# Determination of the metastable and resonance excited atomic states populations in CCP Ar discharge using OES techniques.

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In this work populations of the first two metastable and first two resonant atomic states in CCP Ar discharge have been measured using two independent optical emission methods. The first method is based on the comparison of radiation self-absorption effects for plasmas with two different effective sizes. The second method is based on the measurements of intensity ratios of certain lines which are sensitive to plasma parameters. It was shown, that the first method is preferable to use. The dependences of level populations on the different plasma parameters were obtained. For description of such populations' behaviors the collisional-radiative model, containing the first 14 exited atomic states in Ar, has been built. The behaviors of level densities on plasma parameters in gas mixtures (we added H2, N2 and O2 gases to pure Ar) were also investigated.

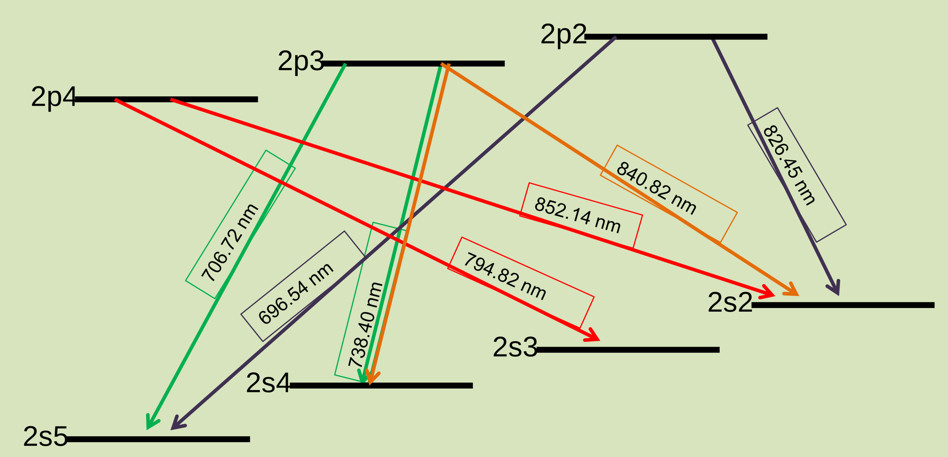
## Two spectroscopic methods

### Method 2 (based on the measurements of intensity ratios of certain lines)

$$\frac{I_{ij}}{I_{ik}} = f(n_j, n_k)$$

*$I_{ij}$ – intensity of i-j line, $n_j$ – concentration of level i*

**Four intensity ratios provide set of equations with four unknown lower level concentrations.**




*Example of pairs of lines, which can be used to obtain 1s5, 1s4, 1s3 and 1s2 concentrations*

| Δ = 10% | \|Δ(1s5)\| | \|Δ(1s4)\| | \|Δ(1s3)\| | \|Δ(1s2)\| |
|---|---|---|---|---|
| Δ (I_696 нм) | 43,94% | 53,36% | 10,43% | 79,28% |
| Δ (I_706 нм) | 16,76% | 47,83% | 9,60% | 74,19% |
| Δ (I_738 нм) | 0,98% | 31,26% | 0,47% | 3,08% |
| Δ (I_794 нм) | 0,00% | 0,00% | 14,23% | 0,00% |
| Δ (I_826 нм) | 41,13% | 41,29% | 8,20% | 65,83% |
| Δ (I_840 нм) | 18,62% | 23,80% | 10,18% | 77,36% |
| Δ (I_852 нм) | 0,00% | 0,00% | 15,02% | 0,00% |

*Estimates of level densities errors for the case of 10% line intensities uncertainness.*

**The table shows that 10% error of line intensity may lead to significant changes in calculated level populations densities. That is the reason, why this method was not chosen to use in our experiment.**

### Method 1 (based on the comparison of radiation self-absorption effects for plasmas with two different effective sizes)

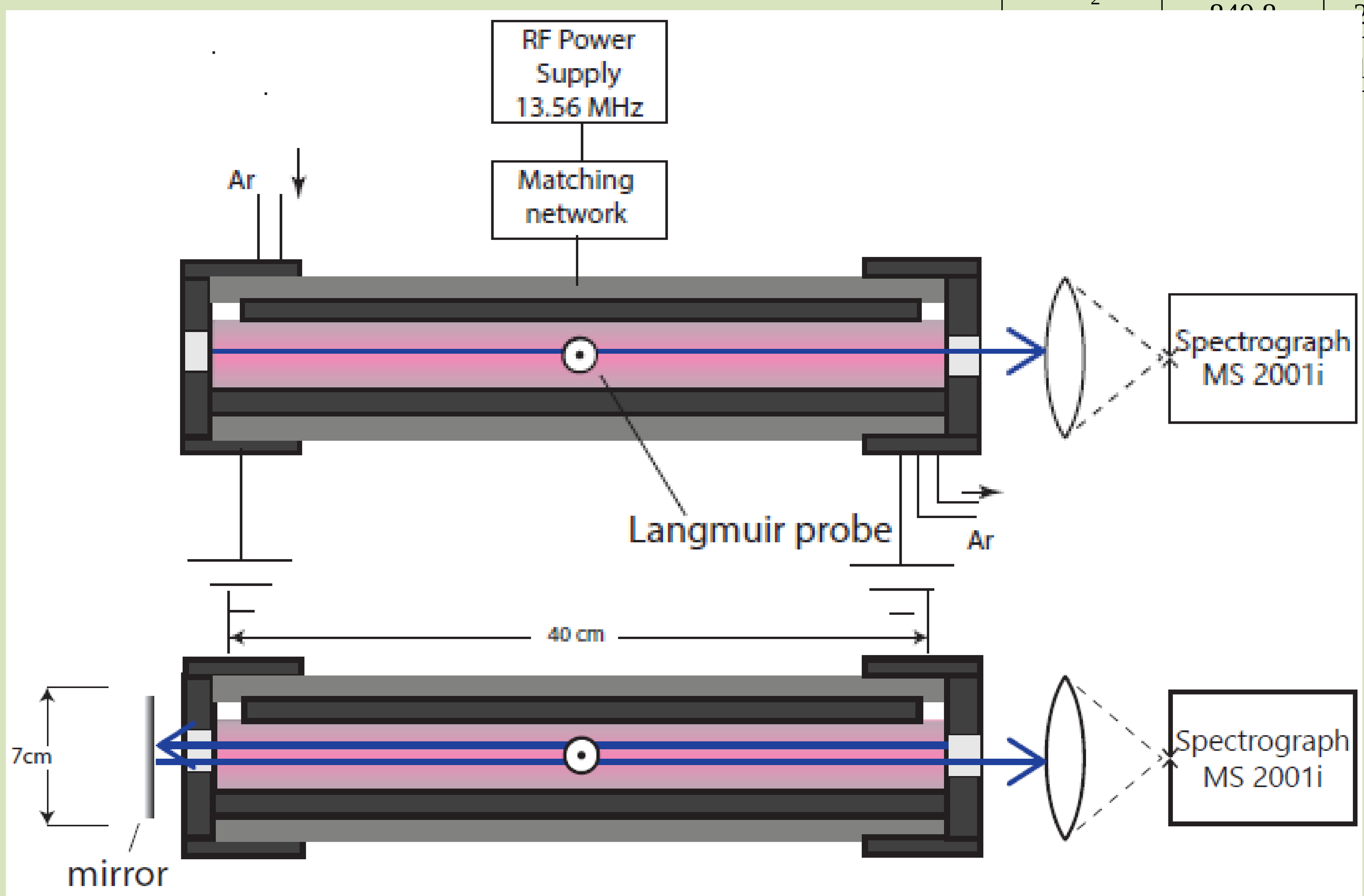
$$\frac{I_m}{I_{nm}} = f(n_i, A_{ij}, \lambda_{ij}, g_i, g_j, l, r)$$

$$\frac{I_m}{I_{nm}} = r*\left(\frac{\int(1-\exp(-k_{ij}(\Delta\nu)*2l))d\nu}{\int(1-\exp(-k_{ij}(\Delta\nu)*l))d\nu}-1\right)+1$$

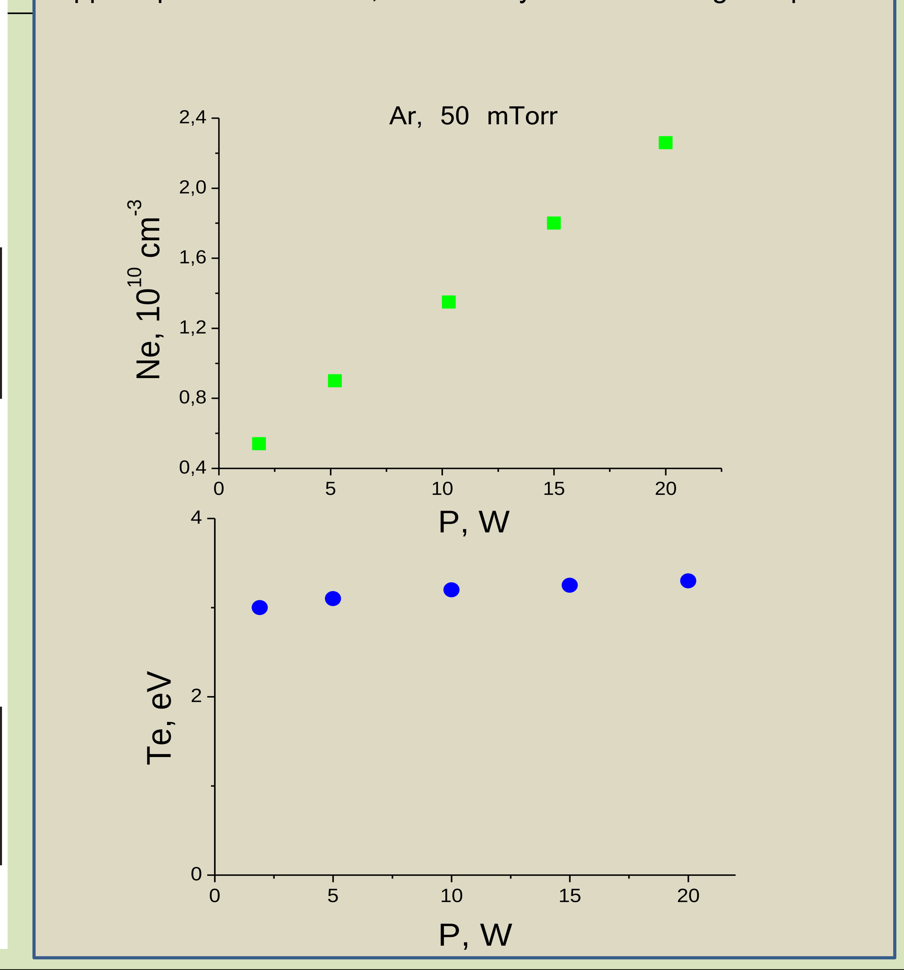
*$I_m$ – line's intensity measured with mirror, $I_{nm}$ – line's intensity measured without mirror, $n_i$ – concentration of level i, $A_{ij}$ – Einstein coefficient, $\lambda_{ij}$ – wavelength of i-j line, $g_i$ – statistical weight of level i, $l$ – effective plasma size, $k_{ij}$ – absorption coefficient, $r$ – effective reflection coefficient of the mirror.*

**Usage of different lines based on the same lower level provides set of independent measurements of this level populations.**

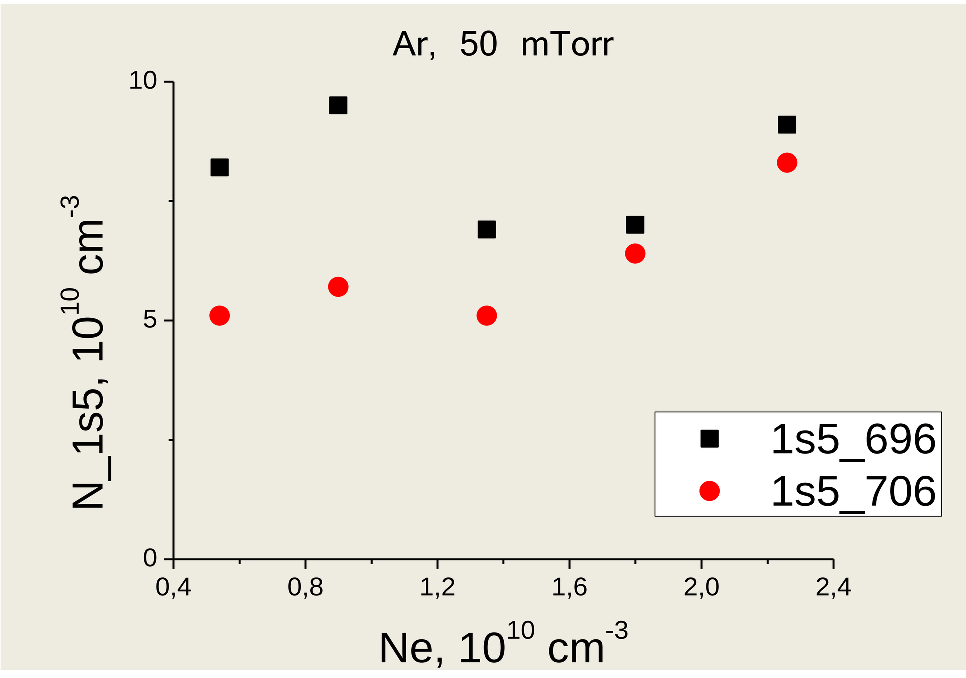
| N | $\lambda_{ij}$, nm | $A_{ij}$, $c^{-1}$ | $E_i$, eV | $E_j$, eV | $g_i$ | $g_j$ |
|---|---|---|---|---|---|---|
| $1s_5$ | 696.5 | 6.39E+6 | 11.55 | 13.33 | 5 | 3 |
| | 706.7 | 3.80E+6 | | 13.30 | | 5 |
| | 763.5 | 2.45E+7 | | 13.17 | | 5 |
| | 811.5 | 3.31E+7 | | 13.07 | | 7 |
| $1s_4$ | 738.4 | 8.47E+6 | 11.62 | 13.30 | 3 | 5 |
| | 751.5 | 4.90E+6 | | 13.27 | | 1 |
| | 810.4 | 2.50E+7 | | 13.15 | | 3 |
| | 842.5 | 2.15E+7 | | 13.09 | | 5 |
| $1s_3$ | 794.8 | 1.86E+7 | 11.72 | 13.28 | 1 | 3 |
| $1s_2$ | 750.4 | 4.45E+7 | 11.83 | 13.48 | 3 | 1 |
| | 826.4 | 1.53E+7 | | 13.33 | | 3 |
| | [illegible] | [illegible] | | [illegible] | | [illegible] |
| | [illegible] | [illegible] | | [illegible] | | [illegible] |



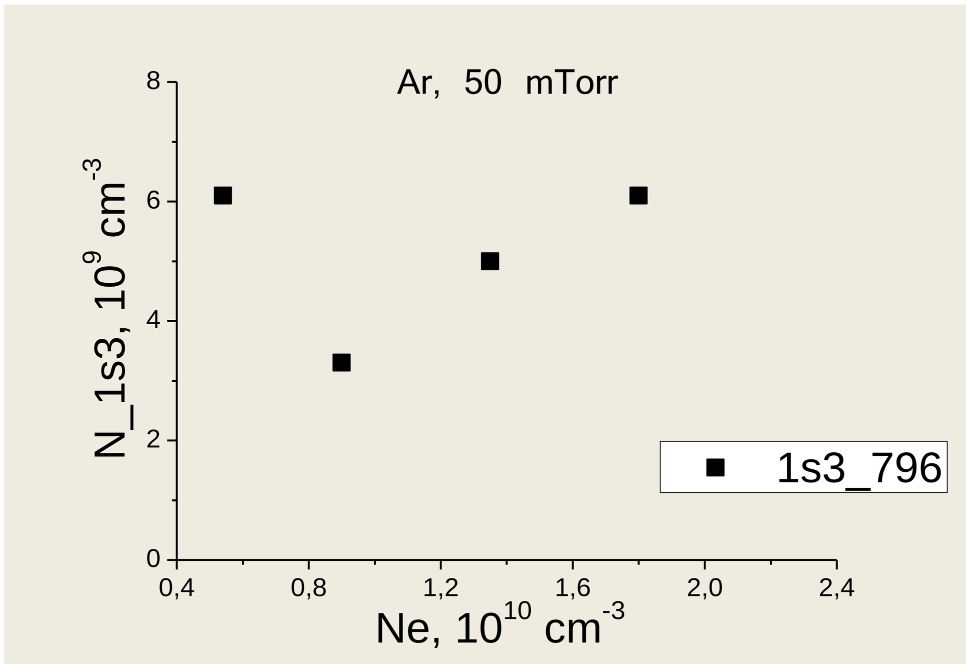

Applied power's calibrate, obtained by means of Langmuir probe.



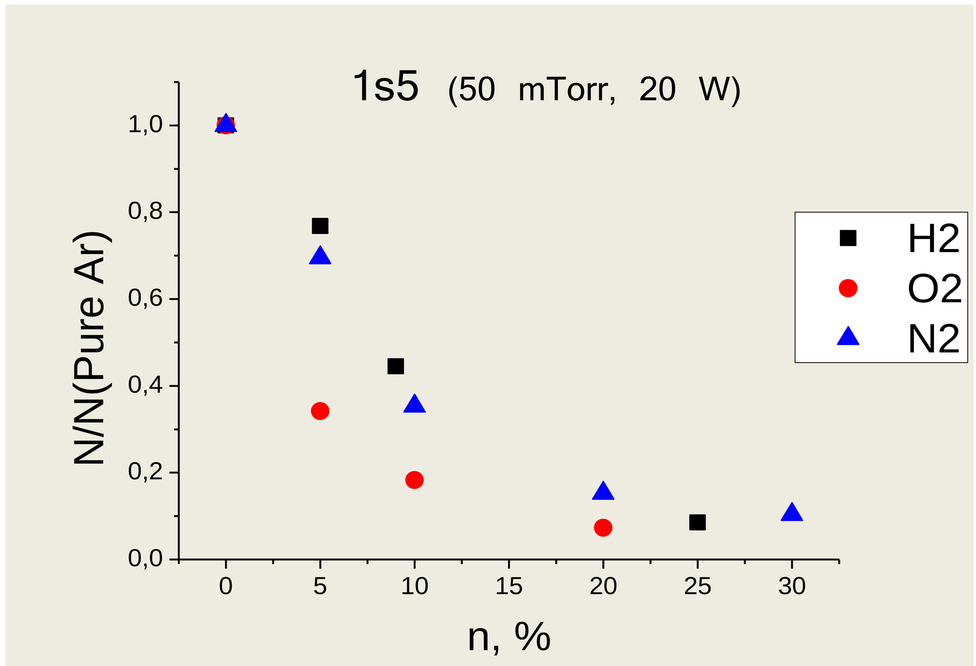

## Measurements results (method 1)



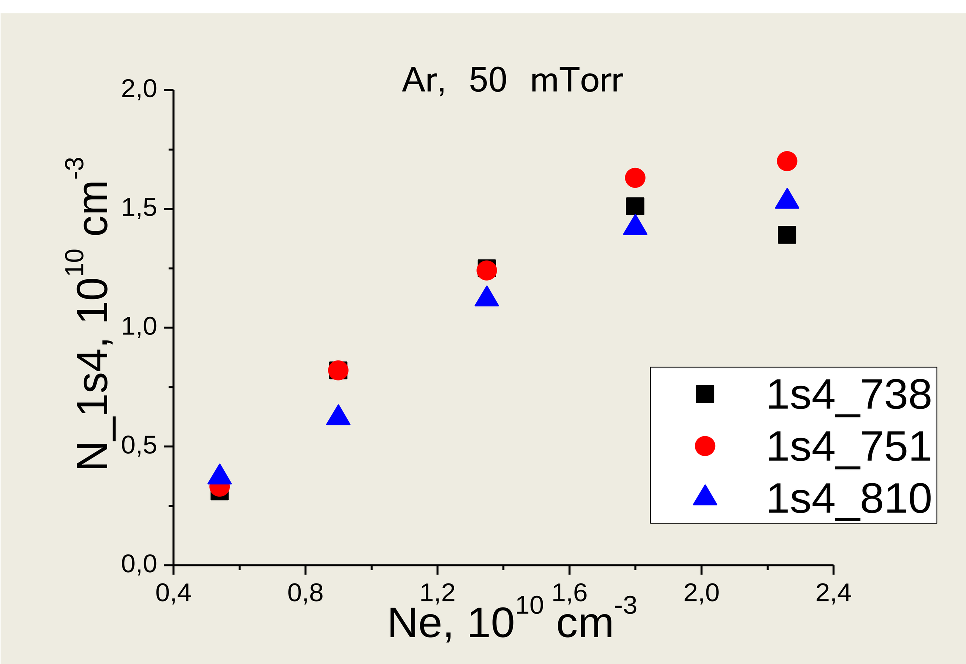

The population density of 1s5 level versus the electron density. Ar, 50 mTorr.



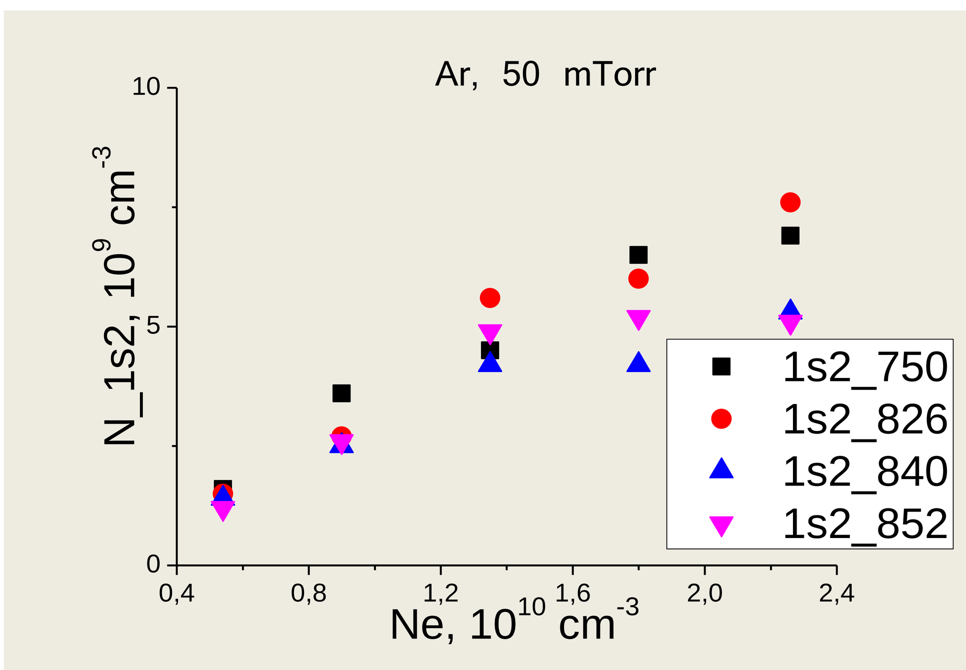

The population density of 1s3 level versus the electron density. Ar, 50 mTorr.



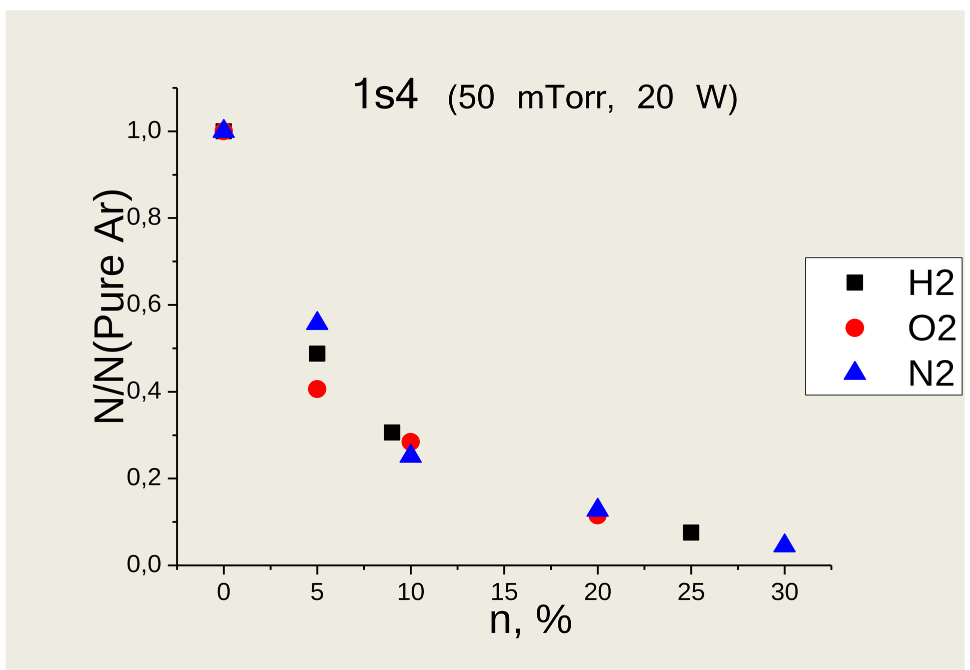

The population density of 1s5 level versus the admixture fraction. 50 mTorr, 20 W



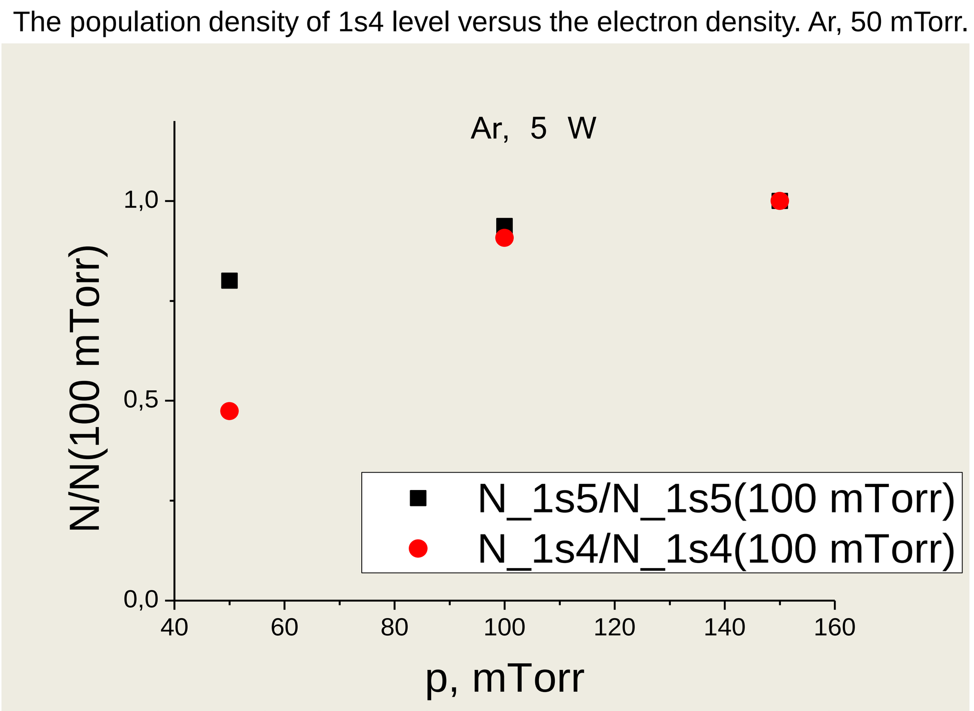

The population density of 1s4 level versus the electron density. Ar, 50 mTorr.




The population density of 1s2 level versus the electron density. Ar, 50 mTorr.




The population density of 1s4 level versus the admixture fraction. 50 mTorr, 20 W




The population density of 1s5 and 1s4 levels versus the gas density. Ar, 5 W.

## Conclusions

- The population densities of the first four excited states in Ar were measured under different plasma conditions by means of two OES-methods.
- It was shown that the method based on comparison of line intensities with different effective plasma size is preferable to use.
- The population densities of all four 1s-levels reduce with increase of admixture fraction (as admixture we used hydrogen, oxygen and nitrogen)

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