Precise measurements and theory of the ground state ionization energy and wavelengths for the $1snp\ ^1P_1 - 1s^2\ ^1S_0(n = 4 - 9)$ lines of Mg XI and F VIII

V.G. Pal'chikov[1], A.Ya. Faenov[1], I.Yu. Skobelev[1], A.I. Magunov[1], T.A. Pikuz[1], F.B. Rosmej[2], D.H.H. Hoffmann[2], W. Suess[2], M. Geissel[3], P. Pirzadeh[3], M. Roth[3], W. Seelig[3], B.Yu. Sharkov[4], R. Bock[5], U. N. Funk[5], U. Neuner[5], S. Udrea[5], A. Tauschwitz[5], N.A. Tahir[5], E. Biemont[6], P. Palmeri[6], P. Quinet[6], A. Sasaki[7], T. Utsumi[7]

[1] *Multicharged Ions Spectra Data Center at National Research Institute for Physical-Technical and Radiotechnical Measurements, Mendeleevo, Moscow Region, 141570 Russia*
Tel +007-095-5350849, Fax +007-095-5359334, E-mail: vitpal@mail.ru
[2] *Technische Universität Darmstadt, Institut für Kernphysik, Abt. Strahlen- und Kernphysik*
Schlossgartenstr. 9, D-64289 Darmstadt, Germany
[3] *Technishe Universitaet Darmstadt, Institut für Angewandte Physik, Schlossgartenstr. 7, D-64289 Darmstadt, Germany*
[4] *Institute of Experimental and Theoretical Physics, Moscow, 117257, Russia*
[5] *Gesellschaft für Schwerionenforschung, Institute for Plasmaphysics, Planckstr. 1, D-64291 Darmstadt, Germany*
[6] *Institut d'Astrophysique, Universite de Liege, B-4200 Cointe - Liege, Belgium*
I.P.N.E. (Bât. B15), Université de Liège, Sart Tilman
[7] *Advance Photon Research Center, Japan Atomic Energy Research Institute, 25-1 Mii-minami-cho, Neyagawa-shi, Osaka 572, Japan*

Precision measurements of transition wavelengths for resonance Rydberg series of two-electron ions provide valuable tests of *ab initio* methods for calculating atomic structure. Such investigations become especially interesting for the multicharged ions because in such cases both electron correlation effects and relativistic corrections are important. The largest effects of electron correlation occur for the $1s$ orbital. However, most of the experimental tests of atomic structure calculations for two-electron ions have measured $n = 2 - 2$ transitions, for which the $1s$ contributions largely cancel. There are some precision measurements of $n = 2 - 1$ transitions, but these transition energies contain significant correlation and QED terms for both $n = 1$ and $n = 2$ orbitals. Because these contributions drop rapidly with n, measurements of ground state transitions from high-n levels directly test theoretical calculations of the ground-state ionization energy.

Experiments were carried out at the "**nhelix − laser**" installation (**n**ano second **h**igh **e**nergy **l**aser for **h**eavy **i**on e**x**periments) at GSI in Darmstadt, Germany . The "**nhelix**" is a Nd-glass/Nd-Yag laser ($\lambda_{las} = 1.06 \mu m$) with the duration of pulse of 15 ns and an energy up to 100 J. The present experiments however were performed with an energy of 50 J. The laser radiation is focused with a plane-convex lens (diameter 100 mm, focal length $f = 130mm$) into a solid teflon (CF_2) or magnesium targets. In order to obtain different laser intensities into the target, the distance between the lens and the target was changed (movement of lens). Investigation of the intensity inside the focus showed that no hot spots appeared.

Quantitative information on X-ray plasma emission was obtained with the help of FSSR-2D spectrometers [1]. These spectrometers employed a mica crystal with lattice spacing $d_1 = 9.95746$ $\AA$ (for the first order of reflection) and d_2=9.96875 $\AA$ (for the second order of reflection), which were spherically bent to a radius $R = 100$ and $R = 150$ mm. The resolving power of the instruments were about $\Delta\lambda/\lambda$ = 4000-5000 for the spectral range 12-15 $\AA$ and $\Delta\lambda/\lambda$ =6000-8000 for the spectral range 7-8 $\AA$. The spatial resolution of spectrometers were about 20-40 μm. The spectral bands investigated in our experiments were 12.5-15.2 $\AA$ (in the first order of crystal reflection) and 7.08-8.2 $\AA$ (in the second order of reflection).

The absolute accuracy of our wavelength measurements is about 0.6-1.6 $m\AA$ for $1snp\,^1P_1 - 1s^2$ lines of F VIII with $n = 4 - 8$ and is about 0.4-0.6 $m\AA$ for $1snp\,^1P_1 - 1s^2$ lines of Mg XI with $n = 4 - 9$ (Table 1). The Rydberg series is used to determine the ground-state ionization energy of Mg XI and F VIII. This method gives: $E_{ion}(F$ VIII$) = 953.96\pm0.11eV$, $E_{ion}(Mg$ XI$)$ $= 1761.87\pm0.15eV$.

Table 1: Wavelengths of $1snp\,^1P_1 - 1s^2$ transitions in He-like F VII and Mg XI, $\AA$.

Lines	F VII	Mg XI
$1s9p\,^1P_1 - 1s^2$		7.1200(10)
$1s8p\,^1P_1 - 1s^2$	13.1848(8)	7.1410(6)
$1s7p\,^1P_1 - 1s^2$	13.2419(15)	7.1736(5)
$1s6p\,^1P_1 - 1s^2$	13.3347(16)	7.2239(5)
$1s5p\,^1P_1 - 1s^2$	13.4885(8)	7.3098(5)
$1s4p\,^1P_1 - 1s^2$	13.7815(6)	7.4729(4)

The theoretical calculations were carried out in the present work by three different and independent methods, namely, 1) the relativistic Hartree-Fock method (HFR), 2) the relativistic multi-configuration Dirac-Fock (MCDF) method and 3) the $1/Z$ expansion method to obtain the most accurate solutions of the non-relativistic wave equation with including relativistic, quantum electrodynamics (QED), and set of corrections due to size and mass effects by perturbation theory [2]. In particular, the method of expansion in the parameter $1/Z$ provides the inclusion of the higher-order relativistic effects and QED corrections. Radiative corrections to the $1s^2\ ^1S_0$ -state are analyzed and compared with experiments. It is found that QED-corrections to the ground-state ionization energy are significant at the present level of experimental accuracy.

[1] B. K. F. Young, A. L. Osterheld, et al, *Rev. Sci. Instrum.* **69** 4049 (1998).
[2] V.G. Pal'chikov and V. P. Shevelko, *Reference Data on Multicharged Ions* (Springer-Verlag, Berlin, 1995).