Hollow ion formation and line shape analysis in dense laser produced plasmas

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X-ray emission from hollow ions is a fascinating field of research for many different branches like, e.g., nuclear physics (interaction of heavy ion beams with matter), atomic physics (atomic structure investigations, correlation effects of multi-electron systems, autoionizing channels of configurations with multiple excited electrons). Moreover, hollow ion configurations and the corresponding x-ray emission is very important for the future GSI-project employing the kilojoule PHELIX-beam: for x-ray scattering diagnostics in the Warm Dense Matter (WDM)/Equation of State (EOS) research and for target diagnostics in stopping power measurements. The important feature of the hollow ion x-ray emission is the optically thin emission even under extreme conditions of strongly coupled large scale dense plasmas.

In the framework of an international collaboration (Marseille-group, France, Mendeleevo-group, Russia) we have performed proof of principle experiments at the nhelix-laser facility at GSI and developed suitable theoretical methods for the analysis. Figure 1 shows the experimental spectrum of the x-ray emission from a 3-electron system recorded by means of spherically bent mica crystals and x-ray film. Experiments have been performed with an energy of 30-60 J and spot sizes ranging from 100-500 µm. The laser pulse duration was about 15 ns.

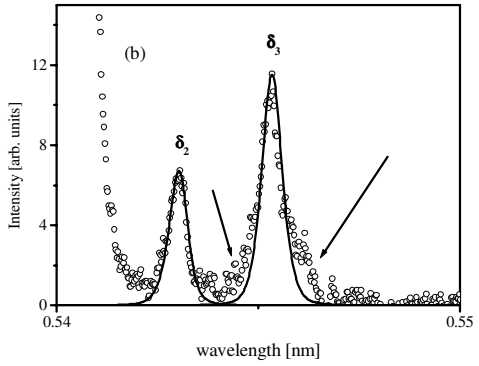

Figure 1: Highly resolved x-ray emission of the He_δ-satellites $1s2l5l'$-$1s^22l''$ of silicon (dotted: experiment, solid: PPP-simulations). The arrows indicate the emission from hollow ion configurations $K^1L^0M^1N^1$.

The solid line is the Stark-broadening analysis of the δ-satellites (δ = $1s2l5l'$-$1s^22l''$) performed with the PPP-code [1]. Excellent agreement is obtained for the δ_2-group (and also for the γ -group, γ = $1s2l4l'$-$1s^22l''$ [2]). For the δ_3-group the arrows indicate a systematic discrepancy caused by hollow ion x-ray emission. By means of the MARIA spectral simulation code [3] developed further for the analysis of hollow ion configurations we could demonstrate, that the corresponding x-ray emission is correlated to excited states.

Figure 2 shows the relevant level scheme of the configurations $K^1L^0M^1N^1$. The simulations show, that the population channel from the excited states is dominating by orders of magnitude compared to the ground state channel. Therefore, these hollow ion configuration are not visible in low density plasmas or typical atomic physics experiments carried out at accelerator facilities.

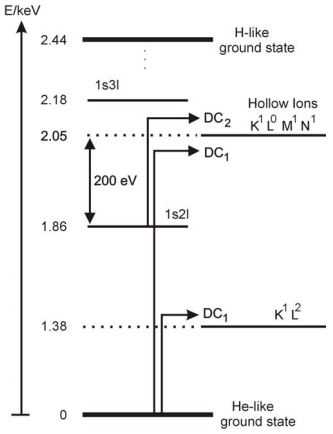

Figure 2: Energy level scheme and excitation channels of hollow ion configurations

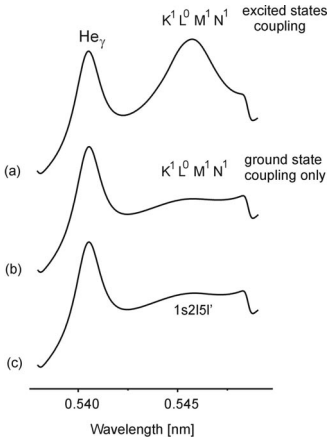

Figure 3: MARIA-simulations of hollow ion x-ray emission, simulation parameters are Z_n = 14, $kT_e = kT_i$ = 100 eV, $n_e = 3\cdot10^{22}$ cm^{-3}, L_{eff} = 10 µm, $\lambda/\delta\lambda$ = 2000.

Figure 3 shows the simulations for typical conditions of strongly coupled laser produced plasmas (coupling parameter Γ > 1): a) inclusion of ground and excited states coupling, b) population of the $K^1L^0M^1N^1$-levels only via dielectronic capture into the He-like ground state, c) all emission of the $K^1L^0M^1N^1$-levels is artificially switched off.

In conclusion the present results indicate a successful atomic physics and diagnostic research of the hollow ion x-ray emission for the future needs of the PHELIX-laser application.

References

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