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ОБЪЕДИНЕННОГО
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ДУБНА

E7 - 9946

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SEARCH FOR INTENSITY OSCILLATIONS IN QUASIMOLECULAR KX-RAY SPECTRA OBSERVED IN HEAVY ION-ATOMIC COLLISIONS

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SEARCH FOR INTENSITY OSCILLATIONS IN QUASIMOLECULAR KX-RAY SPECTRA OBSERVED IN HEAVY ION-ATOMIC COLLISIONS

1. INTRODUCTION

In refs.[1,2] it was reported on intensity oscillations superimposed on the quasimolecular KX-ray continuum obtained by the investigation of the Ni+Ni collision system. This work has inspired an intensive search for oscillations in MO X-ray spectra of different colliding particles[3-6]. As it is outlined in ref.[1], fluctuations of the intensity were observed in the single X-ray spectrum of the Ni+Ni system, immediately beyond the characteristic $K_{\alpha/\beta}$ lines of Ni. They were tried to be explained[2] by sudden perturbations of the atomic and/or molecular wave functions. The concept advanced so far on the formation of such perturbations may be interpreted in the following way. It can be supposed that for distances $R > R_c$ between the colliding nuclei the atomic K shells were screened by outer electrons, to a large extent, from the Coulomb interaction of the partner ion. However, for $R \approx R_c$ the outer quasimolecular states are expected to be formed and a more or less discontinuous change of the screening as well as a sudden disturbance of the K-states is conceivable. Within the relaxation time $\Delta\tau$, where the internuclear distance R_c decreases by $\Delta R_c = v_1 \Delta\tau$, (R_c is a critical radius and v_1 the velocity of the incident ions) this disturbance may vanish and quasimolecular $2p\sigma$ and $1s\sigma$ terms may originate. Further, the authors /2/ believe that a K-vacancy was formed either in a former collision (multiple collision process) or in the collision considered, but at a time prior to $R = R_c$ (one collision two-step process). As a result of the disturbances mentioned above, the molecular transition amplitude of outer electrons to this vacancy on a K-term exhibits an oscillating form /2/ and may explain the observed fluctuations of the intensity.

2. EXPERIMENTAL RESULTS

In refs./5,6/ we described experiments to prove the intensity oscillations in the Ni + Ni (67 MeV) collision system using as a target a thin metallic foil of natural Ni with a thickness of 1 mg/cm^2. The target was placed at an angle of 45° with respect to the beam direction. This caused an effective thickness of 1.4 mg/cm^2 leading to a 30 MeV energy loss of the 67 MeV Ni ions. Except for the chamber wall and a 30 μm thick Be window, which separated the Ge X-ray detector from atmosphere, no absorbers were used.

Figure 1 shows that beyond the Ni lines, intensity oscillations superimposed on the X-ray continuum were not observed. The peak seen at an energy about twice the Ni K_α transition energy seems to be produced by two electron-one photon transitions, which were recently measured by Wölfli et al./7/ with sufficient reliability in Ni + Ni , Ni + Fe and

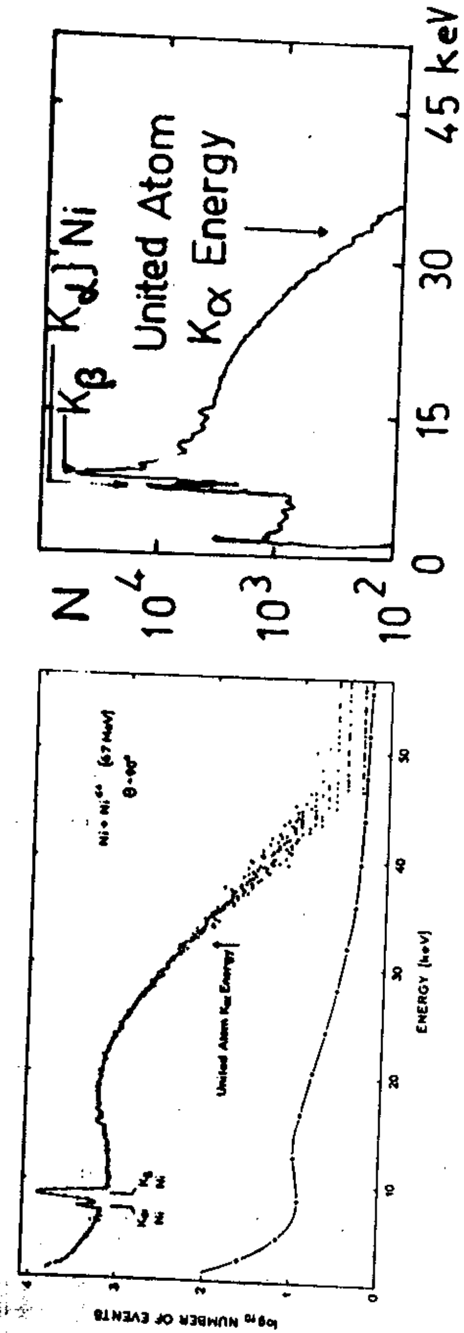

Fig. 1. a) The X-ray spectrum of the Ni + ^{60}Ni (67 MeV) collision system measured by our group. The target consisted of a 1 mg/cm^2 metallic foil. The detector was exposed at 90° with respect to the beam direction. b) The X-ray spectrum of the ^{58}Ni + ^{58}Ni (70 MeV) collision system reported in ref./1/. A ^{58}Ni target with a thickness of only 200 μg/cm^2 was used. The detector was exposed at 90° with respect to the beam direction. In the energy region lying immediately above the NiK_β line the measured intensity oscillations of the quasimolecular KX-radiation can clearly be seen.

$Fe + Fe$ collision systems. As it is pointed out in ref. [2], the cross sections of the intensity oscillations based on sudden distortions and rearrangements in the atomic or molecular K-states are dependent on the velocity v_i of the incident particles. Hence, we believed to have observed a superposition of incoherent intensity oscillations caused by Ni ions in the energy range between 67 MeV and 37 MeV, which may extinguish partially or completely the effect we have looked for. In order to prove this suggestions we computed for the system $Ni + {}^{60}Ni$ the incoherent sum

$$\overline{\frac{d\sigma_{osc}(\omega)}{d(\hbar\omega)}}^{E} = \frac{1}{n}\sum_{i=1}^{n} \frac{d\sigma_{osc}(\omega, E_i)}{d(\hbar\omega)} \qquad (1)$$

of the oscillating cross sections. In accordance with ref. [2] we used

$$\frac{d\sigma_{osc}(\omega, E_i)}{d(\hbar\omega)} = R_c^2 \hbar\omega M_{if}\, e^{-2|\omega-\omega_{if}|\Delta R_c/v_i} \left[\frac{1}{2}(a_1^2 + a_2^2) + a_1 a_2 \left(\frac{\sin 2x}{x} - \left(\frac{\sin x}{x}\right)^2\right)\right], \qquad (2)$$

where $x = \frac{R_c(\hbar\omega - \hbar\omega_{if})}{\hbar v_i}$ is a dimensionless parameter, $\hbar\omega_{if}$ is the energy of the characteristic K_α -transition (8 keV in the case of $Ni + Ni$), $v_i = v_i(E_i)$ is the velocity of the incident ions taking into consideration the remarkable slowing-down in the target material (for E_i we have chosen the values of 70; 65; 60; 55; 50...40 MeV).

The matrix elements M_{if} contain the structure of initial and final molecular states and were assumed to be constant in our case. Finally, a_1 and a_2 are arbitrary quantities, which we have chosen to be equal to unity for the sake of simplicity.

Figure 2 shows the values $\frac{d\sigma_{osc}(\omega, E_i)}{d(\hbar\omega)}$ computed according to formula (2) for the $Ni + {}^{60}Ni$ system using $R_c = 25000$ fm and $2\Delta R_c = 1000$ fm. This figure is representative for all of our results obtained for different values of R_c (10000 - 25000 fm) and $2\Delta R_c$ (0 - 2000 fm).

Figure 3 presents the incoherent cross section sum (1). Using $R_c = 25000$ fm for the critical internuclear distance there are illustrated the mean values $\overline{\frac{d\sigma_{osc}(\omega)}{d(\hbar\omega)}}^{E}$ for $2\Delta R_c = 0$, 1000 and 2000 fm, respectively.

For the collision system $Nb + Nb$ (67 MeV) for a target with the effective thickness of 1.2 mg/cm^2, we obtained results analogous with those shown in fig. 3.

3. CONCLUSIONS

The theory outlined in ref. [2] gives reasons for intensity oscillations of the quasimolecular KX -radiation which should be observed also in experiments with "thick" targets. As fig. 3 demonstrates, at least one maximum and one minimum of the oscillations we have looked for should occur immediately below and above the characteristic transitions. Unfortunately, the oscillations below these lines can be observed only with

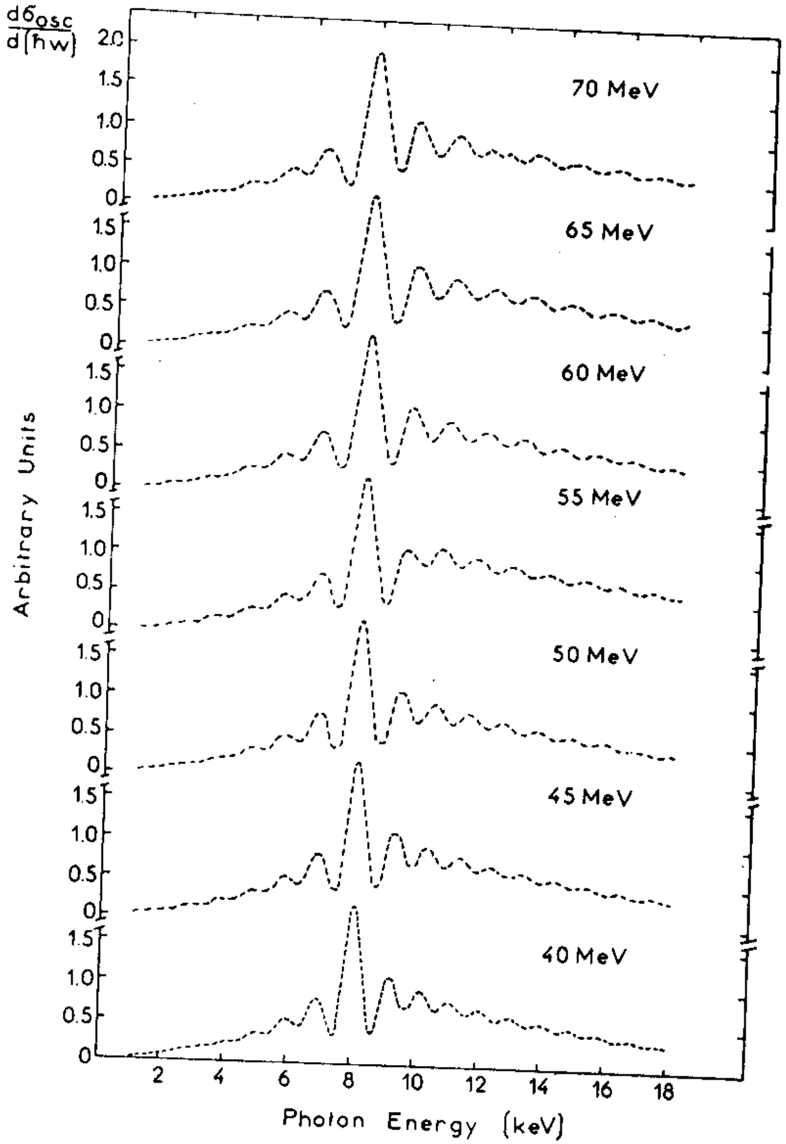

Fig. 2. The oscillating cross section $\frac{d\sigma_{osc}(\omega,E_i)}{d(\hbar\omega)}$ for the $Ni + {}^{60}Ni$ collision system in arbitrary units. The energies of incident Ni ions are given as parameters. The calculations are carried out using $R_c = 25000$ fm and $2\Delta R_c = 1000$ fm.

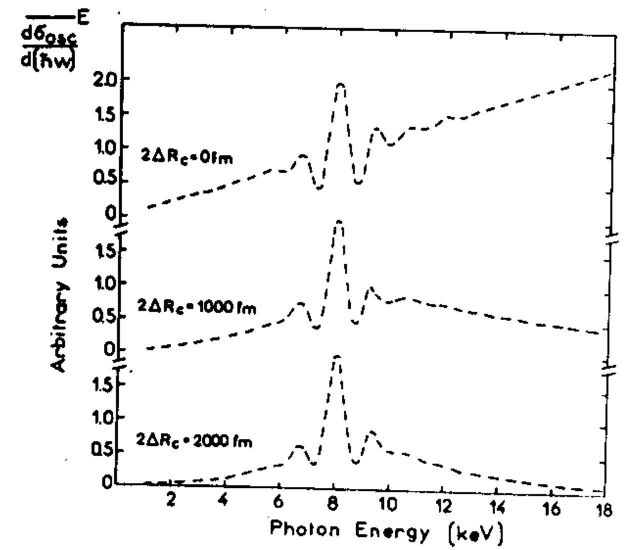

Fig. 3. The mean value $\overline{\frac{d\sigma_{osc}(\omega)}{d(\hbar\omega)}}^{E}$ for incident ion energies in the region $E_i = 70\text{-}40$ MeV.

difficulty, because usually an absorber is used to prevent the pile-up effects. Nevertheless, the oscillations beyond the characteristic lines should clearly be observable. Therefore, although the effect predicted in ref. /2/ probably exists, it can scarcely be measured with such a great amplitude as it is done in ref. /1/.

The authors would like to thank Academician G.N.Flerov for his valuable interest in the problem.

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Received by Publishing Department on July 6, 1976.