STARK BROADENING PARAMETERS FOR ION LINES OF COPPER

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Fundamental atomic parameters are required in many spheres of modern physics and engineering. Particularly, atomic data for spectral lines are widely used in astrophysics, plasma physics and technology, laser engineering. But in many cases there is appreciable lack of such data. Especially, it is refer to ions of heavy elements. Apparently experiment is the only possible source of reliable data in this situation. During last years a number of experiments were carried out with quasi-steady-state plasma accelerator QSPA Kh-50. This scientific activity was related to the physics of plasma accelerating, development of diagnostic techniques of dense plasma, modeling experiments, and applied problem. This work represents the first attempt to apply plasma-target interaction investigations for solving the problems of the atomic physics, particularly determination of fundamental constants – Stark widths and shifts. Experimental data on Stark broadening parameters for some CuII and CuIII spectral lines in the range of 220nm-600nm are offered.
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INTRODUCTION

Detailed descriptions of QSPA Kh-50 installation, experimental conditions and diagnostic facility (including spectroscopy) are adduced in series publications [1,2]. Our previous researches (including optical diagnostics) shows that under the irradiation the solid target by plasma flow the dense plasma shielding layer is formed close to the surface. Shielding layer plasma includes elements of the evaporated target material. Part of the erosion plasma pass away behind target by the ambient stream. Thus, spectra of the evaporated material are observed both in front of the target and in the flowing around stream.

EXPERIMENT AND DIAGNOSTIC PROCEDURE

The present experiments were carried out with such basic characteristics of plasma stream – power density ~ 10 MW/cm^2, $<N_e>$~$0.8*10^{17}$cm^{-3}, T_e~2.7eV; plasma stream duration ~ 150 μS and diameter of the stream ~ 10 cm (comparable with target diameter-12cm). Working gas – H_2 with little dope of N_2 for diagnostic purposes. Process of plasma–target interaction occurred at the conjuncture of the external longitudinal magnetic field H=0.54T (see Fig.1).

The spectral diagnostic technique elements and its assignments:

- diffractive spectrograph DFS-452 (resolution – 0.3 Å, dispersion – 8 Å/mm) - integral spectra registration of plasma radiation;
- monochromator MDR-23 (resolution – 0.5 Å, dispersion – 13 Å/mm). Monochromator with the electron-optical converter (EOC) serves for receiving optical spectra with the temporary and spatial resolution. The monochromator was coupled with the photo multiplier. Signals from the photo multiplier were recorded on oscillograph C8-17.
- photo diodes - monitoring of the integral plasma radiation, plasma velocity measurements;
- micro photometer IFO-451 – spectral data processing.

Spectral measurements were performed in three sections **A**, **B**, **C** as shown in Fig.1. Some intensive spectral lines were registered by the help of photo multiplier for the definition of intensities correlations for CuII, NII,III and other impurity lines - CII,III; OII. With the same aim the separate spectral range (450÷470nm) contained CuII, NII,III lines has been registered (cross-section **‘C’** Fig.1) by the EOC with high time (~1μS) and spatial (~1cm) resolution. Analysis of these correlations shows, that we may use average values of N_e,T_e obtained from lines contours and intensities of NII,III as

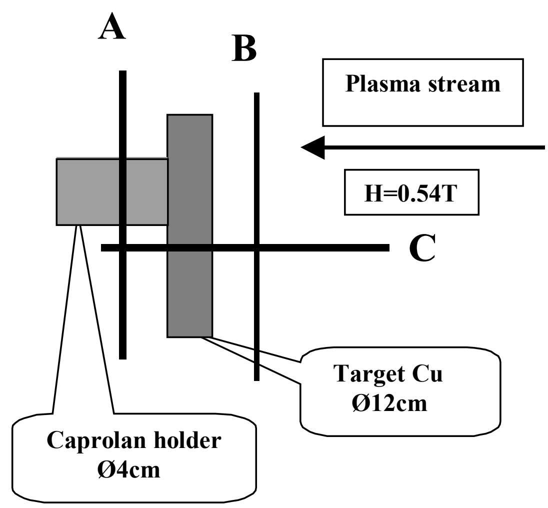

Fig.1 Scheme of spectra observations

acceptable for the determination of Cu lines radiation conditions. The main results on Stark widths were obtained from the integral spectra – DFS-452. Such measurement technique gives correct ratio between Stark widths for different Cu lines and permits us to avoid errors specified with repeatability of plasma conditions.

Some examples are presented at Fig. 2. We have the following plasma parameters: $N_e=5\cdot10^{17}$cm^{-3}, T_e=3.6eV- near target region – upper arrows in Fig. 2a, 2b; $N_e=1.4\cdot10^{17}$cm^{-3}, T_e=3.2eV in ambient plasma stream – arrow in Fig. 2c. All atomic data, constants, parameters of ions (ionization and excitation potentials, stat. weights, oscillator forces, Stark broadening parameters, etc.) are available for these procedures in [3,4].

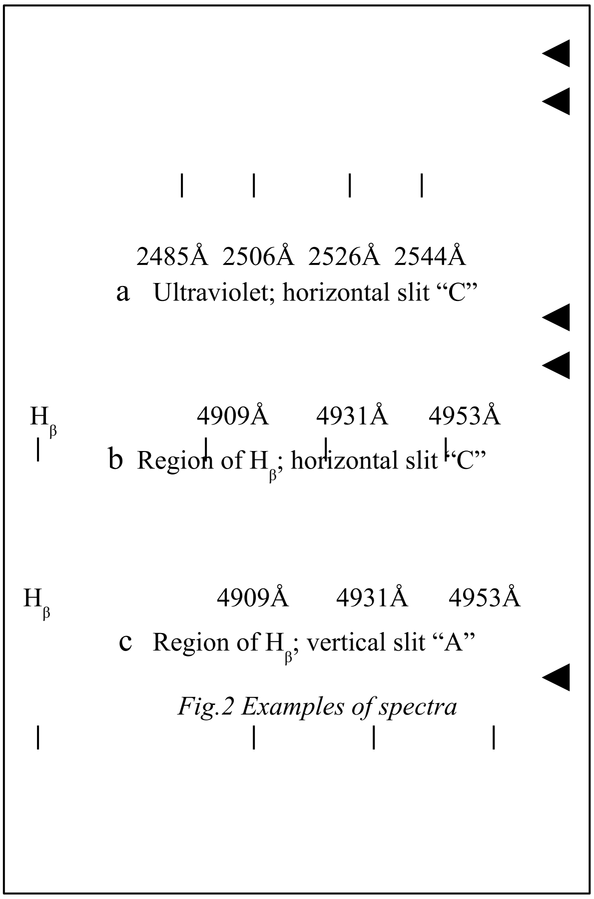

Fig.2 Examples of spectra

Slit '**A**' was used for the analysis CuII lines with large Stark constants, which are hardly observable on a wing of H_β – Fig. 2b. Slit '**B**' was used for the data testing – correspondent values of N_e~$2\cdot10^{17}cm^{-3}$ (lower arrows in Fig. 2 a,b). Calculations of contour parameters for Cu (and other lines) namely Doppler and Stark contributions, were executed by well known Foigt function technique using N_e data from Stark broadening of NII as standard. Contribution of Zeeman effect was taking into account too. Table.1 contains values of different broadening mechanisms for some spectral lines and characterizes "technical" uncertainties of this procedure. Δλ, ΔλD, ΔλA, ΔλG, ΔλZ, ΔλS – measured, Doppler, apparatus, Gauss, Zeeman, Stark widths (in Å) correspondently.

Table 1

λ,Å	Δλ	ΔλD	ΔλA	ΔλG	ΔλZ	ΔλS
2400	0.48	0.04	0.3	0.303	0.031	0.25
2791	0.56	0.047	0.3	0.304	0.042	0.345
3686	0.56	0.067	0.3	0.307	0.073	0.31
4556	0.68	0.076	0.1	0.126	0.111	0.544
5065	5.3	0.084	0.1	0.131	0.137	4.34
4953	2.8	0.083	0.1	0.13	0.131	2.66

Testing contours on self-absorption was executed in the following way. Line intensities ratio with same energy exciting of upper level are compared for different region – with certainly small optical thickness (lower arrow at Fig. 2a) and with "dangerous" from the point of view self-absorption (upper arrow at Fig. 2a). It is clear corrections for Stark data are developed with corresponding impairment of accuracy.

SUMMARY

All summarized information is collected in Tab.2,3*. Along with our results **Col.6**; previous results are included in **Col.7**. Stark widths are normalized to $N_e=10^{17}cm^{-3}$. It is necessary to point, that data concerning UV-range (<400nm) are estimated under $N_e=5\cdot10^{17}cm^{-3}$, T_e=3.6eV and for λ>400nm - $N_e=1.4\cdot10^{17}cm^{-3}$, T_e=3.2eV. There are two previously published experimental works (known for us) on the problem of Stark broadening of Cu lines – [5,6]. In [5] capillary-spark source was used for the spectral measurements with follows plasma conditions: $N_e=1.9*10^{18}cm^{-3}$ (on the base of Stark broadening of H_α), T_e= 24000K (ratio intensities of CuII lines). Stark widths of ***11*** CuII lines in the UV range were obtained from the integral spectra. The report [6] contains results of the analogous researches with arc like plasma source with Ar as a buffer gas. Their experimental conditions are as follows. The range of the electron densities $2*10^{16} \div 10^{17}cm^{-3}$ (profiles of some Ar and H lines are used), T_e= 13000K (intensities of ArII and CuI lines are used). Data on *7* CuII lines are obtained. As a favorable distinct from our case and [6] all measurements are performed with time resolution.

Under data tabulation we used following, denotation:

- **A** - grade of accuracy; uncertainty less than 15%.
- **B** - grade of accuracy 15%÷25%.
- **ε**=Δλ/λ² – "energy equivalent" of line broadening, that one can used for extrapolations and reliability testing.
- **E** – extrapolated values, using parameter **ε**.
- **!** – the most reliable and advisable data (our opinion).
- **?** – questionable data, owing to different reasons.

It is necessary to point, that **A**,**B** – signify relative data errors one respective to another. But there is systematic uncertainty, agreed upon uncertainties under N_e determination from Stark data of NII. As for agreement with [5,6], we hope that essential discrepancies for some long-wave lines [6] are due to significant differences with the electron temperature.

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* Tables 2 and 3 are presented in the Supplement.

SUPPLEMENT

Table 2 CuII

λ, Å	E_l, eV	E_u, eV	Transition	J - J	Δλ,Å	Δλ,Å	ε,cm^{-1}
2294,3	2,83	8,23	4s ^{3}D – 4p ^{3}P^0	2 – 2	0.046E		0.87
2489,6	3,26	8,23	4s ^{1}D – 4p ^{3}P^0	2 – 2	0.09B?		1.45?
2400,1	3,26	8,42	4s ^{1}D – 4p ^{3}P^0	2 – 1	0.05 B	0.041[5)]	0.87
2369,8	3,26	8,49	4s ^{1}D – 4p ^{3}F^0	2 – 3	0.07 B		1.27
4555,9	8,23	10,95	4p ^{3}P^0 – 4s^2 ^{3}P	2 – 2	0.39A!	0.4[6)]	1.87
4505,9	8,23	10,99	4p ^{3}P^0 – 4s^2 ^{3}P	2 – 1	0.39A!		1.87
4758,4	8,42	11,02	4p ^{3}P^0 – 4s^2 ^{3}P	1 – 0	0.39A		1.87
3686,5	8.49	11.85	4p ^{3}F^0 – 4s^2 ^{1}G	3 – 4	0.062B	0.54[6)]	0.456
2403,3	8,23	13,39	4p ^{3}P^0 – 5s ^{3}D	2 – 3	0.18A	0.124[5)]	3.17
2526,5	8,49	13,39	4p ^{3}F^0 – 5s ^{3}D	3 – 3	0.06 B		0.94
2544,8	8,52	13,39	4p ^{3}F^0 – 5s ^{3}D	4 – 3		0.141[5)]	
2689,2	8,78	13,39	4p ^{3}D^0 – 5s ^{3}D	3 – 3	0.2 A	0.12[5)]	2.75
2737,3	8,86	13,39	4p ^{3}D^0 – 5s ^{3}D	2 – 3	0.21E		2.75E
2769,6	8,92	13,39	4p ^{1}F^0 – 5s ^{3}D	3 – 3	0.18A	0.134[5)]	2.36
2884,1	9,09	13,39	4p ^{1}D^0 – 5s ^{3}D	2 – 3	0.21E		2.55E
2473,3	8,42	13,43	4p ^{3}P^0 – 5s ^{3}D	1 – 2	0.14A		2.26
2506,2	8,49	13,43	4p ^{3}F^0 – 5s ^{3}D	3 – 2	0.17A!	0.127[5)]	2.7
2598,8	8,66	13,43	4p ^{3}F^0 – 5s ^{3}D	2 – 2	0.2A!		2.95
2666,2	8,78	13,43	4p ^{3}D^0 – 5s ^{3}D	3 – 2	0.14A!	0.135[5)]	1.93
2713,5	8,86	13,43	4p ^{3}D^0 – 5s ^{3}D	2 – 2	0.14E	0.125[5)]	1.93E
2745,2	8,92	13,43	4p ^{1}F^0 – 5s ^{3}D	3 – 2	0.14E		1.93E
2837,3	9,06	13,43	4p ^{3}D^0 – 5s ^{3}D	1 – 2	0.16E		1.93E
2877,6	9,12	13,43	4p ^{1}P^0 – 5s ^{3}D	1 – 2		0.125[5)]	
2424,4	8,54	13,65	4p ^{3}P^0 – 5s ^{3}D	0 – 1	0.038B?		0.65?
2485,7	8,66	13,65	4p ^{3}F^0 – 5s ^{3}D	2 – 1	0.25A?	0.113[5)]	4?
2590,5	8,86	13,65	4p^{3}D° – 5s ^{3}D	2 – 1	0.19A!	0.091[5)]	2.8
2703,1	9,06	13,65	4p ^{3}D^0 – 5s ^{3}D	1 – 1	0.2 A!		2.7
2721,6	9,09	13,65	4p ^{1}D^0 – 5s ^{3}D	2 – 1	0.17A		2.3
2700,9	9,09	13,68	4p ^{1}D^0 – 5s ^{1}D	2 – 2	0.25A		3.4
2600,2	8,92	13,68	4p ^{1}F° –5s ^{1}D	3 – 2	0.18A!		2.7
2718,7	9,12	13,68	4p ^{1}P^0 – 5s ^{1}D	1 – 2	0.19A!		2.6
2529,3	8,78	13,68	4p ^{3}D° – 5s ^{1}D	3 – 2	0.15A!		2.3
2355,0	8,42	13,68	4p ^{3}P^0 – 5s ^{1}D	1 – 2	0.14E		2.5E
2348,7	9,06	14,34	4p ^{3}D^0 – 4d ^{3}P	1 – 1	0.16E		2.9E
2286,6	8,92	14,34	4p ^{1}F^0 – 4d ^{3}P	3 – 2	0.15E		2.9E
2376,2	9,12	14,34	4p ^{1}P^0 – 4d ^{3}P	1 – 1	0.17A		2.9
5124,4	14,42	16,84	4d ^{3}F – 4p\` ^{3}G^0	3 – 4	1.26A	0.50[6)]	4.8
4909,7	14,33	16,85	4d ^{3}G - 4f ^{3}H°	5 – 6	1.4A!		5.8
4931,6	14, 34	16,85	4d ^{3}D – 4f ^{3}H°	4 – 5	2.0A!	0.58[6)]	8.2
5041,3	14,39	16,85	4d^{3}F— 4f ^{3}G°	3 – 2	3.E		12E
5051,7	14,43	16,88	4d^{3}F— 4f ^{3}G°	4 – 5	3.1A		12
5012,6	14,42	16,89	4d ^{3}F — 4f ^{3}G°	3 – 4	3.0E		12E
4953,7	14,61	17,12	4d ^{1}G — 4f ^{1}H°	4 – 5	1.9A!		7.7
5067,0	14,70	17,14	4d ^{3}F — 4f ^{3}G^0	2 – 3	3.2E		12E
5065,4	14,69	17,14	4d ^{1}F - 4f ^{1}G^0	3 – 4	3.7A!		14

Table 3 CuIII

λ, Å	E_l, eV	E_u, eV	Transition	J - J	Δλ,Å	Δλ,Å	ε,cm^{-1}
2643.9	11.04	15.72	a^{2}G –z^{2}F^0	9/2-7/2	0.05B!		0.7
2522.4	11.04	15.95	a^{2}G –z^{2}F^0	7/2-5/2	0.05E		0.7E
2609.3	9.99	14.74	a^{4}P –z ^{4}D^0	5/2-7/2	0.03B!		0.375
2482.3	9.99	14.95	a^{4}P –z ^{4}D^0	3/2-5/2	0.03B!		0.375
2438.5	9.67	14.74	b^{2}D –z ^{4}D^0	5/2-7/2	0.03E		0.375E
2346.2	9.67	14.95	b^{2}D –z ^{4}D^0	5/2-5/2	0.03E		0.375E

ПАРАМЕТРИ ШТАРКІВСЬКОГО РОЗШИРЕННЯ ДЛЯ ІОННИХ ЛІНІЙ МІДІ

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Знання фундаментальних атомних параметрів потрібно в багатьох сферах сучасної фізики та інженерії. Особливо широко ці параметри спектральних ліній використовуються в астрофізиці, фізиці плазми, лазерній інженерії і технології. Але в багатьох випадках відчувається значний дефіцит цих даних. Головним чином це стосується іонів важких елементів. Безсумнівно, експеримент є єдиним можливим джерелом одержання достовірних даних у таких випадках. Останнім часом була проведена велика кількість експериментів з квазістаціонарним плазмовим прискорювачем КСПП Х-50. Ця наукова діяльність торкається фізики прискорення плазми, розвитку діагностичної техніки для щільної плазми, моделювання експериментів та проблем прикладного характеру. Ця стаття представляє першу спробу застосувати дослідження взаємодії плазма-мішень для рішення проблем атомної фізики, зокрема, визначення фундаментальних констант – штарківських полуширин і зрушень. Представлено експериментальні дані параметрів штарківського розширення для деяких спектральних ліній CuII і CuIII у діапазоні довжин хвиль 220нм – 600нм.

ПАРАМЕТРЫ ШТАРКОВСКОГО УШИРЕНИЯ ДЛЯ ИОННЫХ ЛИНИЙ МЕДИ

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Знание фундаментальных атомных параметров требуется во многих сферах современной физики и инженерии. Особенно широко эти параметры спектральных линий используются в астрофизике, физике плазмы, лазерной инженерии и технологии. Но во многих случаях ощущается существенный дефицит этих данных. Главным образом это касается ионов тяжелых элементов. По-видимому, эксперимент является единственным возможным источником получения достоверных данных в таких случаях. В последнее время было проведено большое количество экспериментов с квазистационарным плазменным ускорителем КСПУ Х-50. Эта научная деятельность затрагивает физику ускорения плазмы, развитие диагностической техники для плотной плазмы, моделирование экспериментов и других проблем прикладного характера. Эта статья представляет первую попытку применить исследования взаимодействия плазма-мишень для решения проблем атомной физики, в частности, определение фундаментальных констант – штарковских полуширин и сдвигов. Представлены экспериментальные данные параметров штарковского уширения для некоторых спектральных линий CuII и CuIII в диапазоне длин волн 220нм – 600нм.