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QUASIMOLECULAR KX-RAY EXCITATION BY BOMBARDING Zr, Nb AND Mo TARGETS WITH 96 MEV Nb IONS

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Возбуждение квазимолекулярного KX -излучения при облучении мишеней Zr, Nb и Mo ионами Nb с энергией 96 МэВ

При бомбардировке разных мишеней ионами Nb с энергией 96 МэВ наблюдались сплошные спектры X -лучей, имеющих максимальные энергии в области энергий характеристических KX -лучей квазиатомов с ядерным зарядом $Z=Z_1+Z_2$. Высокоэнергетическая часть этих сплошных спектров интерпретируется как KX -излучение квазимолекул, которые образуются кратковременно в адиабатических столкновениях тяжелых ионов.

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Frank W., Gippner P., Kaun K.-H., Sodan H., Schulze W., Tretyakov Yu.P. **E7 - 8616**

Quasimolecular KX-Ray Excitation by Bombarding Zr, Nb and Mo Targets with 96 MeV Nb Ions

By bombarding various targets with 96 MeV Nb ions continuous X -ray distributions have been obtained, which range up to the KX-ray energies of quasiatoms with $Z=Z_1+Z_2$. The high energy parts of these continua are interpreted as KX-radiation of quasimolecules transiently formed during the adiabatic heavy ion-atomic collisions.

The investigation has been performed at the Laboratory of Nuclear Problems.

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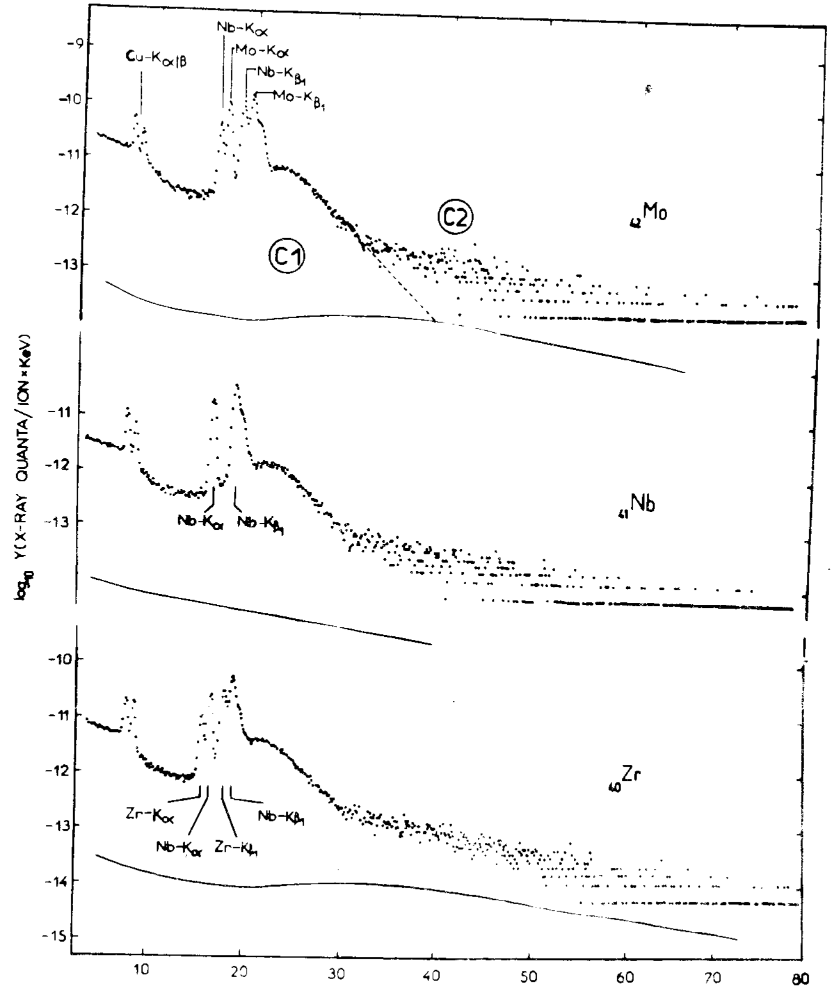
The possibility, first proposed by Greiner and coworkers [1], of observing new processes in quantum electrodynamics, as well as the predictions of some properties of quasimolecular X -rays [2] gave rise to numerous investigations of X -ray transitions between the transient molecular orbitals formed in heavy ion-atom collisions [3]. As an extension of our previous investigations of quasimolecular KX -ray emission in the collisions of 65 MeV Nb ions with the Zr, Nb, Mo and Rh target atoms [4], new measurements with Nb ions of higher energy have been performed.

At the U-300 heavy ion cyclotron of the JINR, Laboratory of Nuclear Reactions, Nb^{6+} ions were accelerated to an energy of 96.8 MeV. The ion source used was described elsewhere [5]. The ion current measured at the target position amounted to about 0.2 μA, corresponding to $2x10^{11}$ particles per second. 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 measurements were carried out with a target placed at an angle of 45° with respect to the beam direction, whereas the X -ray emission was measured at 90°. The data were obtained using a Si(Li) detector with an energy resolution of 300 eV at the X -ray energy of 6 keV [6]. The thickness of the target foils used exceeded the range of 96 MeV Nb ions [7]. The highly excited characteristic KX -radiation of the colliding atoms was strongly suppressed by 0.2 mm Cu and 0.5 mm Al absorbers. This allowed to get better statistics for the X -ray continua investigated. In addition, the counting rates ($\approx 50\ s^{-1}$) were low enough to avoid considerable pile-up contributions.



X-ray spectra measured by bombarding thick Zr, Nb *and* Mo *targets with 96 MeV* Nb *ions. The full lines show the background described in the text, the dashed line demonstrates the separation of the continua* (C1) *and* (C2).

The figure shows prompt X-ray spectra obtained by Nb^{6+} ion bombardment of Zr, Nb and Mo targets without any corrections made. The low-energy regions of all the spectra contain the well resolved characteristic KX-radiation of the projectiles, targets and the absorber materials, while in the region of higher energies two X-ray continua

TABLE 1: CHARACTERISTIC ATOMIC KX-RAY AND CONTINUOUS X-RAY YIELDS IN BOMBARDMENT OF THICK TARGETS WITH Nb IONS. THE HIGH-ENERGY CONTINUUM C2 IS INTERPRETED AS KX-RADIATION OF THE QUASIMOLECULES WITH $Z = Z_1 + Z_2$

E_0 (MeV)		TARGET	ABSOLUTE X-RAY YIELDS (1) PER 10^9 PROJECTILES								RELATIVE YIELDS	
			Y(KXα-TARGET)		Y(KXα-Nb)		Y(C1) (2)		Y(C2) (3)		Y(C2)/Y(KXα-Nb)	
Nb^{5+}	Nb^{6+}		Nb^{5+}	Nb^{6+}	Nb^{5+}	Nb^{6+}	Nb^{5+}	Nb^{6+}	Nb^{5+}	Nb^{6+}	Nb^{5+}	Nb^{6+}
65	-	$_{33}As$	-	-	9.4×10^3	-	0.9×10^4	-	<1	-	$\leq 10^{-4}$	-
65	96	$_{40}Zr$	5.1×10^5	7.1×10^5	2.7×10^5	4.5×10^5	1.0×10^5	1.9×10^5	8.2	23.5	$(3.0\pm0.6)\times10^{-5}$	$(5.2\pm1.2)\times10^{-5}$
65	96	$_{41}Nb$	2.3×10^5	8.1×10^5	2.3×10^5	8.1×10^5	6.2×10^4	2.6×10^5	7.0	25.2	$(3.0\pm0.6)\times10^{-5}$	$(3.1\pm0.8)\times10^{-5}$
65	96	$_{42}Mo$	3.4×10^5	4.9×10^5	5.8×10^5	7.4×10^5	2.4×10^5	4.9×10^5	15	26.4	$(2.7\pm0.5)\times10^{-5}$	$(3.6\pm0.8)\times10^{-5}$
65	-	$_{45}Rh$	4.4×10^4	-	4.6×10^5	-	1.8×10^5	-	4.3	-	$(0.9\pm0.2)\times10^{-5}$	-

1 Maximal error = ±30% (2) Y(C1): 16 keV $\leq E_x \leq$ 30 keV

3 Y(C2): $E_x \geq 30$ keV

can clearly be distinguished. The same picture has been observed in our experiments with 65 MeV Nb^{5+} ions [4]. In the table the absolute and relative yields of both components (C1) and (C2) of the measured X-ray continua for ion energies of 65 MeV and 96 MeV are presented. The yields are determined after the subtraction of the background and after the correction made for the detector efficiency. The background drawn in the figure consists of the delayed background measured, a prompt component fitted from the measured points above 85 keV X-ray energy and the calculated dipole component of nuclear bremsstrahlung (see the figure and ref. [8]).

To evaluate the yields of the low energy components (C1) of the continua, the energy region higher than 16 KeV was only taken into account, because the shape of these distributions for energies lower than 16 KeV is quite unknown. The separation of the continua (C1) and (C2) was carried out as shown schematically in the figure.

According to ref. [4] we assume that the continua (C2) for all the colliding systems we have investigated are mainly formed by quasimolecular KX-radiation. It follows from the table that the yields $Y(KX_{\alpha}-Nb)$ of the characteristic KX-radiation for projectiles, as well as the yields $Y(KX_{\alpha}$ -target) for target materials increase as the Nb ion energy becomes higher. This can be explained qualitatively in terms of the molecular orbital model. The ratio $Y(C2)/Y(KX_{\alpha}-Nb)$ for all measurements with 65 MeV Nb^{5+} ions is nearly constant. In the results obtained in the measurements with 96 MeV Nb^{6+} ions this value is considerably larger and varies within a factor of 1.7 in going from the system $Zr+Nb^{6+}$ to $Nb+Nb^{6+}$. This variation can not be due to statistic errors which amount to about 25%. The increase in the ratio $Y(C2)/Y(KX_{\alpha}-Nb)$ with increasing ion energy may be caused by the diminished mean distances between the partners in all of the collision systems investigated.

It seems natural to explain the appearance of the continua (C1) as due to the bremsstrahlung of secondary electrons, ejected from the inner shells of the target atoms as a result of heavy ion impact. However, the calculations

done by Anholt [9] on the basis of Folkman's theory [10] for 60 MeV Nb+Nb have a yield integral for the X-ray energy range between 16 KeV and 30 KeV, which is at least three orders of magnitude smaller than the value 6.2×10^{-5} per ion measured [4]. In addition one must, of course, consider the bremsstrahlung due to bound electrons ejected from the outer shells of the incident Nb ions. The cross section for this process was not calculated, but its inclusion is unlikely to account for the high yields Y(C1) observed [4]. After correcting for the detector efficiency and absorber attenuation, the linear extrapolation of the spectra (C1) in a logarithmic representation shows that the experimental yield Y(C1) goes down like E_x^{-n} with $n \approx 20$. This disagrees drastically with the results of Anholt [9] who found, that $n \approx 6$. Therefore, further theoretical and experimental investigations are needed to explain the origin of the conspicuous continua (C1).

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