E7 - 8006

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QUASIMOLECULAR KX-RAY EXCITATION BY BOMBARDING As, Zr, Nb, Mo AND Rh TARGETS WITH Nb IONS

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Возбуждение квазимолекулярного KX -излучения при бомбардировке атомов As , Zr , Nb , Mo и Rh ионами Nb

При бомбардировке разных мишеней ионами Nb с энергиями 65 и 40 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.

Препринт Объединенного института ядерных исследований. Дубна, 1974

Gippner P., Kaun K.-H., Sodan H., Stary F., Schulze W., Tretyakov Yu.P. **E7 - 8006**

Quasimolecular KX -Ray Excitation by Bombarding As , Zr , Nb , Mo and Rh Targets with Nb Ions

By bombarding various targets with 65 and 40 MeV 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.

Preprint. Joint Institute for Nuclear Research. Dubna, 1974

As an extension of our previous investigations of quasimolecular KX-ray emission in heavy ion-atom collisions [1], experiments with 65 MeV and 40 MeV Nb ions have been performed. The available information on quasimolecular KX-radiation [1,2,3] leads to the question of the influence of other processes contributing to the continua observed [4]. It is well known that, e.g., the dipole component of the nuclear bremsstrahlung strongly contributes to the high energy X-ray continuum. However, the cross section of this component contains the factor $(Z_1/A_1 - Z_2/A_2)^2$, where Z_1 and Z_2 are the atomic numbers and A_1 and A_2 the mass numbers of the projectile and target nucleus, respectively. Therefore, one can expect that for "exactly" symmetric systems of projectiles and target nuclei, for which the expression $Z_1/A_1 = Z_2/A_2$ is valid, the contribution of nuclear E1-bremsstrahlung to the examined X-ray continuum vanishes [5]. For this reason we have investigated the KX-radiation arising from the bombardment of Nb (with chemical purity of 99.999%), As, Zr, Mo and Rh targets with Nb^{5+} ions. In the case of the "exactly" symmetric collision system ${}^{93}_{41}Nb + {}^{93}_{41}Nb$ the intensity of nuclear bremsstrahlung should have been reduced by some orders of magnitude.

At the U-300 heavy ion cyclotron of the JINR, Dubna, Nb^{5+} ions were accelerated up to an energy of 65 MeV. An improved variant of the earlier described ion source [6] was applied, making use of cathode sputtering of solids for production of metallic ions. The ion current measured at the target position amounted to about 1 μA, corresponding to 10^{12} particles per second. In the measurement with 40 MeV Nb ions the energy of the projectiles was decreased from 65 MeV to 40 MeV by means of a 2.15 mg/cm^2 thick Au foil exposed near the reaction chamber. The experiments were performed at the γ-ray beam tract described previously [7]. The beam pulsing of 2 ms beam-on time and 2 ms beam-off time offered the possibility of reducing the background by measuring the spectra in a prompt-delayed regime. The targets were exposed at an angle of 45° with respect to the beam direction. The thickness of the target foils used was greater than the range of the 65 MeV ions except for the 0.9 mg/cm^2 Nb target (see table 1). For the detection of the KX-rays, a Si(Li) detector with a cooled FET preamplifier [8] and 300 eV energy resolution at 6 keV X-ray energy was used. The intensively excited KX-radiation of Nb and the target atoms has been strongly suppressed by using absorbers of 0.5 mm Al and 0.2 mm Cu. Due to a counting rate lower than 50 s^{-1} no pile-up effects were expected in the measurements described in this paper.

Figure 1 shows the measured prompt X-ray spectra obtained by bombarding some target materials with Nb^{5+} ions. Besides the intensive KX-lines of the absorber material, projectiles and targets atoms, the spectra contain continuous intensity distributions, which range up to energies of 70 - 80 keV. The logarithmic presentation of the spectra gives clear evidence for two distinct components in each of the continua. In table 1

the absolute and relative yields of these components for the investigated targets and for projectile energies of 65 MeV and 40 MeV are summarized. The yields are determined after the subtraction of the background and after correction for the detector efficiency. The background was evaluated from the measured points above 85 keV and was extrapolated to lower energies. For the low energy component (C1) only the energy region higher than 16 keV was taken into account, because the shape of this distribution for energies up to 16 keV is unknown.

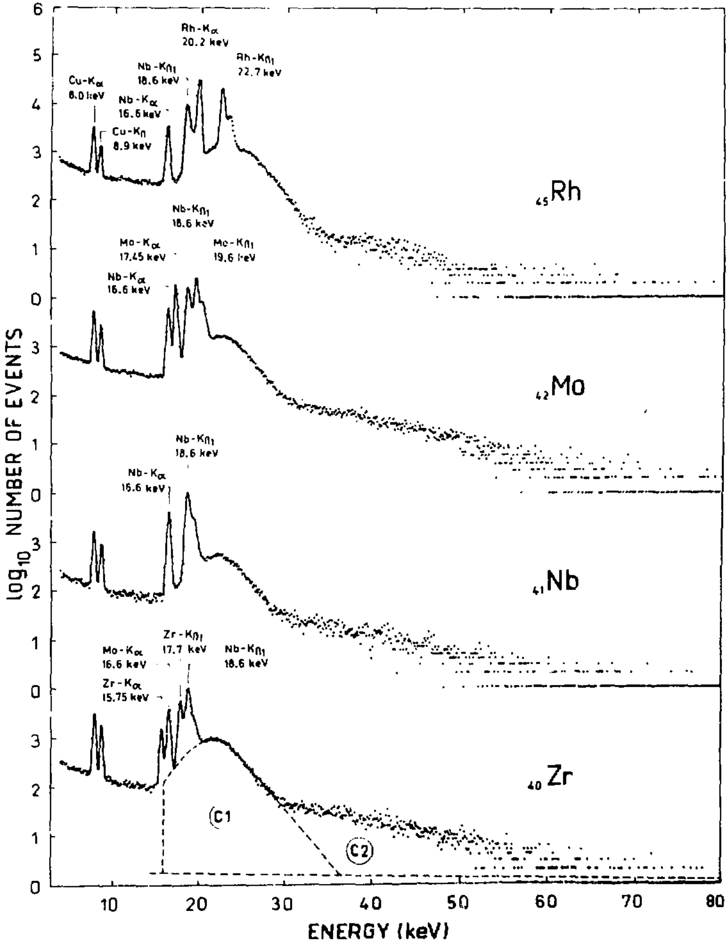

Fig. 1. X-ray spectra measured by bombarding thick Zr , Nb , Mo and Rh targets with 65 MeV Nb ions. No normalization of these spectra to equal charges was carried out.

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 $Y(KX_\alpha\text{-TARGET})$	$Y(KX_\alpha\text{-Nb})$	$Y(C1)$ ③	$Y(C2)$ ④	RELATIVE YIELDS $Y(C2)/Y(KX_\alpha\text{-Nb})$
65	$_{33}As$	—	9.4×10^3	0.9×10^4	<1	$< 10^{-4}$
65	$_{40}Zr$	5.1×10^5	2.7×10^5	1.0×10^5	8.2	$(3.0 \pm 0.6) \times 10^{-5}$
65	$_{41}Nb$	2.3×10^5	2.3×10^5	6.2×10^4	7.0	$(3.0 \pm 0.6) \times 10^{-5}$
65	$_{42}Mo$	3.4×10^5	5.8×10^5	2.4×10^5	15	$(2.7 \pm 0.5) \times 10^{-5}$
65	$_{45}Rh$	4.4×10^4	4.6×10^5	1.8×10^5	4.3	$(0.9 \pm 0.2) \times 10^{-5}$
65	$_{41}Nb$ ②	1.2×10^5	1.2×10^5	—	2.7	$(2.3 \pm 0.6) \times 10^{-5}$
40	$_{41}Nb$ ②	1.9×10^4	1.9×10^4	—	0.7	$(3.6 \pm 1.0) \times 10^{-5}$

① Maximum error = ± 30 %

② 0.9 $mgcm^{-2}$ thick targets

③ $Y(C1)$: 16 keV $\leq E_x \leq$ 30 keV

④ $Y(C2)$: $E_x \geq$ 30 keV

The separation of the low and high energy components of the continua was performed as is indicated schematically in fig. 1.

The yields of the characteristic KX -radiation show a behaviour which may be qualitatively explained by means of the molecular orbital (MO) model [9,10]. In accordance with this model the K shells of the lighter collision partner become preferably ionized, and the yields of target KX -rays decrease with increasing atomic number Z_2 . The high energy components (C2) of the continua have endpoint energies which nearly correspond to the energies of the characteristic KX -rays of quasiatoms with $Z = Z_1 + Z_2$. Because of the nearly exponential decrease of the high energy continuum, the endpoint energies are difficult to determine [4]. The energy value at which the spectrum intensity was 1% of its maximum value at about 30 keV was taken as an endpoint one. In practice, at these energies the intensities of the continua are equal to the evaluated background. Figure 2 shows the endpoint energies as a function of $Z = Z_1 + Z_2$ for our experiments with Nb ions (this paper) and Ge ions [1]. As can be seen from this figure, the observed continua have endpoint energies extended to the maximum energies of the quasimolecular KX -radiation. With increasing Z_2 the absolute yields Y(C2) show a relatively wide maximum at nearly symmetric collision systems (see table 1). The highest yield was obtained by the $_{41}$Nb– $_{42}$Mo collisions. This agree, in principle, with the results of ref. [11] where it is pointed out that multiple ionization of outer shells leads to a maximum of the K-electron promotion probability of projectiles (Z_1) for targets with atomic numbers $Z_2 = Z_1 + a$ ($a = 2, 3, 4$). As can easily be seen, for all collision systems with $Z_2 \leq 42$ investigated in this work the K-shell ionization of Nb projectiles is the main process for the formation of quasimolecular 1s vacancies. For $Z_2 = 40$–45 the relative yields $Y(C2)/Y(KX_a - Nb)$ are nearly the same and amount to about $3 \cdot 10^{-5}$. For nearly symmetric collision systems these values correspond to the MO intensities predicted by the simple model of Meyerhof [3] for the formation of 1s vacancies

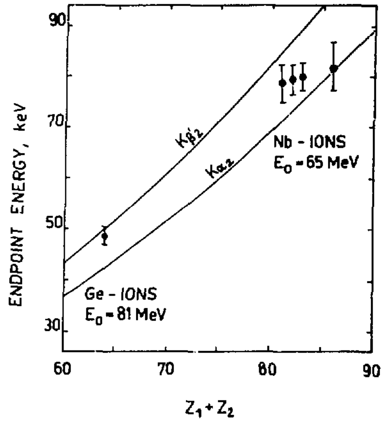

Fig. 2. Endpoint energies of the high energy components (C2) in our measurements with Nb ions (this paper) and Ge ions (ref. /1/). The solid lines correspond to characteristic KX-ray energies of atoms with $Z=Z_1+Z_2$.

in quasimolecules by one and two step collisions. These facts allow the conclusion that the components (C2) of the measured continua consist mainly of quasimolecular KX-radiation. This conclusion is confirmed by measurements with 65 MeV and 40 MeV Nb ions and a 0.9 mg/cm^2 thick Nb target which degrades the ion energy by about 10 MeV. As can be seen from table 1, the yields $Y(KX_\alpha-Nb)$ and $Y(C2)$ strongly depend on the incidence energy ($Y \sim E^p$, where $p \approx 3$), whereas the quotient $Y(C2)/Y(KX_\alpha-Nb)$ is nearly constant. Further the endpoint energy of the component (C2) does not vary within statistical errors.

The continua (C1) corrected for the detector efficiency decrease very rapidly with X-ray energy. By taking into account the results of refs. /12,13/ the interpretation of these continua by secondary electron induced bremsstrahlung seems to be suitable. On the other hand, a relative minimum in the yield Y(Cl) has been found for the collision system $_{41}$Nb + $_{41}$Nb. Therefore one can suppose that the continua (Cl) observed in the asymmetric collision systems are partially caused by the low energy parts of the nuclear dipole bremsstrahlung. Our future investigations will be aimed at confirming our interpretation of the continuous X-ray spectra by carrying out experiments with Nb^{6+} ions at an energy of about 100 MeV.

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