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We have first shown in our previous experiments with Ge, Nb and La ions [1-3] that the x-ray continuum lying above the intensive characteristic KX-lines of the ions and the target material consists of low-energy and high-energy components, denoted by us as (C1) and (C2), respectively. The high-energy part (C2) of the continuum has been interpreted as quasimolecular KX-radiation. Besides the properties of the (C2) component, the physical nature of the low-energy component (C1) is of special interest. Competing effects such as REC, electronic and nuclear bremsstrahlung cannot account for this component of the x-ray continuum [4,5]. Recently, Heinig et al. [6] tried to give an explanation to the origin of the component (C1). The authors advanced the idea that the continuum (C1) is produced by intermediate L–K molecular-orbital transitions from higher terms to the $2p\sigma$ level.

In order to obtain additional experimental information about the proposed quasimolecular origin of both the components (C1) and (C2) of the x-ray continuum, we have performed experiments aimed at the determination of

(1) the velocity of the radiative system using the x-ray energy Doppler shift in the Nb + Nb collisions at 67 *MeV* and

(2) the laboratory anisotropy of the continuous x-ray spectrum of the Nb + Nb system.

There are two reasons why it is important to determine the Doppler shift of the continuous x-ray spectra from heavy-ion collisions. (1) If the x-rays are emitted by the projectile-target atomic system, the x-ray spectrum should be Doppler shifted in accordance with the centre-of-mass velocity of this system, irrespective of the detailed emission mechanism. (2) In order to extract an intrinsic anisotropy from experimental data, Doppler shift corrections are necessary. It has been shown that the interpretation of the experimental anisotropy of the quasimolecular x-rays is rather sensitive to the magnitude of the Doppler velocity /7/. Recently, Meyerhof et al. /8/ have proposed an experimental method for an independent determination of the emitter velocity for quasimolecular KX-radiation in the Kr + Zr system.

Our experiments were performed using an external beam from the U-300 heavy-ion cyclotron of the JINR Laboratory of Nuclear Reactions with a beam intensity of about 10^{12} particles/sec. Using the experimental arrangement shown schematically in *Fig. 1* we have

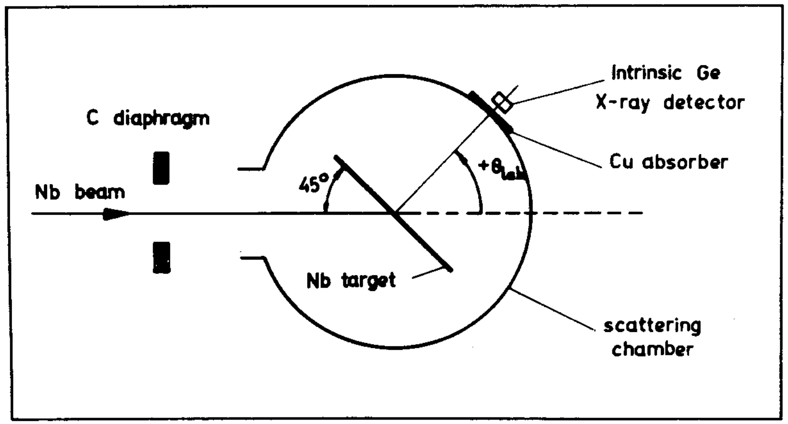

Fig. 1. The principal experimental arrangement for Doppler shift measurements.

measured the continuous spectrum from the Nb + 67 *MeV* Nb system to lie above the characteristic KX-lines. The reaction chamber with a diameter of 50 *mm* and a wall thickness of 1 *mm* was made of Al. The ion beam was collimated by a C diaphragm (ϕ 12 *mm*). The x-rays emitted were detected by an intrinsic $(25x5)mm^3$Ge detector. The energy resolution was better than 200 *eV* at an x-ray energy of 10 *keV*. The solid angle and the resolution of the emission angle amounted to about $1.8x10^{-2}\pi$ and $\Delta\theta$=16°, respectively. The target consisted of a 1.4 mg/cm^2 metallic pure niobium and was exposed at +45° with respect to the beam direction. The intensively excited KX-radiation of Nb atoms was strongly suppressed by using an absorber of 0.18 *mm* Cu. Due to a counting rate lower than 60 sec^{-1}, no pile-up effects were expected in these measurements.

The measurements were made at 90° and 135° with respect to the beam direction in front of the target and at 0°, -90° and 45° behind the target, respectively. The spectra obtained were corrected for target and absorber attenuation and for the detection efficiency. To minimize systematic errors, all continuous spectra were normalized to the $Nb-K_\alpha$ intensity (after a correction made for absorber attenuation of the Doppler shifted and non-Doppler shifted parts of the line). *Figure 2* shows a typical x-ray spectrum observed in the experiment at $\theta = 135°$ (θ is the angle between the x-ray emission and the beam direction). The dashed line represents the mean background measured in a delayed regime. The continuous x-ray spectrum has the two-component structure described above.

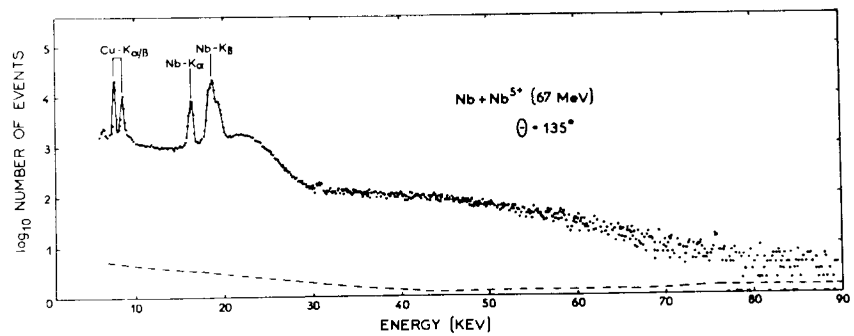

Fig. 2. The x-ray spectrum measured by bombarding a Nb *target with 67 MeV* Nb *ions. The dashed line represent the mean background measured in a delayed regime.*

To show that the measurements were not affected by systematic errors appreciably we present the ratio R of the normalized 90° lab. to -90° lab. spectra as a function of the lab. x-ray energy in *Fig. 3(a)*. No large systematic errors are apparent. *Fig. 3(b)* gives the 45°/135° yield ratio. Without the Doppler correction made the ratio differs from unity markedly. The deviation from unity seen in *Fig. 3(b)* occurs as a result of

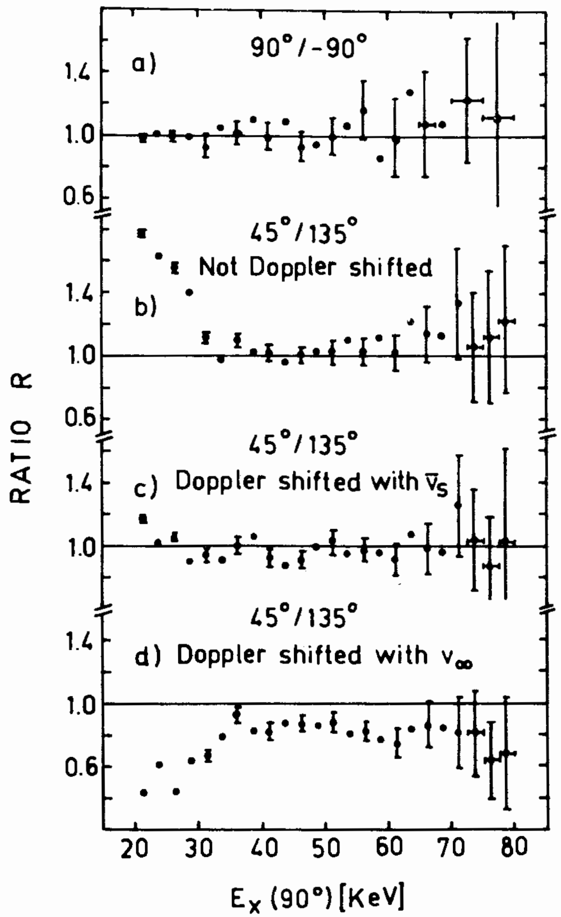

Fig. 3. Ratios of normalized x-ray spectra from Nb *+67 MeV* Nb *collisions, without (a), (b) and with (c), (d) the Doppler shift correction made.*

the fact that at angles of 45° and 135° the x-ray energy Doppler shift has an opposite sign. Therefore we corrected each spectrum for the Doppler effect on the x-ray energy, using the projectile velocity v_∞ to obtain the mean center-of-mass velocity $\bar{v}_s$. The resultant yields shown in *Fig. 3(c)* are very close to unity. Finally, *Fig. 3(d)* shows the corrected yields using the projectile velocity v_∞. Here, a strong overcorrection is seen.

From the results of the Doppler shift measurements we conclude that (1) the emitter velocity obtained for the MO radiation coincides with the mean center-of-mass velocity $\bar{v}_s$ of the Nb+Nb system and (2) both the components (C1) and (C2) of the x-ray continuum originate from quasimolecular transitions in the Nb+Nb system.

After determining the Doppler velocity for the Nb+Nb system in the experiment described above we can evaluate the intrinsic anisotropy η of the quasimolecular radiation as a function of the x-ray energy.

We have carried out measurements of the x-ray anisotropy in the region of quasimolecular continua (C1) and (C2) in the Nb + 67 *MeV* Nb system. The results of these experiments are shown in *Figs. 4* and *5*. Open and

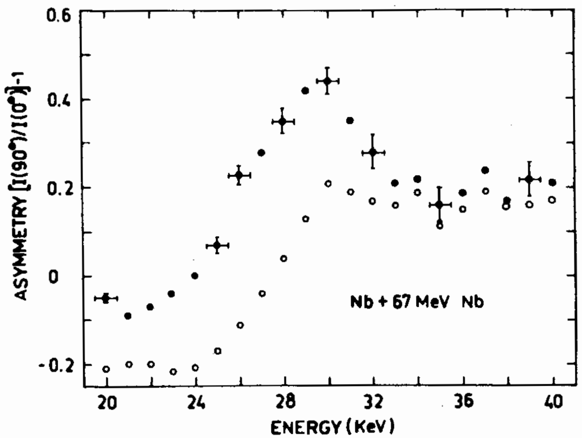

Fig. 4. The asymmetry $\eta = I(90°)/I(0°) - 1$ of the quasi-molecular x-ray spectra obtained in the Nb+67 *MeV* Nb *measurements. The open and closed circles show the η values without and with the Doppler correction, respectively.*

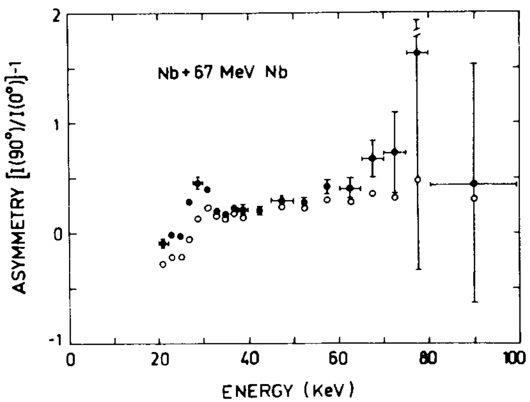

Fig. 5. See caption in Fig. 4.

closed circles denote the η values without and with the Doppler correction, respectively. The correction was introduced by the formula

$$E_m = E_0(1 + \frac{\bar{v}_s}{c}\cos\theta),$$

where E_m is the energy measured, $\bar{v}_s = 1/2\frac{\pi}{4} v_\infty$ is the mean c.m. velocity and θ is the photon emission angle. The $\bar{v}_s$ value has been calculated by integrating over all impact parameters corresponding to classical ion trajectories which intersect the K-shell radius of the Nb atom. One can see that after the Doppler correction made the asymmetry has two maxima in the energy regions of 29 *keV* and 80 *keV*, which just correspond to the maximum energies of the two continuum components (C1) and (C2) of the quasimolecular spectrum observed. At the same time they correspond to the maximum energies of possible transitions in the Nb + Nb quasimolecule to the $2p\sigma$ and $1s\sigma$ states at small internuclear distances (see *Fig. 6*).

It has been shown by Müller and Greiner [10] that the anisotropy of the continuum x-radiation is a typical quasimolecular phenomenon caused by induced transitions between molecular electronic states. Measurements of the directional anisotropy of the x-ray continuum furnishes a unique proof of the quasimolecular nature of the radiation measured. Therefore our new results on the angular asymmetry of both the components provide at least additional independent experimental evidence in favor of the previous interpretation of quasimolecular K x-ray spectra as having the two-component structure.

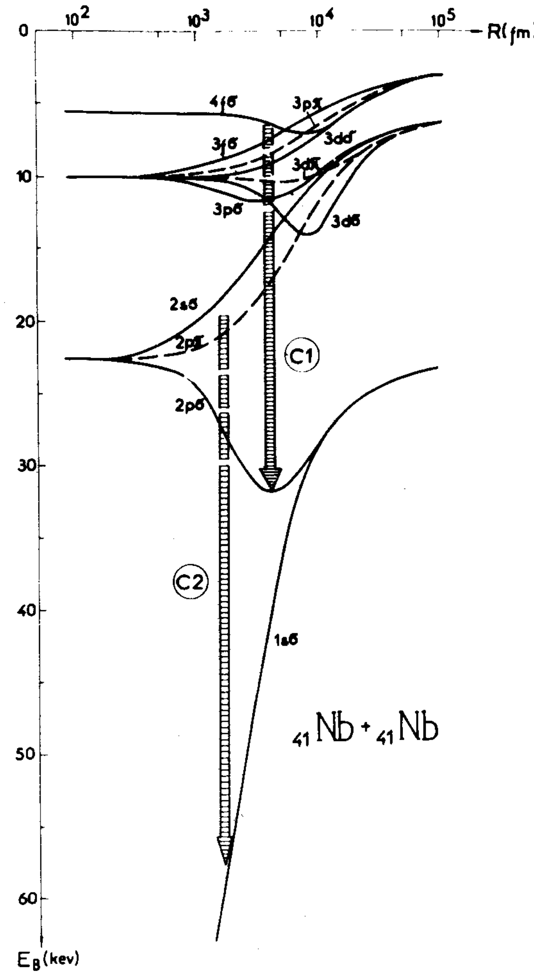

Fig. 6. Quasimolecular levels of the Nb + Nb *system calculated by N.F.Truskova* [9].

Our experimental findings lead to the following conclusions: i) the x -ray continuum having the two-component structure in the Nb+67 *MeV* Nb system is indeed produced by the quasimolecule with Z =82, and ii) both the anisotropy maxima are correlated to the maximum energies of possible transitions in the Nb+Nb quasimolecule to the $2p\sigma$ and $1s\sigma$ states at small internuclear distances. These results will stimulate future spectroscopic studies of superheavy quasimolecules.

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