Radio Physics Faculty of Taras
Schevchenko National University of Kyiv

ATOMIC DATA AND STARK BROADENING OF CuI AND AgI SPECTRAL LINES: SELECTION AND ANALYSIS

9th SCSLSA
Banja Koviljača
May 13-17, 2013
Serbia

IX Serbian conference on spectral line shapes in astrophysics

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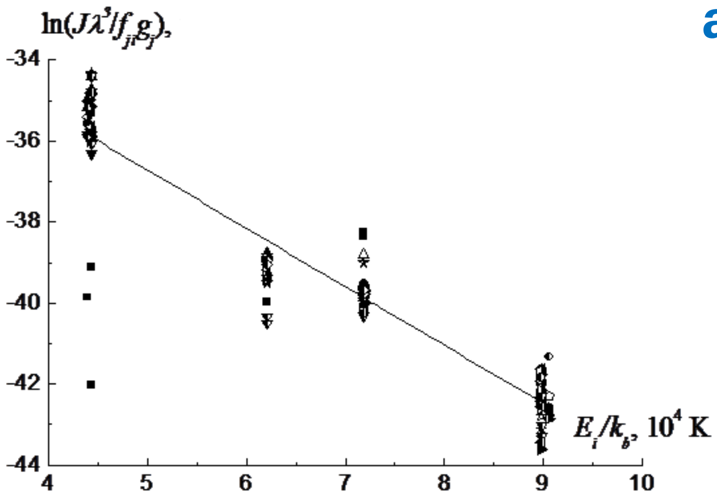
V. F. Boretskij,
A. N. Veklich

9th SCSLSA

Optical emission spectroscopy

Selection of CuI spectral lines and their atomic data



Boltzmann plot obtained by CuI spectral lines at arc current 3.5 A using large variety of up-to-date atomic data.

λ, nm	$g_j f_{ji}$	References	Legend
427.5	0.9097	[1]	☆
465.1	1.4218	[1]	☆
510.5	0.0197	[2]	▼
515.3	1.6466	[3]	⬢
521.8	1.9717	[4]	▲
570.0	0.0057	[5]	◈
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793.3	0.4246	[3]	⬢
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Selected CuI spectral lines and their atomic data.

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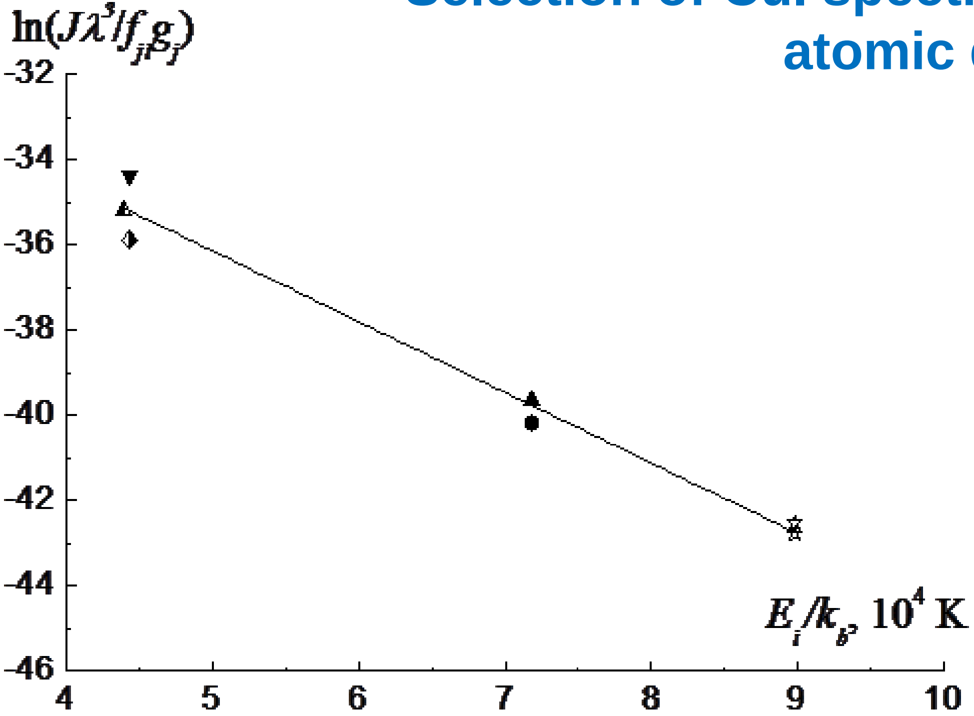

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Babich, I.L., Boretskij, V.F., Veklich, A.N., Ivanisik, A.I., Semenyshyn, R.V., Kryachko, L.A., Minakova, R.V., Spectroscopy of electric arc plasma between composite electrodes Ag-CuO // Electrical contacts and electrodes / Kiev: "Frantsevich Institute for Problems of Materials Science". 2010, p. 82-115 (in Ukrainian) // http://dspace.nbuv.gov.ua/bitstream/handle/123456789/28892/12-Babich.pdf – accessed May 14, 2013.

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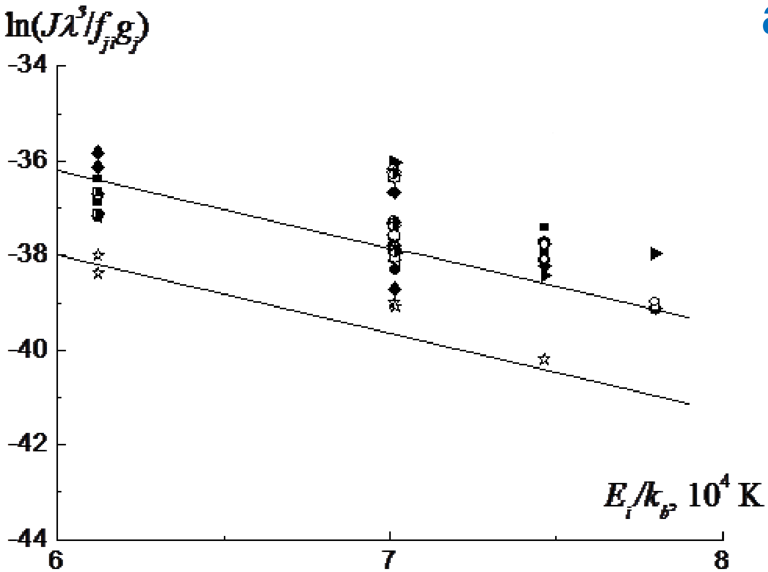
Optical emission spectroscopy

Selection of AgI spectral lines and their atomic data



Boltzmann plot obtained by AgI spectral lines at arc current 3.5 A using large variety of up-to-date atomic data.

λ, nm	$g_j f_{ji}$	References	Legend
405.5	0.2636	[8]	□
447.6	0.0300	[8]	○
466.8	0.0787	[9]	▶
520.9	1.0902	[4]	■
546.5	2.0335	[10]	★
547.2	0.3640	[11]	●
768.8	0.2392	[4]	■
827.4	0.1367	[12]	◆

Selected AgI spectral lines and their atomic data.

8. Lavin C. Almaraz M. A., Martin I. Relativistic oscillator strengths for excited state transitions in some ions of the silver isoelectronic sequence // Z. Phys. D – 1995. – 34. – P. 143-149.

9. Plehotkina G. L. Radiative lifetimes Ag I, Ag II // Optics and Spectroscopy. – 1981. – 51, № 1. – P. 194-196.

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11. Migdalek J. and Baylis W. E. Influence of atomic core polarisation on oscillator strengths for 2S1/2-2P1/2,3/2 and 2P1/2,3/2-2D3/2,5/2 transitions in Cu I, Ag I and Au I spectra // J. Phys. B: At. Mol. Phys. – 1978. – 11, No. 17. – P. L497-L501.

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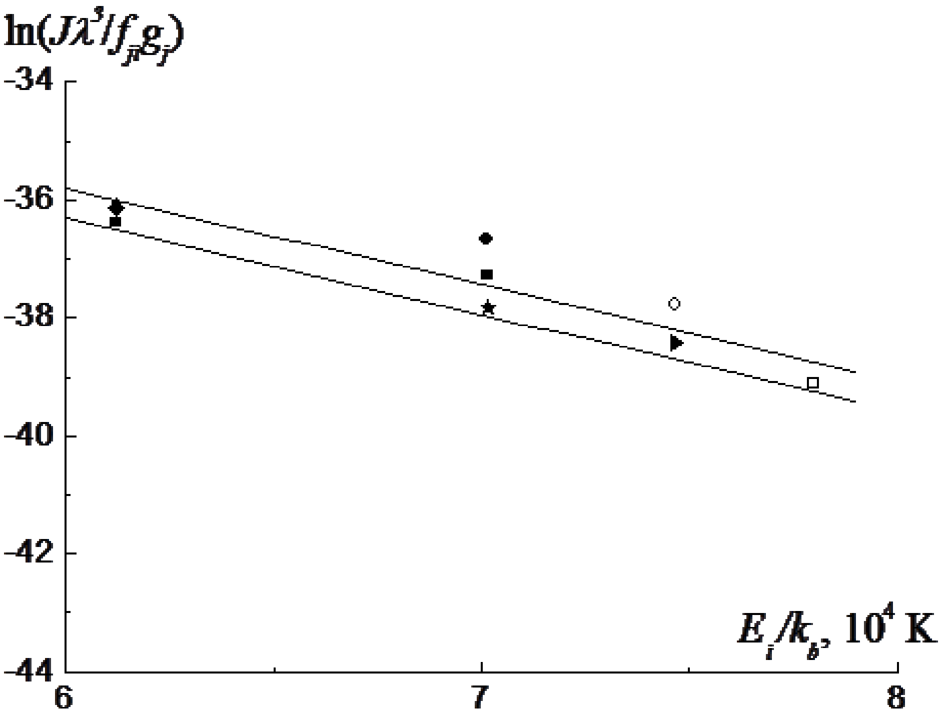
Optical emission spectroscopy

Selection of AgI spectral lines and their atomic data



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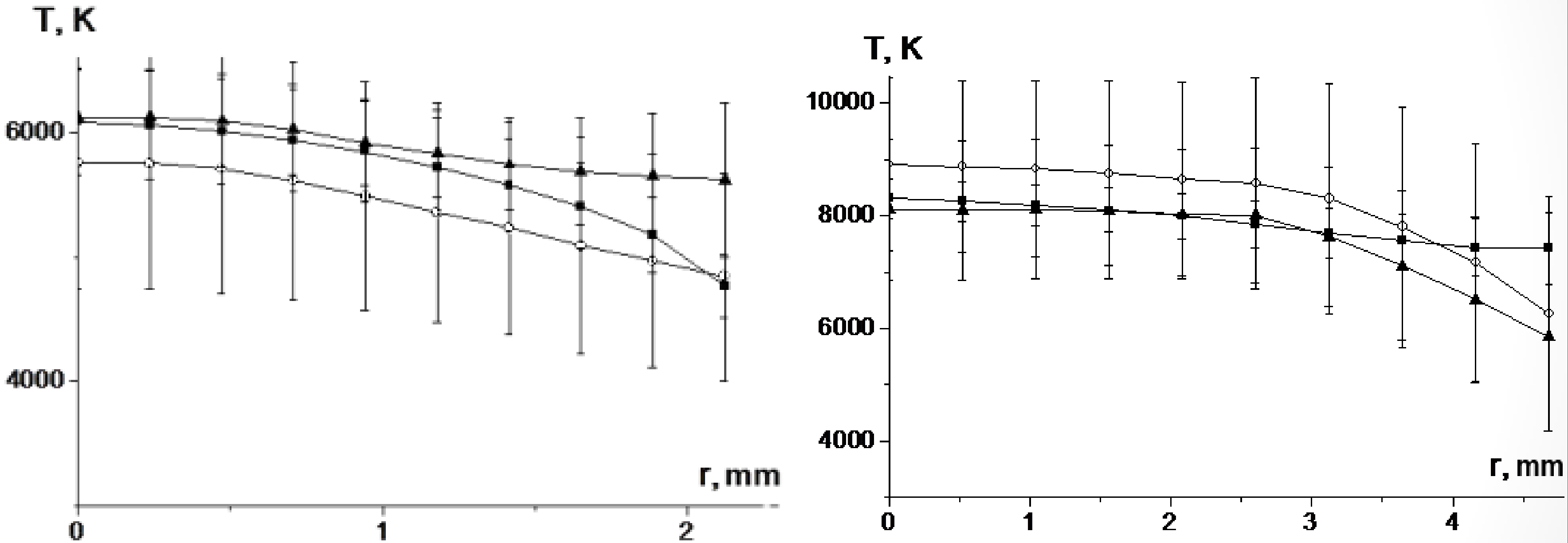
Selected AgI spectral lines and their atomic data.

Optical emission spectroscopy

Temperature measurement



a *b*

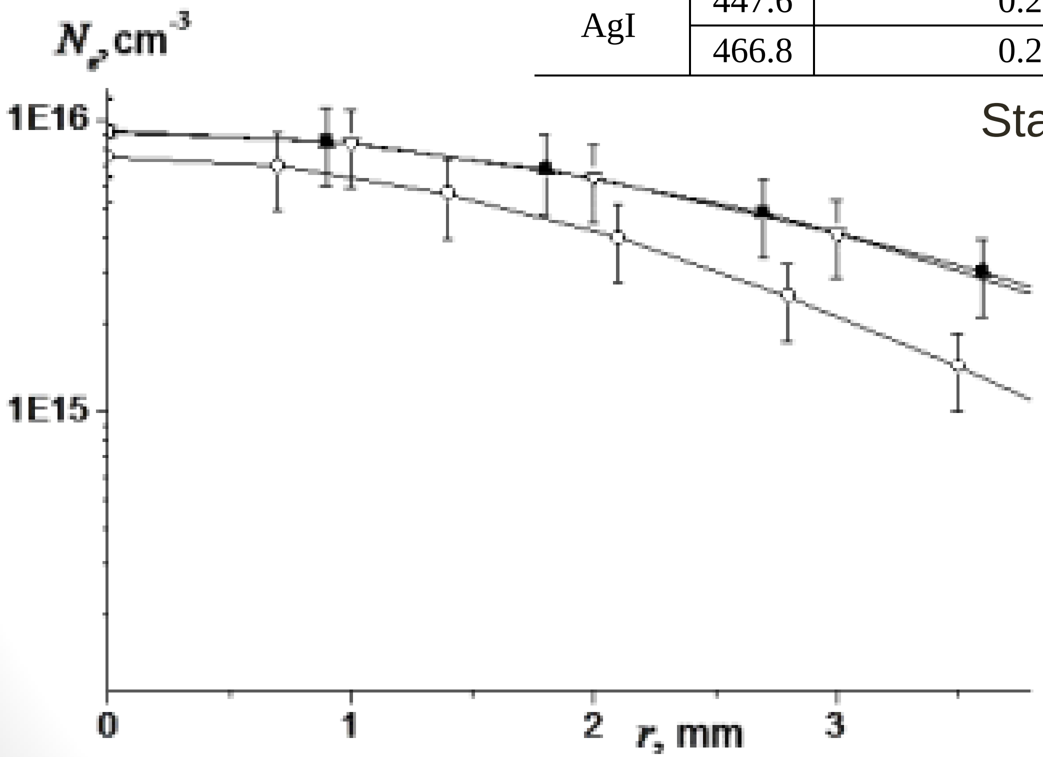
Radial profiles of electric arc plasma temperatures in air, obtained by Boltzmann plot technique using CuI (■), AgI (○) spectral lines and by relative intensities of AgI 405.5 – 768.8nm (▲), arc currents 3.5 A (a) and 30 A (b).

Optical emission spectroscopy

Electron density measurement

Element	λ, nm	w, nm $T = 10\,000K$, $N_e = 10^{17}$ cm^{-3}	$K = N_e/w$, 10^{24} cm^{-4}	Reference
CuI	448.0	0.422	2.370	[13]
	515.3	0.346	2.890	[13]
AgI	447.6	0.209	4.785	[14]
	466.8	0.230	4.348	[14]

Stark broadening data.



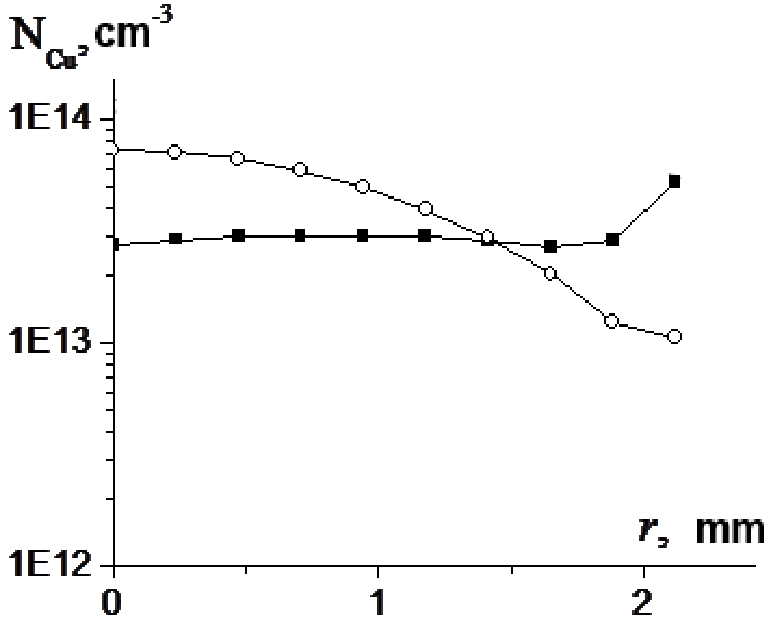
Radial distributions of electron density obtained by AgI 447.7 (■), AgI 466.8 (▲), CuI 448.0 (○) and CuI 515.3 (▽) nm in arc current 30 A

13. Konjevich R., Konjevich N. Stark broadening and shift of neutral copper spectral lines // Fizika. – 1986. – 18, No. 4. – p. 327-335.

14. Dimitrijevic M. S., Sahal-Brechot S. Atomic Data and Nuclear Data Tables. – 2003. – 85. – P. 269-290.

Laser absorption spectroscopy

Comparison of copper density measurement



Radial profiles of cooper atoms density of electric arc discharge plasma obtained using OES (■) and LAS(○), arc current 3.5 A.

Conclusions

- Atomic data of CuI and AgI spectral lines were carefully analyzed and selected. Namely, oscillator strength of these elements are recommended for spectroscopic diagnostics of plasma sources with copper and/or silver vapours.

- Stark broadening of CuI and AgI spectral lines and parameters of this mechanism are testified.

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Thank you
for your attention

More detailed information concerning experiment organization and measurement techniques will be described during report:

"Spectroscopy peculiarities of thermal electric arc discharge plasma between composite electrodes Ag-SnO_2-ZnO"

(15.40 p.m., 16th of May)

References

1. Kerkhoff P. Micali G., Werner K., Wolf A., and Zimmermann P. Radiative decay and autoionization in the 4D-States of the 3d94s5s configuration in Cu I / H. Kerkhoff, // Z. Phys. A - Atoms and Nuclei – 1981. – 300. – P. 115-118.

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Supplementary information

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Table.2. Selected AgI spectral lines and their atomic data.

Element	λ, nm	*w, nm* $T = 10\,000K$, $N_e = 10^{17}\ cm^{-3}$	$K = N_e / w$, $10^{24}\ cm^{-4}$	Reference
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Table.3. Stark broadening data.

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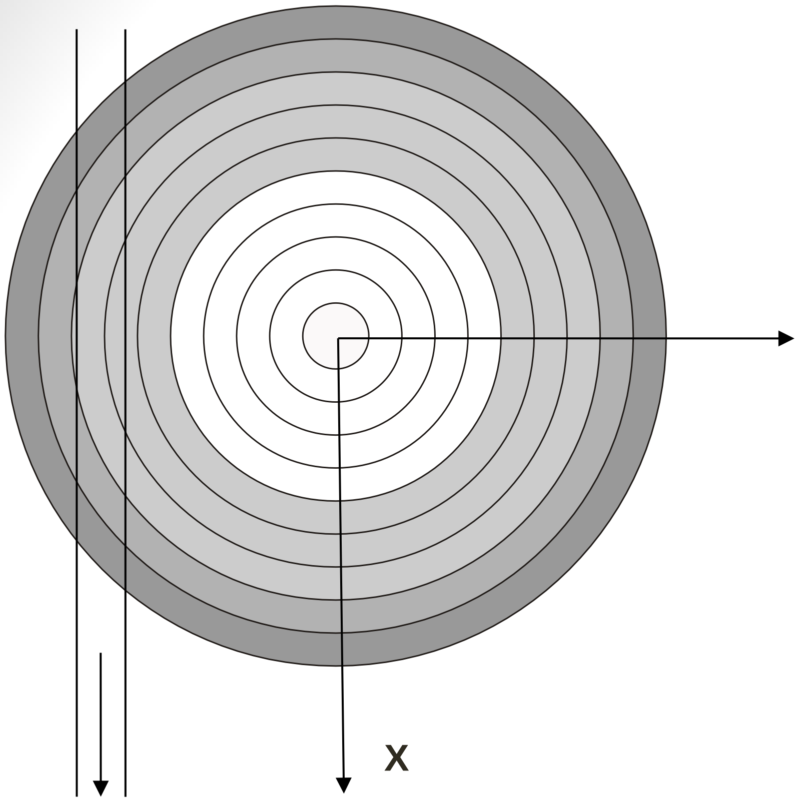

Abel transformation:

$$I(y) = 2\int_0^{\sqrt{R^2+y^2}} \varepsilon(r)dx = 2\int_y^R \frac{\varepsilon(r)rdr}{\sqrt{r^2-y^2}}$$

ε(r) – local emissivity

$$\varepsilon(r) = -\frac{1}{\pi}\int_r^R \frac{\partial I(y)}{\partial y}\frac{dy}{\sqrt{r^2-y^2}}$$

[*] proposed a method of representation of the this integral equation as a system of linear equations

$$\varepsilon(r) = \sum_{k=1}^{n} \beta_{ik} I(y_k)$$

* *Bockasten K. Transformation of Observed Radiances into Radial Distribution of the Emission of a Plasma // Journal of the optical society of America. – 1961. − V. 51, − P. 943-947.*

Model of local thermal equilibrium

$$dn(v) = n4\pi \left(\frac{m}{2\pi k_Б T} \right)^{3/2} \exp\left(-\frac{mv^2}{2k_Б T} \right) v^2 dv$$

- distribution law of velocities of plasma particles (atoms, molecules, ions) is subordinate to Maxwell

$$\frac{n_i}{n_k} = \frac{g_i}{g_k} \exp\left(-\frac{\Delta E_{ik}}{k_Б T} \right)$$

- value of concentrations of particles in the i-th and k-th state are from the Boltzmann formula

$$\frac{n^+ n_e}{n_a} = \frac{2\sum^+}{\sum_a} \left(\frac{2\pi m k_Б T}{h^2} \right)^{3/2} \exp\left(-\frac{E_1}{k_Б T} \right)$$

- concentrations of plasma components (electrons, atoms and ions) linked Saha equation of ionization

Technique of relative intensities of spectral lines

$$I_{ki} = N_k A_{ki} h\nu_{ki}$$

- Intensity of spectral lines

$$I = \int I_\nu d\nu = \frac{1}{4\pi} \frac{g_k A_{ki}}{\sum_a} nh\nu \exp\left(-\frac{E_k}{k_Б T}\right)$$

- for optically thin plasma the intensity of spectral lines

$$\frac{I_1}{I_2} = \frac{A_1 g_1 n_1 \lambda_2 \sum_2}{A_2 g_2 n_2 \lambda_1 \sum_1} \exp\left(-\frac{E_1 - E_2}{k_Б T}\right)$$

- the ratio of intensities of two spectral lines

$$\frac{I_1}{I_2} = \frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1} \exp\left(-\frac{E_1 - E_2}{k_Б T}\right)$$

- if two lines belong to the same atom or ion

$$T[K] = \frac{E_2 - E_1}{k_Б \left(\ln \frac{I_1}{I_2} - \ln \frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1} \right)}$$

- temperature of plasma from method of relative intensities of spectral lines

Electron density in case of dominating Stark broadening of spectral lines

$$N_e = K \cdot \Delta\lambda$$

K – proportionality coefficient, which reflects the electrons density normalized to the half-width of the spectral line

Method of calculation electron density in case with current 3.5A

$$N_e = \sum N_j \,; \qquad j \to Cu, Zn, N, O$$

$$N_e N_{j^+} = 4.85 \cdot 10^{15} N_j \frac{U_{j^+}}{U_j} T^{3/2} e^{-E_j^i / kT}$$

$$N_e^2 = 4.85 \cdot 10^{15} T^{3/2} \sum \left(N_j \frac{U_{j^+}}{U_j} e^{-E_j^i / kT} \right)$$

$$N_e^2 = 4.85 \cdot 10^{15} T^{3/2} N_{Cu} \sum \left(\frac{U_{j^+}}{U_j} e^{-E_j^i / kT} \right)$$

$$B \approx \left. \frac{N_{Cu}}{I_{5153} U_{Cu} \cdot e^{E_{5153\_up} / kT}} \right|_{I=30A}^{r=0}$$

$$N_{Cu} = B \cdot I_{5153} U_{Cu} \cdot e^{E_{5153\_up} / kT}$$