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Development of x-ray-induced fluorescence spectroscopy with highly charged ions

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Introduction

To measure atomic transitions precisely, laser-induced fluorescence spectroscopy is quite useful. However the laser spectroscopic experiment is limited by energy oscillated by lasers (up to 5 eV). On the other hand, excitation energies of highly charged ions (HCIs) increase to 280 eV such as the $1s^2 2s\ ^2S_{1/2}$ - $1s^2 2p\ ^2P_{1/2}$ transition of U^{89+} ion [1]. In order to measure transition energies of HCIs, we are developing a new experimental technique which uses x rays instead of laser light.

Experimental

The experimental setup is shown in Fig. 1. Laser plasma is produced by focusing the laser radiation on the target surface. Ions are extracted from the laser plasma under acceleration voltage of 26 kV and focused by the einzel lens. The target is mounted on the drum revolved by an electric motor. The Nd:YAG laser, which has a maximum power of 450mJ/pulse and a pulse duration (FWHM) of 6 ns, is used for production of plasma. The power density of the laser radiation flux on the target is estimated to be 1.2 x 10^{13} W/cm^2. The charge states of the ions are selected by the dipole magnet, and the ion beam propagates to the fluorescence detector. The ion beam is focused on the fluorescence detector by the electrostatic quadrupole lens. In the detector, the ions excited by x ray decay to the ground state with emitting fluorescence photons. The resonance spectrum is measured by scanning of the x-ray energy. The level scheme of the C^{4+} ion is shown in Fig. 2. Four microchannel plates (MCPs) with a 30 mm aperture and a faraday cup with a 10 mm aperture are mounted in the fluorescence detector. From the faraday cup C^{4+} beam which has peak current of 160 μA and bunch width of 500 ns was measured. It corresponds to the number of ions of 1.3 x 10^8 ions/bunch.

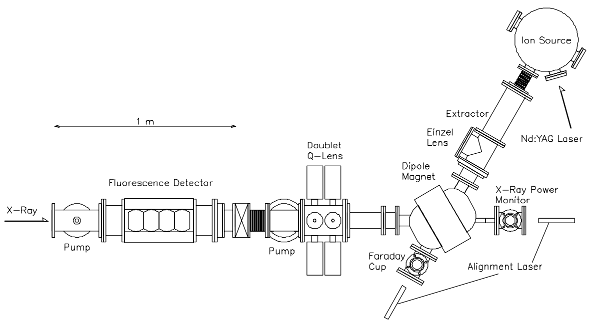

Figure 1: Experimental setup.

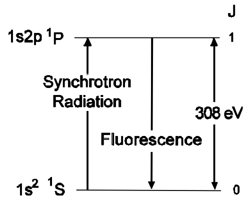

Figure 2: Level scheme of C^{4+} ion.

Estimation of Count Rate

The count rate of the fluorescence (R_{signal}) is calculated as,

$$R_{signal} = B \cdot \frac{\rho_x}{\Delta\nu} \cdot N_i \cdot t \cdot f_i \cdot f_{laser} \cdot \varepsilon_{mcp} \cdot \Omega_d .$$

The Einstein coefficient of induced emission (B) is calculated from the spontaneous transition probability (A) [2]. The parameters for the demonstration experiment are summarized in Table 1. As a result, R_{signal} is estimated to be 0.3 cps. The x-ray intensity used for the estimation is 1.0 x 10^{12} photons/s/0.1%bw with a repetition rate of 500 MHz. The result indicates the ion beam current is enough to carry out an x-ray-induced fluorescence spectroscopy experiment with SR. Under the present condition, the count rate of the noise was measured to be 3 cps. It will be suppressed by improving the vacuum of the detector, because the noise is caused by the collisions of the ions and the residual gas in the detector. As compared to the noise from the ion beam, the noise from the x-ray beam is negligible. The noise rate was measured at BL-16B.

Table 1: Parameters for estimation.

Spontaneous probability (/s)	A	8.873 x 10^{11}
Power density of x ray (J/m^3)	ρ_x	1.6 x 10^{-5}
Repetition rate of laser (/s)	f_{laser}	3
Bandwidth of x ray (Hz)	$\Delta\nu$	7.4 x 10^{13}
Quantum efficiency of MCP	ε_{mcp}	0.4
Solid angle of detector	Ω_d	0.063
Interaction rate	f_i	250
Number of ions (/bunch)	N_i	1.3 x 10^8
Interaction time (s)	t	2 x 10^{-9}

References

[1] J. Schweppe, el al.: Phys Rev Lett 66, 1434 (1991).
[2] http://physics.nist.gov/cgi-bin/AtData/main_asd/

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