Spectroscopy of Highly Charged Ions with Free Electron Lasers

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Resonant laser spectroscopy of soft x-ray transitions in highly charged ions (HCIs) by means of Free Electron Lasers (FELs) has been proven [1] to be a promising technique with the potential for unprecedented precision on energetic transitions unreachable by traditional laser spectroscopy. The technique relies on combining a state-of-the-art EBIT [2] with the Free electron LASer at Hamburg (FLASH [3]), measuring the resonant fluorescence yield by the trapped HCIs as a function of the wavelength of the FLASH-light. Three fundamental transitions at energies E_0 were investigated, namely $1s^22s\ ^2S_{1/2}$–$1s^22p\ ^2P_{1/2}$ in Li-like Fe^{23+} at 48.6 eV, Li-like Cu^{27+} at 55.2 eV, and $1s^22s\ ^2S_{1/2}$–$1s^22p\ ^2P_{3/2}$ in Fe^{23+} at 65.3 eV. The later demonstrates resonant laser spectroscopy of multiply or highly charged ions at more than one order of magnitude higher transition energies as reported elsewhere [4]. The resolutions achieved were around $E_0/\mathrm{FWHM} = 3000$ for the individual spectral lines, resulting in relative precisions (preliminary) of 2 parts-per-million (ppm) for determining the center-of-mass wavelength.

By means of known absorption lines present in neutral neon we were able to achieve an absolute accuracy (preliminary) in the Fe^{23+} case of roughly 20 ppm, which is close to the accuracy of the most accurate reported measurements [5]. Pushing the absolute accuracy further down (e.g. to the achieved relative precision) can hardly be done by comparison to absorption lines of rare gases, but instead requires lines of H-like and He-like low-Z ions (C,N,O,F) for calibration, which then would establish independent wavelength standards in this spectral region with ppm accuracy.

Thus, we expect significant impact of our technique on precision spectroscopy of transitions important for atomic structure theory, e.g. strong-field QED [6], or of astrophysical relevance.

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