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QUASIMOLECULAR KX-RAY EXCITATION BY BOMBARDING La TARGETS WITH La AND Xe IONS

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QUASIMOLECULAR KX-RAY EXCITATION BY BOMBARDING La TARGETS WITH La AND Xe IONS

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Возбуждение квазимолекулярного KX-излучения при облучении мишени La ионами La и Xe

Изучено рентгеновское излучение при облучении толстых мишеней La ионами Xe с энергией 85-150 МэВ и ионами La с энергией 115 МэВ. Измерены спектры X-лучей и определены их выходы. Обнаружены непрерывные распределения X-лучей с энергиями выше характеристического излучения мишеней и падающих частиц. Высокоэнергетические части сплошных спектров интерпретируются как KX-излучение квазимолекул с эффективными атомными номерами Z =111 и Z =114 соответственно.

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Quasimolecular KX-Ray Excitation by Bombarding La Targets with La and Xe Ions

The X-ray emission in the 85-to-150 MeV Xe and 115 MeV La bombardments of thick natural La targets has been measured. The spectra and yields of X-ray emission are obtained. Continuous X-ray distributions have been found to lie beyond the target and projectile characteristic X-ray energies. The high energy parts of these continua are interpreted as K-radiation of quasimolecules with effective atomic numbers Z = 111 and Z = 114, respectively.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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1. Introduction

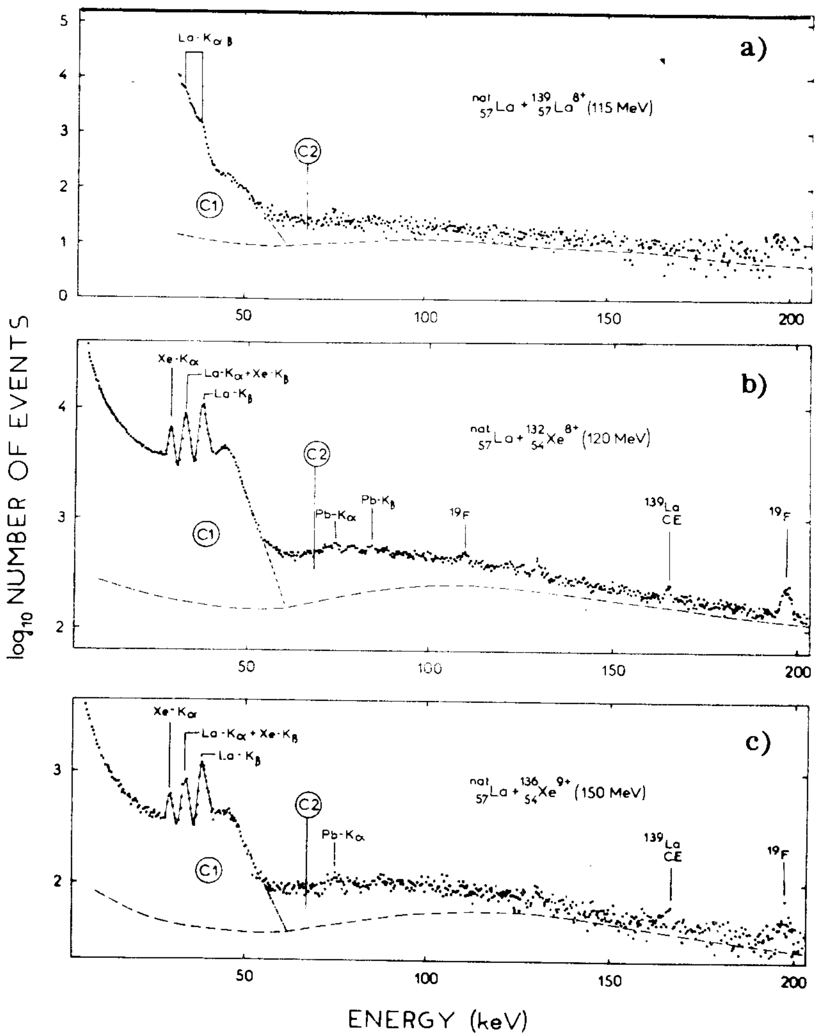
The possibility of observing new fundamental processes in quantum electrodynamics proposed by Greiner [1] and Popov [2] has motivated a recent search for KX-ray transitions between the transient molecular orbitals (MO) formed during collisions of heavy ions with heavy atoms.

Hitherto, quasimolecular KX-ray emission up to systems Nb + Nb (Z=82) have been investigated [3-7]. Experiments with high-energy La and Xe ions, described in this paper, first enable one to observe the MO KX-radiation of superheavy systems with Z = 114 and Z = 111, respectively.

2. Experimental Methods and Results

At the U-300 heavy ion cyclotron of the JINR Laboratory of Nuclear Reactions, $^{139}La^{8+}$, $^{132}Xe^{8+}$ and $^{136}Xe^{9+}$ ions were accelerated to an energy of 115, 120 and 150 *MeV*, respectively. In a subsequent measurement the energy of the Xe projectiles was decreased from 120 to 85 *MeV* by means of a 2.15 $mg\ cm^{-2}$ thick Au foil exposed near the reaction chamber.

Thick metallic natural La targets were used. They were irradiated at an angle of 45° with respect to the beam direction, whereas the X-ray emission was measured at 90°. The emitted X-rays were detected by an intrinsic Ge detector with a resolution of about 450 *eV* at 100 *KeV*, and two Ge(Li) detectors, whose resolution was better



X-ray spectra measured by bombarding thick natural La targets with (a) 115 MeV $^{139}La^{8+}$, (b) 120 MeV $^{132}Xe^{8+}$ and (c) 150 MeV $^{136}Xe^{9+}$ ions. The dashed lines denote the delayed background.

than 1.5 *keV* at 100 *keV* X-ray energy. In order to reduce the high rate of low-energy X-rays, Al foils were inserted between the target and detector. Thus, the counting rates (max. 60 s^{-1}) were low enough to avoid considerable pile-up contributions.

The beam pulsing of 2 *ms* beam-on and 2 *ms* beam-off time offered the possibility of reducing the background by measuring the spectra in a prompt-delayed regime.

The figure shows our experimental spectra without any corrections made. In the table the absolute and relative yields of the measured characteristic atomic X-rays and continuous components C1 and C2 are presented. The yields are determined after the subtraction of the background and after the correction made for the detector efficiency.

The figure shows the prompt X-ray spectra obtained by the La^{8+}, Xe^{8+} and Xe^{9+} ion-bombardments of thick natural targets. The spectrum (a) was measured in a 8.5 *h* run using a 2.0 cm^3 Ge(Li) planar detector and a 0.5 *mm* Al absorber. The ion current amounted to about 0.1 μA, corresponding to 7.8 x 10^{10} particles per second. The spectrum (b) was obtained using a 25 cm^3 coaxial Ge(Li) detector and a 0.5 *mm* Al absorber. The ion current was about 0.4 μA corresponding to 3 x 10^{11} particles per second. Finally, we obtained the spectrum (c) using the same detector and Al absorber, but with an ion current of about 0.1 μA which corresponds to 7 x 10^{10} particles per second.

As the figures show, the low-energy regions of all the spectra contain the characteristic KX-radiation of the projectiles and target materials, while in the region of higher energies two X-ray continua C1 and C2 can clearly be distinguished. The separation of these continua was carried out as shown schematically in the figure (dotted-dashed lines). The background shown in the figure consists of the delayed background measured.

The spectra (b) and (c) contain the fluorescence KX-radiation of Pb, which is produced in a cylindrical lead shielding surrounding the 25 cm^3 Ge(Li) detector. Further, a Coulomb excitation line (C.E.) of ^{139}La and those of the ^{19}F deexcitation are seen in the spectra. Before the yields of the continua C2 were calculated, the spectra were corrected for these effects. The dipole component of nuclear bremsstrahlung, which occurs as a

Table

Characteristic atomic KX-ray and continuous X-ray yields obtained by bombardment of thick La targets with La and Xe ions

IONS	E_0 (MeV)	TARGET	ABSOLUTE X-RAY YIELDS PER 10^9 PROJECTILES: $Y(KX_\alpha\text{-La})$	$Y(KX_\beta\text{-La})$	$Y(KX_\alpha\text{-Xe})$	$Y(C1)$ ①	$Y(C2)$ ②	RELATIVE YIELDS $Y(C2)/Y(KX_\alpha\text{-PROJECTILE})$
$^{132}Xe^{8+}$	85	La	—	$(1,5\pm0,3)\times10^1$	$(1,1\pm0,2)\times10^3$	—	—	—
$^{139}La^{8+}$	115	La	* $(2,9\pm0,5)\times10^3$	* $(3,6\pm0,6)\times10^2$	—	$(5,7\pm1,7)\times10^1$	$0,4\pm0,1$	$(1,4\pm0,6)\times10^{-4}$
$^{132}Xe^{8+}$	120	La	—	$(2,0\pm0,5)\times10^2$	$(8,5\pm3,3)\times10^3$	$(4,0\pm1,2)\times10^1$	$0,5\pm0,2$	$(5,9\pm4,1)\times10^{-5}$
$^{136}Xe^{9+}$	150	La	—	$(3,9\pm0,6)\times10^2$	$(1,8\pm0,6)\times10^4$	$(7,9\pm2,4)\times10^1$	$2,5\pm0,6$	$(1,4\pm1,0)\times10^{-4}$

* the La KX-yields are divided by 2 ① $E_x \geq 40$ keV ② $E_x \geq 58$ keV

competing effect to the quasimolecular X-ray continuum searched, was calculated /8/. The results of this calculation show that this component can be neglected under the present experimental conditions.

3. Discussion

At the impact energies used the orbital velocities of the K-shell electrons are large compared with the velocity of the incident particles. For example, at the 115 *MeV* impact energy the orbital velocity of the La-K electrons is about 10 times larger than that of the La ions. Hence, the spectra can be discussed in the framework of the molecular orbital model. In accordance with our results obtained previously /3-5/, we conclude that the continua C2 for all the colliding systems investigated are mainly formed by KX-radiation of the quasimolecules with the atomic number $Z = Z_1 + Z_2$.

The results (see the table) evaluated from the measured spectra demonstrate that the yields of the characteristic X-rays ($Y(K_\beta X\text{-La})$, $(Y(K_\alpha X\text{-projectile}))$ as well as the continuous quasimolecular yields $Y(C2)$ increase with increasing ion energy, whereas the relative yields $Y(C2)/Y(K_\alpha X$-projectile) remain nearly constant. This behaviour is in agreement with the results of the measurements of Armbruster et al. /9/ and with the calculations of Burch /10/, which show that the cross sections for both characteristic and quasimolecular X-ray excitation increase with increasing incident energies.

As in the X-ray spectra measured in the reactions Ge + Ge and Nb + Nb described elsewhere /3,4/, we found again continuous parts of X-radiation, which we denote C1 (shown in the figure). These continua C1 lie beyond the energies of the target and projectile characteristic X-rays. Their origin is still an open question. Electron bremsstrahlung cannot account for the continua C1, because the calculated yield integrals are four orders of magnitude smaller than the values measured /8/. Further, the models of Briggs and Macek /11/ and Müller /12/ predict for heavy ion collisions quasimolecular X-ray continua, described by a static approximation, with an endpoint energy near the united atomic limit and a smearing of the distribution beyond this "classical" limit, caused by dynamic effects. Generally, the continua C1 measured in our experiments look like the "static" distributions (in particular, they have shoulders as predicted in ref. [11]) but their end energies lie much lower than the united atomic limit.

In order to study the shape of the X-ray continua in dependence of the united atomic number $Z = Z_1 + Z_2$, we have recently carried out measurements of the colliding systems Ni + Ni (Z = 56) [13]. The X-ray continuum obtained extends beyond the united atomic limit but it does not permit the separation into two continuous parts either before or after making correction for the detector efficiency. On the other hand, in the Ge + Ge (Z=64) colliding system separation can be done after this correction [3] and in the heavier systems such as Nb+Nb (Z = 82) [4] and La + Xe (Z = 111) (this work) two continua can clearly be seen. So we conclude that the formation of two separated X-ray continua is mainly caused by the increasing atomic number Z of the colliding system. In the future, investigations of the angular asymmetry will be performed to obtain further information about the origin and character of these continua C1.

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