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SPECTROSCOPIC SOURCE OF MULTICHARGED IONS

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The works on the X-ray spectroscopy of charged ions have begun at the JINR. To do this a crystal-diffraction spectrometer has been created (CDS)[1]. First experiments on the characteristic X-ray radiation spectrometry with Kr^{35+} ions neutralization have been done on the surface of solid by crystal-diffraction methods[2]. An electron beam source (EBIS)[3] has been used as an ion source. The CDS has a resolution $\Delta E/E \sim 2\cdot 10^{-5}$ and the light efficiency $\sim 10^{-8}$. This setup permits one to perform spectrometric investigations of characteristic radiation, to measure energy transition shifts and ionization cross sections, to determine other physical characteristics of highly charged ion electron shells. For the effective CDS operating we need a source, capable of creating a high number of multicharged ions with atomic number $I \gtrsim 30$ and charge $z \gtrsim I/2$. Today we use an EBIS and sources on the electron-cyclotron resonance (ECR) to produce multicharged ions. The highest charges of heavy ions have been produced at Dubna at the KRION-2 - Xe^{52+}[3]. To create these ions we need the ionization time 5-10 s. During this delay we lost the most of ions from the source and the maximum number of Xe^{52+} ions is 10^5 per cycle. ECR sources produce ion beams with intensity up to $3\cdot 10^{-4}$ a[4]. But the possibilities of multicharge ion production are limited by the electron energy in the source. The biggest obtained charges of Xe ions at ECR sources are about thirty with currents $<< 10^{-6}$ a. High intensities of multicharged ions of heavy elements can be provided by the source[5] of ions with electron rings (ERIS) using the adgezator of collective accelerator. Electron rings of the collective accelerator have following typical parameters[6]: major radius R = 3.5 cm, small semidimensions a = 0.2-0.3 cm, number of Ne electrons up to $0.5\cdot 10^{13}$, electron energy E = 20 MeV, lifetime in a compressed state 1 ms, electron flow density $j = 0.5\cdot 10^{23}$ cm^{-2} c^{-1}. Thus, the ionization factor $j\tau = 0.5\cdot 10^{20}$ cm^{-2}. It is enough to produce Xe^{14+} ions. And the number of Ni ions is limited by the condition Ni <Ne/Z. Electron relativistic energy permits one to ionize inner shells of the most heavy elements. For this purpose the increase of the lifetime of electron-ion ring is necessary. In the experiments on the long confinement time of electron rings on small radii in magnetic fields, decreasing in time by the exponent, the electron ring lifetime attained

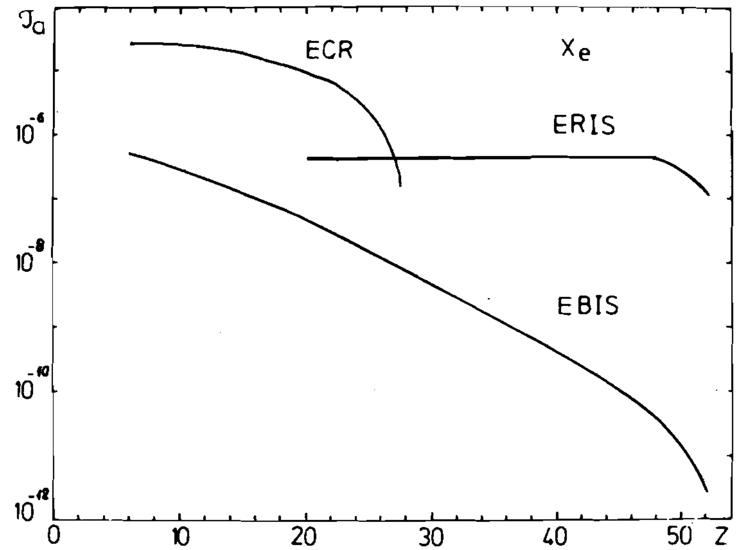
40 ms without destruction and considerable increase of small dimensions[7]. The ring major radius R was practically constant, because the radius alternation provoked by the magnetic field decreasing was compensated by the electron energy losses for the synchrotron radiation. The ionization factor $j\tau$, at the electron number in the ring $Ne = 2\div 3\cdot 10^{12}$, attained the value $1\cdot 10^{21}$. The detailed analysis of factors limiting the ring lifetime has shown that the electron-ion ring confinement time, when the pressure is 10^{-9} torr, is limited by the range 50--100 ms[5]. During this time, when the ring dimension is constant we can produce the Xe ions with charge 40-44 and U ions with charge 62-68. The production of ions with higher charge requires considerable increase of electron ring density. We can decrease the final dimension of the electron ring in given initial and final values of magnetic field on the orbit of electron ring by forming the electron ring in the magnetic field with $\overline{B} \lesssim 2B$, that is equal to the decrease of total moment of electron, or by creating the magnetic field with the field index near-by 1. The most effective is the last method, based on the final radii compression, where the energy losses for synchrotron radiation are relatively considerable. So we can compress the ring up to R = 1.5-2 cm and increase its density by 5-10 times[5].

The Table presents the calculated dependences on time in the exponentially decreasing magnetic field with decrement 50 ms of electron ring radius R, electron energies E, ionization factor $j\tau$ and Xe and U ions mean charge when $Ne = 5\cdot 10^{12}$ for the given ring and supplementary compressed electron ring.

Table

t ms	R cm	E MeV	$j\tau$ 10^{22} cm^{-2}	Z_{Xe}	Z_U	R cm	E MeV	$j\tau$ 10^{22} cm^{-2}	Z_{Xe}	Z_U
3	3.5	25	0.005	14	20	3.5	20	0.005	14	20
7	2.0	18	0.05	32	48	3.4	17	0.025	26	36
15	1.5	12	0.2	44	68	3.3	13	0.08	34	56
30	1.3	8	0.7	48	82	3.6	10	0.15	43	66
60	1.5	5	1.5	51	84	4.5	7	0.2	44	68
100	2.4	3	2.0	52	86					

The ion mean currents depending on the charge for ECR[4], ERIS[3] and ERIS at the frequency of 1 Hz are presented in the figure. The Spectrometer efficiency is determined by its light efficiency and X-ray quantum flow from multicharged ions. The



CDS-type spectrometers having a high resolution have a low sensitivity and require a high intencity multicharged ion sources. The ERIS is the best for these requirements. The total number of X-ray quanta created when filling the vacancies in the interior K shells of multicharged ions in the electron ring

$$n_f = Ni\,Ne\,\sigma_k\,c\,\omega_k\,P_{k_{a_j}}\,\Delta t/V,$$

where σ_k is ionization cross-section of K-shells; ω_k, fluorescence exit probability; $P_{k_{a_j}}$, line probability; V, ring volume; Δt, charge state lifetime or measuring time. If we neglect the radiation absorption between the source and CDS and assume that all γ-quanta in the spectrometer are registered, so the number of registered photons will be $n_\gamma = n_f L\,\Delta V/V$, where ΔV is a part of electron ring being in the field of vision of CDS. The estimates show that if the multicharge Xe K_{a_1}, K_{a_2} spectra radiate, the CDS will register ~10 events per second and it will permit one to obtain the total spectrum with high resolution in some hours. The ERIS creation and its operation will permit one in combination with CDS to resolve following tasks:
- to investigate relativistic and quantum-electrodynamic corrections when the charges are high enought;
- to investigate the ions neutralization radiation;
- to investigate extremal populations, distributions of vacancies and the excited atom decay mechanism;

- to determine the ionization cross-section by electron impact in relativistic region of energies;
- to investigate the charge distribution of ions and degrees of stored ion ionization.

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Спектрометрический источник многозарядных ионов

Рассмотрены вопросы создания источника ионов с электронными кольцами ERIS на базе адгезатора коллективного ускорителя. Приведено расчетное изменение среднего заряда ионов ксенона при длительном удержании существующего электронного кольца и в дополнительно сжатом электронном кольце. Проведено сравнение ERIS с электронно-лучевыми источниками EBIS и источниками на электронно-циклотронном резонансе (ECR). Показано, что ERIS может иметь значительный выигрыш по интенсивности многозарядных ионов перед EBIS, а по зарядности ионов - перед ECR источниками. Проведены оценки эффективности совместной работы ERIS с кристалл-дифракционным спектрометром высокого разрешения и показано, что ERIS может успешно служить задачам рентгеновской спектроскопии многозарядных ионов.

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Spectroscopic Source of Multicharged Ions

The problem of creation of an ion source with electron rings ERIS on the base of Collective Accelerator Adgezator is discussed. The calculated change of Xe ion mean charge, at long confinement time and in supplementary compressed electron ring, is given. The comparison of ERIS with electron beam and electron-cyclotron sources is presented. It is shown that the ERIS can have considerable advantages in the intensity of multicharged ions compared with ERIS, and as to the ions charge - comparing to the ECR sources. The estimates of the crystal-diffraction spectrometer of high resolution with ERIS common work efficiency are given. It has been shown that the ERIS can be successfully used for the multicharge ion specrtoscopy.

The investigation has been performed at the Scientifical-Methodical Division of High Energy Physics, JINR.

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