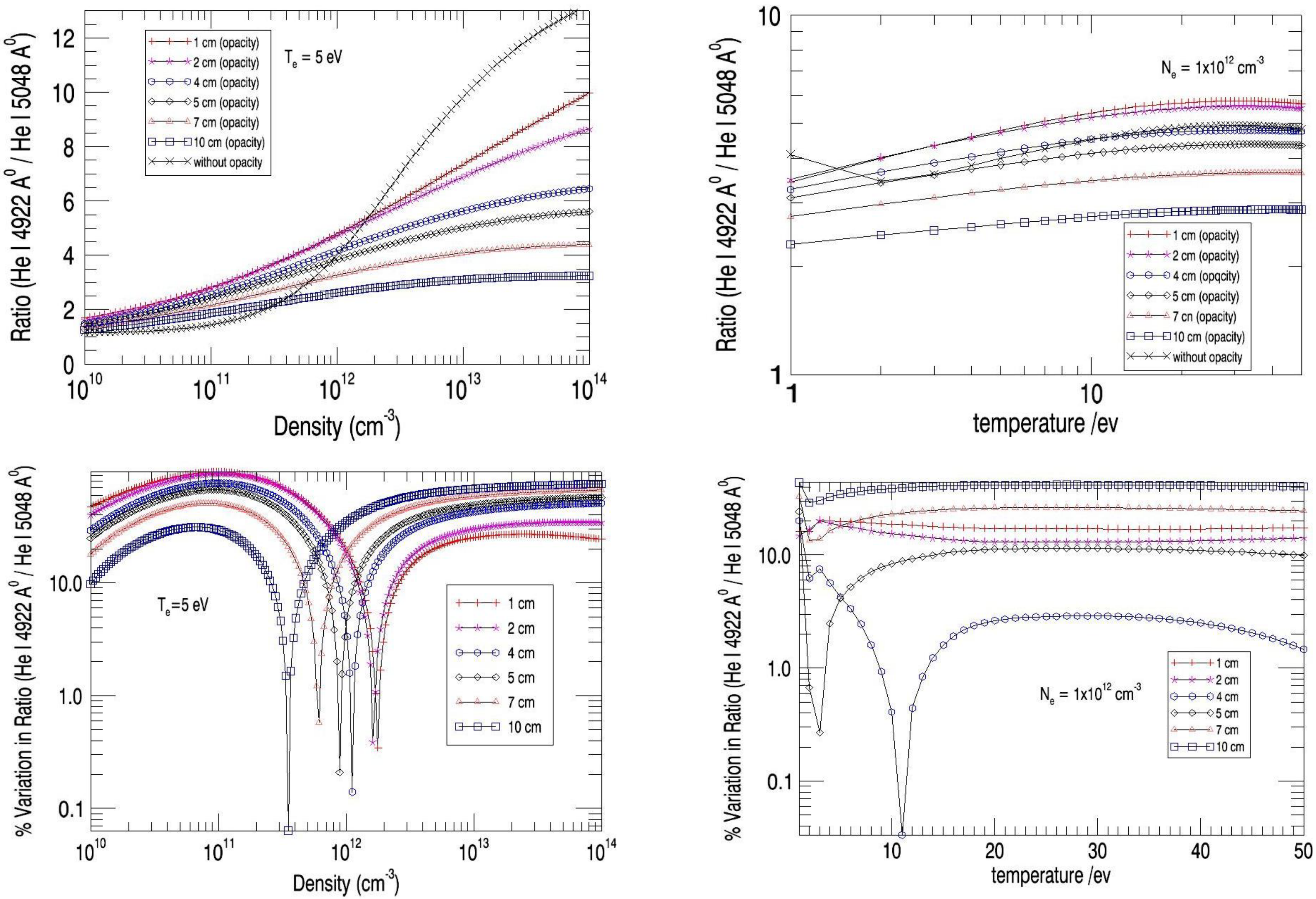




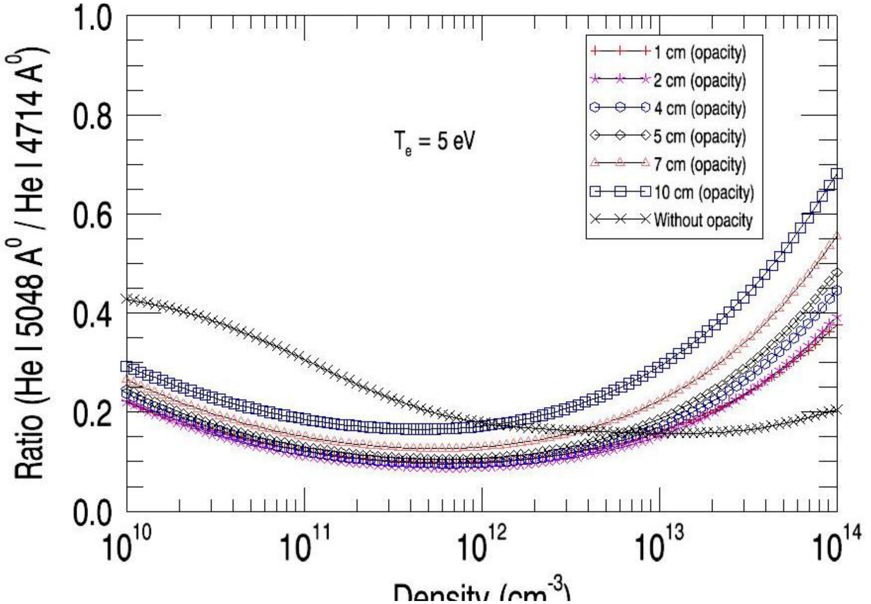


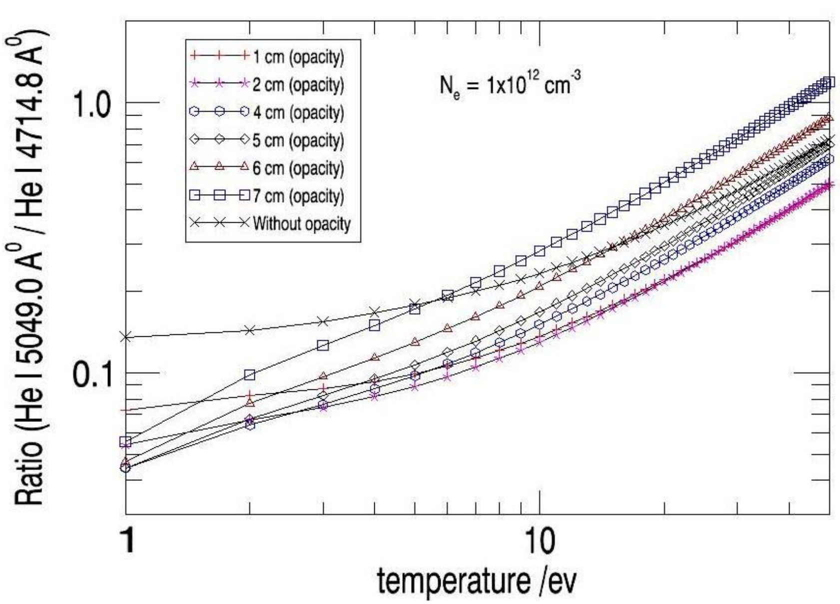


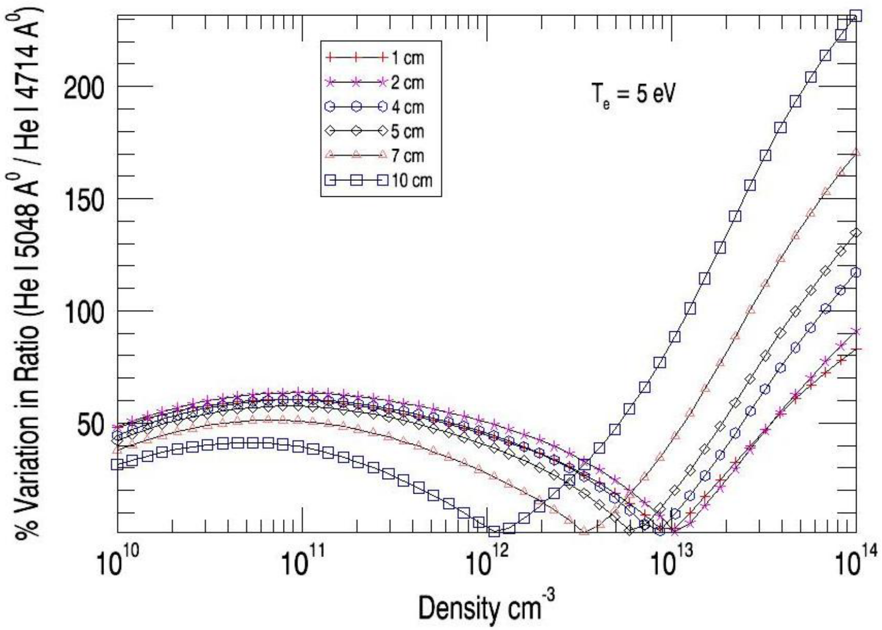
Opacity Effect on the ratio 4922/5048

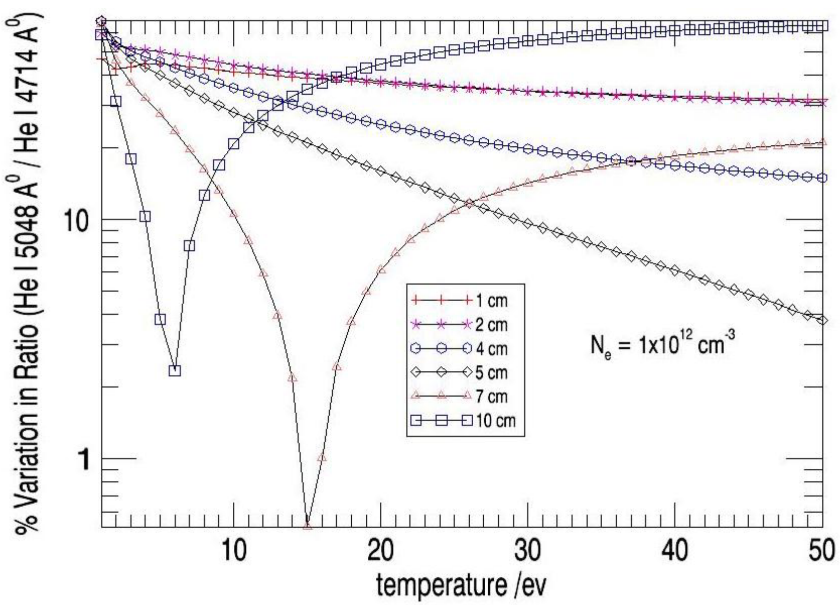


Opacity Effect on the ratio 5048/4714

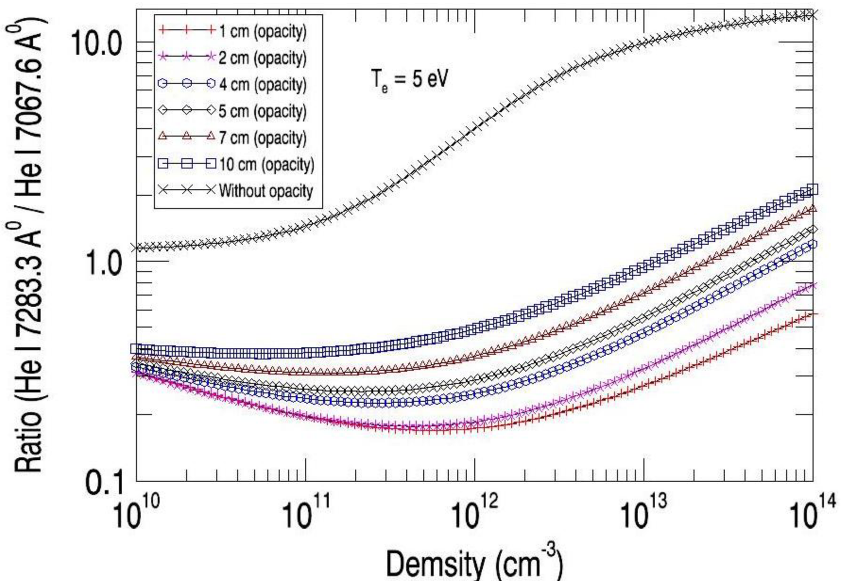


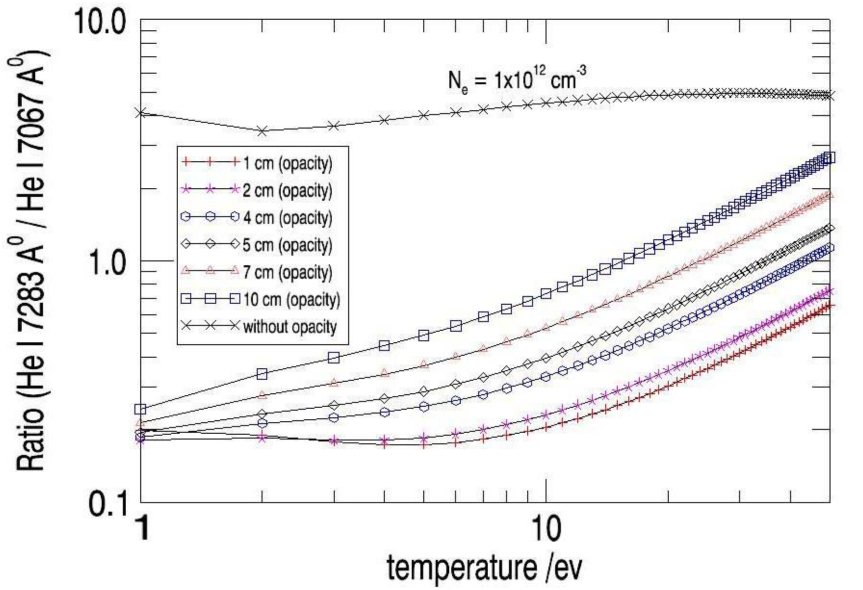


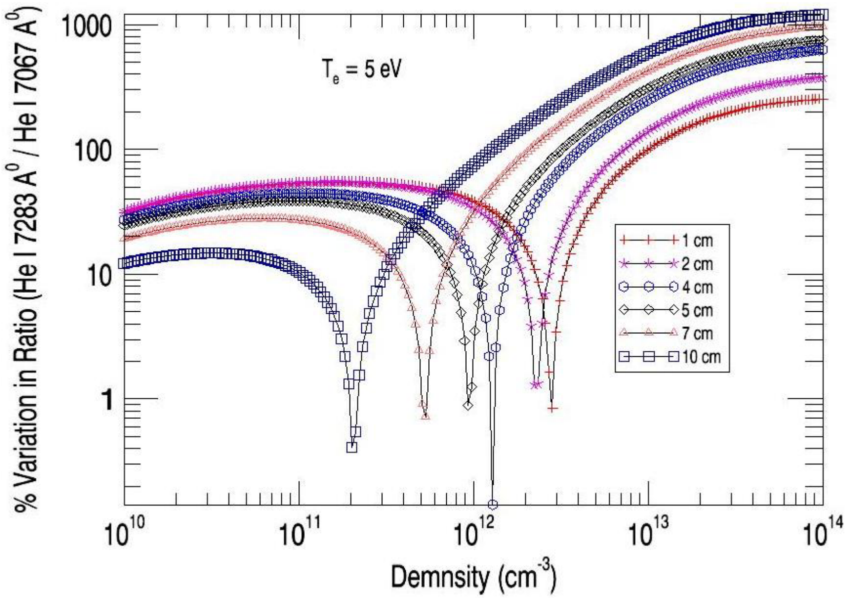


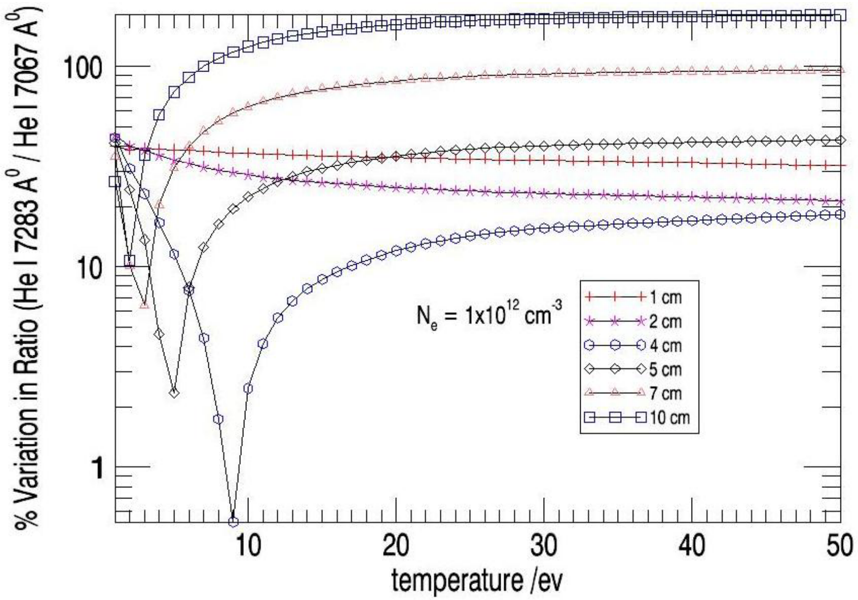


Opacity Effect on the ratio 7283/7067









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Thanks for your Kind patience.