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ANISOTROPY AND ANGULAR DISTRIBUTION OF QUASIMOLECULAR KX-RADIATION EMITTED IN Ge+Ge COLLISIONS

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ANISOTROPY AND ANGULAR DISTRIBUTION OF QUASIMOLECULAR KX-RADIATION EMITTED IN Ge+Ge COLLISIONS

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Франк В. и др.

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Анизотропия и угловое распределение квазимолекулярного КХ-излучения, испускаемого при столкновениях Ge + Ge

Облучалась металлическая мишень из обогащенного ^{74}Ge ионами ^{74}Ge с энергией 54 МэВ. Наблюдаемый при этом спектр квазимолекулярного КХ-излучения имеет двухкомпонентную структуру. Определены с учетом допплеровского смещения энергии квантов анизотропия и дифференциальное угловое распределение квазимолекулярного КХ-излучения.

Работа выполнена в Лаборатории ядерных реакций ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1977

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Anisotropy and Angular Distribution of Quasimolecular KX-Radiation Emitted in Ge + Ge Collisions

An enriched ^{74}Ge target was bombarded with 54 MeV ^{74}Ge ions. The quasimolecular KX-ray spectrum obtained shows the two-component structure. By applying Doppler shift corrections the intrinsic anisotropy and differential angular distribution of the quasimolecular KX-radiation are determined.

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

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1. INTRODUCTION

The dynamics of the collision process in heavy ion-atom collisions leads to an anisotropic angular distribution of the quasimolecular X-radiation emitted during collisions, which manifests itself already in the anisotropy η defined by $\eta(E_x) = I(E_x, 90^\circ)/I(E_x, 0^\circ) - 1$. This effect was predicted in the theoretical work by Müller et al.[1] and first proved experimentally by Armbruster et al.[2], Kraft et al.[3], and Greenberg et al.[4]. The theoretical calculations as well as these first experiments have shown that the anisotropy $\eta(E_x)$ has a maximum lying near the energy of the united atomic limit of the systems with $Z = Z_1 + Z_2$. Because of this fact, it was suggested, as early as in the first papers, to use this effect for spectroscopy of the inner shells of the quasimolecule. This prospect has stimulated broad experimental and theoretical investigations of the anisotropy of the quasimolecular radiation. For instance, Smith et al.[5] were able to describe satisfactorily the measured $\eta(E_x)$ distribution in Ni+Ni experiments using their dynamical alignment-theory under the assumption of special 2p-alignments and taking into account the electron-slip effect[6].

The aim of the present paper is to get more experimental results on the anisotropy of the quasimolecular KX-rays of symmetric collision systems, lying in the region of atomic numbers $Z = Z_1 = Z_2 > 28$. For such collision systems as Ge+Ge, Nb+Nb and La+La [7-10] we have found that the quasimolecular KX-ray spectra ($E_x > E_{K\beta}$) have a two-component structure. This structure has been identified by systematic theoretical and experimental investigations as superposition of quasimolecular radiation emitted by transitions to the $2p\sigma$-MO level (low-energy component) and $1s\sigma$-MO level (high-energy component) [11,12]. Moreover, in the case of the Nb+Nb system it was possible to show convincingly that this double structure of the K-MO-spectra manifests itself in the form of the K-MO-function [9].

A logical step in the direction of the anisotropy studies of the MO-KX-rays is the investigation of the Ge+Ge system, whose atomic number lies between the atomic numbers of the Ni+Ni and Nb+Nb systems. Our earlier measurements have shown that in this system a two-component structure of the MO-radiation also exists [7]. Here we would like to report on the measurements carried out under better experimental conditions and at various emission angles Θ*.

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*The preliminary results of this investigation were already reported by K.-H.Kaun at the XI th International School on Nuclear Physics, Predeal, Romania, 1976.

2. EXPERIMENTAL TECHNIQUE

The experiments were carried out on an external beam from the U-300 heavy-ion cyclotron of the JINR Laboratory of Nuclear Reactions in Dubna. The principal experimental arrangement used to measure the angle anisotropy of the ^{74}Ge+^{74}Ge (54 MeV) system is shown in Fig.1 and has been described in detail elsewhere [9]. In order to decrease the room background the scattering chamber and the detector were surrounded by a special Pb shielding. The target was made of enriched ^{74}Ge (500 μg cm^{-2}) on a 0.21 mm thick pure Al-backing and was exposed at 45^{o} with respect to the beam direction. The ion current measured on the target amounted to about 40 nA corresponding to about $6 \cdot 10^{10}$ ions per second. The measurements were carried out at 90^{o} and 135^{o} with respect to the beam direction in front of the target and at 0^{o} and 45^{o} behind the target. No additional absorbers were used. Due to a counting rate lower than 70 s^{-1}, no electronic pile-up effects were expected in these measurements.

3. RESULTS

A typical x-ray spectrum emitted by the collision system Ge + 54 MeV Ge is shown in Fig.2. The spectrum displays characteristic lines due to Ge and Cu (the Cu content of the chamber material used is about 3 %) as well as a broad x-ray continuum lying above the atomic lines. This quasimolecular KX-radiation consists of two well-known components. In the spectrum one can also see a γ-line at 68.9 keV, which is emitted by Cou-

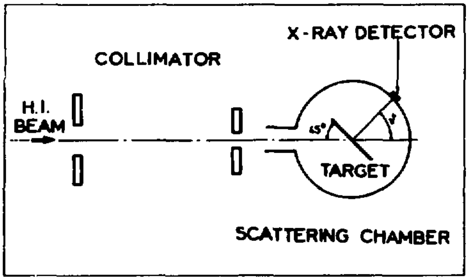

Fig.1. The principal experimental arrangement for the anisotropy measurements.

lomb excitation of ^{73}Ge contained in the highly enriched ^{74}Ge target. The dashed line in the spectrum represents the sum of the measured and calculated backgrounds (bremsstrahlung).

The following evaluation procedure was used to determine the anisotropy. First of all, the measured spectra were corrected for absorption effects in the Al-backing and target, for the detector efficiency, for background effects as well as for the angle-dependent Doppler shift using the mean center-of-mass velocity of the collision system. All the continua measured at different angles were normalized to the intensity of the ^{73}Ge Coulomb excitation line at 68.9 keV, which is assumed to be nearly isotropic.

Figure 3 shows the anisotropy $\eta(E_x)$ of the Ge + Ge system. From this figure one can see that $\eta(E_x)$ has a distribution with two clearly separated maxima. The low-energy maximum

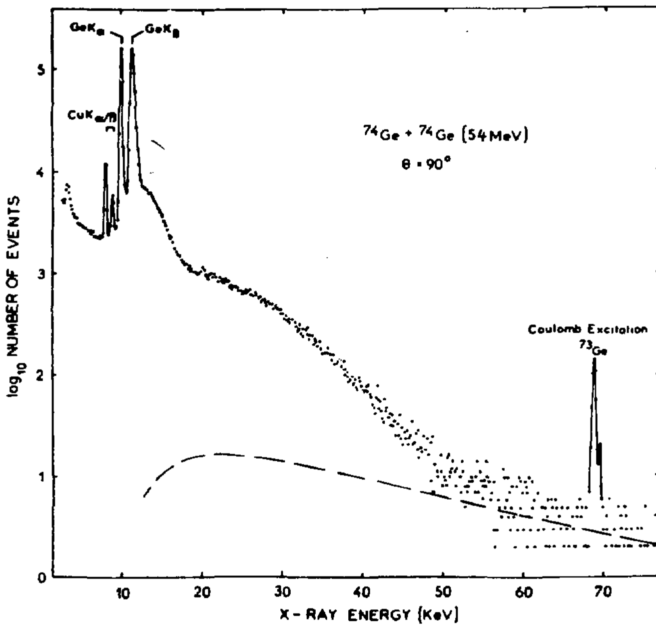

Fig.2. The x-ray spectrum obtained from the Ge + 54 MeV Ge system. The dashed line represents the sum of measured and calculated backgrounds.

is well defined, whereas the high-energy one is only a broad bump with large statistical errors due to background effects (room background and bremsstrahlung) taken into account exactly in the calculation of the anisotropy $\eta(E_x)$. The maxima are lying in the energy regions $E_x \approx 17$ keV and $E_x \approx 47$ keV, respec-

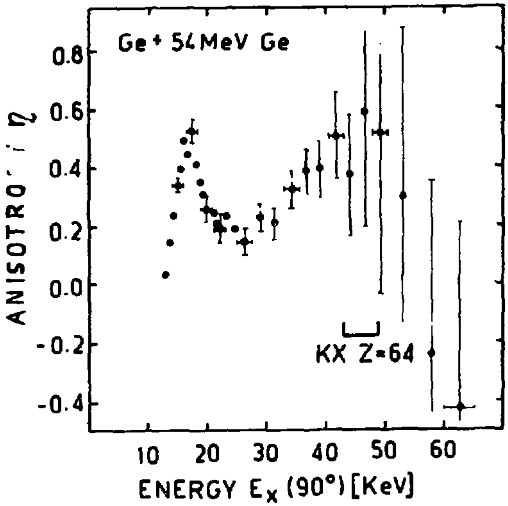

Fig.3. The anisotropy $\eta(E_x) = I(E_x, 90°)/I(E_x, 0°) - 1$ of the quasimolecular x-ray spectra obtained in the Ge + 54 MeV Ge measurements.

tively, and correspond to the maximum energies of possible transitions in the Ge + Ge quasimolecule to the $2p\sigma$ and $1s\sigma$ states at small internuclear distances. In both the anisotropy peaks the maximum magnitude amounted to about 50%.

Finally, in Fig.4 are shown the experimental results of the differential angular distribution investigations of the quasimolecular KX-radiation emitted by Ge+Ge collisions. In the figure are plotted the experimental yields normalized to the 90°-yields versus the emission angles Θ. Because of the

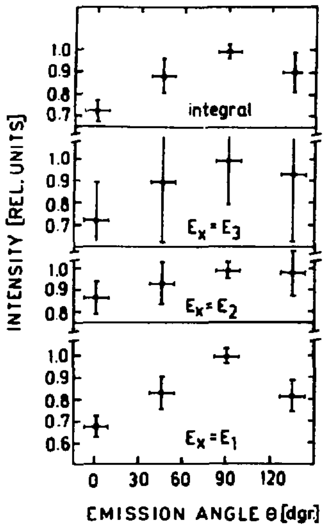

Fig.4. The differential and integral angular distributions obtained in the Ge+54 MeV Ge measurements $E_1 = (17.2 \pm 1.2)$keV, $E_2 = (26.6 \pm 1.2)$keV and $E_3 = (44.3 \pm 1.2)$ keV.

structure of the $\eta(E_x)$-function, three energy windows with a window width of $\Delta E = 2.4$ keV were set in the spectrum, lying at $E_1 = 17.2$ keV, $E_2 = 26.6$ keV and $E_3 = 44.3$ keV, respectively. Therefore, they are in the energy region of both maxima and the minimum of the $\eta(E_x)$ -function. In addition, the figure shows the angle distribution of the integral quasi-molecular yields ($E_x > E_{K_\beta}$). It can be seen from Fig.4 within the experimental uncertainty that in the energy region of both significant maxima of the $\eta(E_x)$-function (at E_1 and E_3) the distributions display a relative maximum around $\Theta = 90^o$, whereas in the region of the anisotropy mimimum (at E_2) no marked maximum is seen.

4. DISCUSSION

As in previous measurements using the Nb+Nb and La+La systems, in this new Ge-measurement a quasimolecular KX-ray spectrum having the two-component structure has been obtained. It was shown in more detail in refs.[11,12] that this structure is caused by superposition of the radiation due to transitions from higher states to the $1s\sigma$ and $2p\sigma$ levels. This structure manifests itself in the form of the $\eta(E_x)$-function. Both components of the quasimolecular spectrum have a characteristic energy-dependent anisotropy with maxima in the energy regions, which nearly correspond to the accepted maximum energies of transitions to the $2p\sigma$ and $1s\sigma$ states in the Ge+Ge-sytem . The same result was obtained by us already in the Nb+Nb investigations[9].

The results described in the present paper and covering our earlier findings on the Ni and Nb systems[8,9] lead to the following statements:

i) The quasimolecular KX-ray spectra emitted by symmetric collision systems with atomic numbers $Z=Z_1+Z_2>56$ display a two-component structure caused by superposition of the quasimolecular transitions to the $2p\sigma$ and $1s\sigma$ states at small internuclear distances.

ii) This structure is also seen in the form of the anisotropy function $\eta(E_x)$ of the collision systems. This function has two peaks lying near the accepted maximum energies of transition to the $2p\sigma$ and $1s\sigma$ states in the quasimolecule. The energetic position of the "$2p\sigma$"-peaks can be defined well, whereas this is difficult in the case of the "$1s\sigma$" bump because of its shape and bad statistics. This results from the fact that the cross section for molecular K-transitions is very small and above the united atomic limit the effect is already swamped by the background.

iii) The results of the measured differential angle distribution of the quasimolecular K-radiation show that in the region of the "$1s\sigma$"-and "$2p\sigma$" maxima of the $\eta(E_x)$-function, a distribution exists having a maximum magnitude at $\Theta = 90°$. More detailed in - vestigations must follow to support this first experimental finding.

As a result of the fact indicated above, the question arises as to how one can use this typical quasimolecular effect of the energy dependent angle asymmetry of the MO radiation to get information on the two-center levels in the quasimolecule. For lighter systems with $Z = Z_1 + Z_2 \lesssim 56$, following Wölfli/13/, this is ought to be possible for the $1s\sigma$-levels via the maximum of the $\eta(E_x)$-function. For heavy and superheavy collision systems an additional possibility opens up of the determination of the maximum energy of the transitions to the $2p\sigma$ level by means of the "$2p\sigma$" -maximum of the $\eta(E_x)$-function. As the results on different systems including La + La have shown/10/ , the "$2p\sigma$" -yields are by a factor of 10^2 to 10^3 higher than the "$1s\sigma$"-yields, so that measurements with a sufficiently small statistical error are possible. In addition, the internuclear distances, which are required for the emission of the "$2p\sigma$" -radiation, can materialize already at projectile energies of the order of 1 MeV/n. The full measurement of the

$2p\sigma$ -levels for such heavy and superheavy quasimolecules seems to be possible in experiments with the impact-parameter selection. Such experiments for lighter systems have been carried out recently by the group of Schmidt-Böcking et al. /14/.

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