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QUASIMOLECULAR KX-RAY EXCITATION BY BOMBARDMENT OF Ge ATOMS WITH Ge IONS

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1. Introduction

In order to explain some characteristic features of the inner shell ionization in heavy ion-atom collisions, the transient formation of quasimolecules has been assumed /1,2/. In spite of the success of this hypothesis, a direct evidence would be provided by the observation of the characteristic X -radiation of the quasimolecules. No sharp X -ray lines are to be expected because the level energies continuously depend on the distance between the colliding atoms. Some band-like weak intensity distributions were interpreted as quasimolecular L -radiation /3/ and M -radiation /4/ the latter being attributed to superheavy quasiatoms of $Z = 132$, 143 and 145. On the other hand, the observation of a continuous distribution /5/ has been ascribed to the KX -radiation of quasimolecules formed in ${}_6C + {}_6C$ collisions. The maximum energy (about 1 keV) of the continuum corresponded to the energy of ${}_{12}Mg$ KX-rays.

Symmetric collision systems are advantageous for such investigations because of their maximum inner shell vacancy production /6/. Moreover, the use of monoisotopes is favoured by the vanishing cross section of E1 - bremsstrahlung excitation /7/. We, therefore, investigated the systems ${}^{nat.}_{32}Ge + {}^{74}_{32}Ge$ and ${}^{74}_{32}Ge + {}^{74}_{32}Ge$.

2. Experimental Arrangement

At the U-300 heavy ion cyclotron of the JINR, Dubna, ${}^{74}Ge^{5+}$ ions were accelerated to an energy of 81 MeV. The ion current measured at the target position amounted to $1 \mu A$, corresponding to about 10^{12} particles per second. The experiments were performed at the γ-ray beam tract described previously /8/, but with a Si(Li) detector and a cooled FET-preamplifier /9/ of 400 eV energy resolution at 20 keV X-ray energy. Figure 1 shows the LX- and γ-ray spectrum of ^{241}Am, which served for the energy calibration. Because of a thick absorbing window, the maximum spectrometer efficiency was achieved at 26 keV.

The target of natural germanium consisted of a single crystal slice 220 mg/cm² thick, whereas the ^{74}Ge target (enriched to 99.9%) was composed of small 55 mg/cm² thick foil pieces sticked onto a 1.4 mg/cm² aluminium foil.

3. Results

The measured spectra of the natural Ge target and the enriched ^{74}Ge target are shown in figs. 2 and 3, respectively. In both cases a continuous intensity distribution was observed, ranging up to an energy of 40-50 keV, which corresponds to the KX-ray energies of $_{64}Gd$. The intensively excited Ge KX-ray lines are strongly suppressed, because of the window absorption. Due to a low counting rate of only 60/s no pile-up effects are to be expected in the spectrum of the natural Ge target.

From the intensity ratio of the Compton distribution to the 60 keV photo peak shown in fig. 1 it was concluded that at energies above 10 keV the Compton distribution of the Coulomb excited 68 keV γ-ray line (fig. 2) contributes only 0.7% to the continuum observed. The Coulomb excited ^{73}Ge γ-ray lines and the nuclear bremsstrahlung continuum of the neighbouring Ge isotopes were avoided by using the enriched ^{74}Ge target. Unfortunately the ^{74}Ge taken from the cyclotron ion source was contaminated with soldering tin so that the spectrum presented in fig. 3 contains also the KX-ray lines of Sn and the LX-ray lines of Pb. The latter were

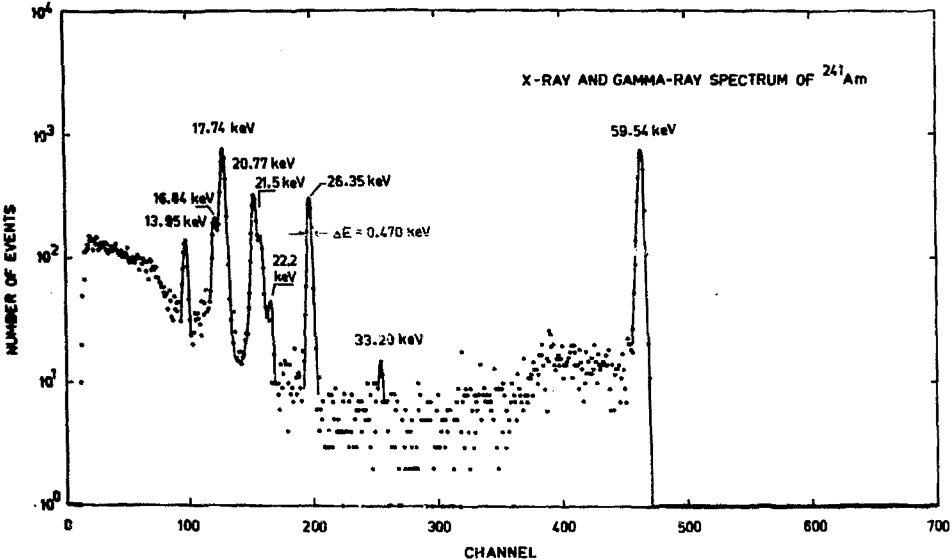

Fig. 1. LX-ray and γ-ray spectrum of the ^{241}Am decay, measured with the Si(Li) spectrometer.

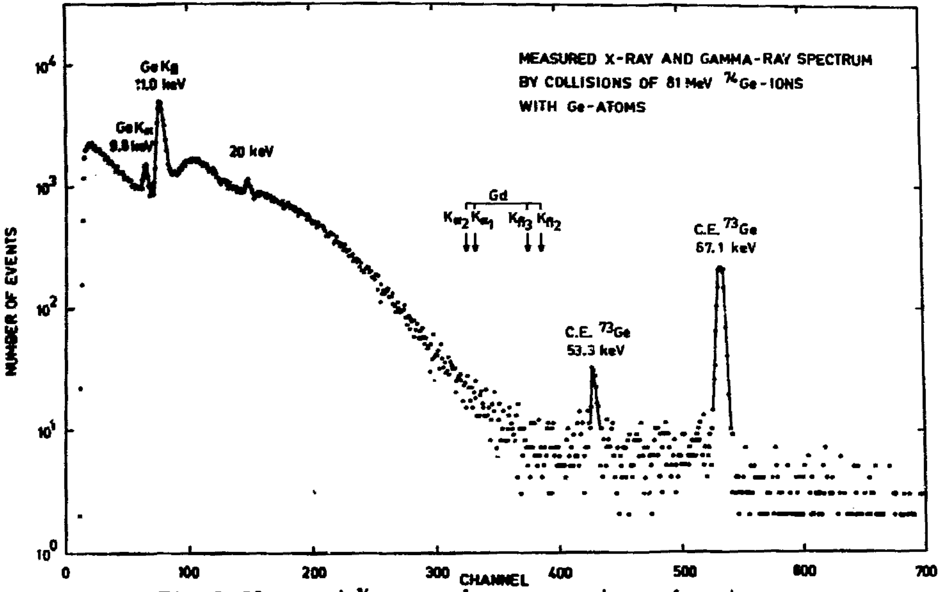

Fig. 2. Measured X -ray and γ -ray spectrum of a natural Ge target bombarded by 81 MeV - ^{74}Ge ions. The measuring time was 3 hours, the ion current about $1 \mu A$.

detected with high efficiency and could, in principle, contribute to the observed continuum up to an energy of about 32 keV, owing to the pile-up effects. An estimation of the E1 -bremsstrahlung yield /7/ shows that the lead isotopes give rise to nearly the tenfold intensity as compared with the various germanium isotopes (fig. 2), while the weighted mean value for the tin isotopes gives a value close to that for Ge isotopes. The spectrum shown in fig. 3, may, therefore, also contain a big contribution from bremsstrahlung radiation.

The line at 20 keV observed in both spectra could not be explained. The line shape and the low Ge KX-ray counting rates exclude it to be due to the pile-up effect though the energy corresponds to twice the energy of the Ge K_{α}X-ray transition.

4. Discussion

The spectra shown in figs. 2 and 3 corrected for the detector efficiency are given in figs. 4a and 4b. A small background has also been subtracted. The logarithmic presentation gives clear evidence of the existence of two distinct continua in each of the spectra. The low energy continuum may be ascribed to nuclear bremsstrahlung. Because the high energy continuum in both cases has a maximum energy which corresponds nearly to the KX-ray energy of $_{64}$Gd, we may conclude that it mainly consists of quasimolecular radiation. After the experiment had been performed we got aware of the results of Meyerhof et al. /10/, which show a similar behaviour but with much poorer statistics, because the collected charge amounted only to 100μC, compared with about 10 mC collected in our experiment with natural germanium. For estimating the yield of quasimolecular radiation, in figs. 4a and 4b the area of the high-energy continuum was determined after the subtraction of a constant background and of the extrapolated low-energy continuum. In order to avoid any Ge KX-ray pile-up contribution, only the energy range above 22 keV was taken into account. The

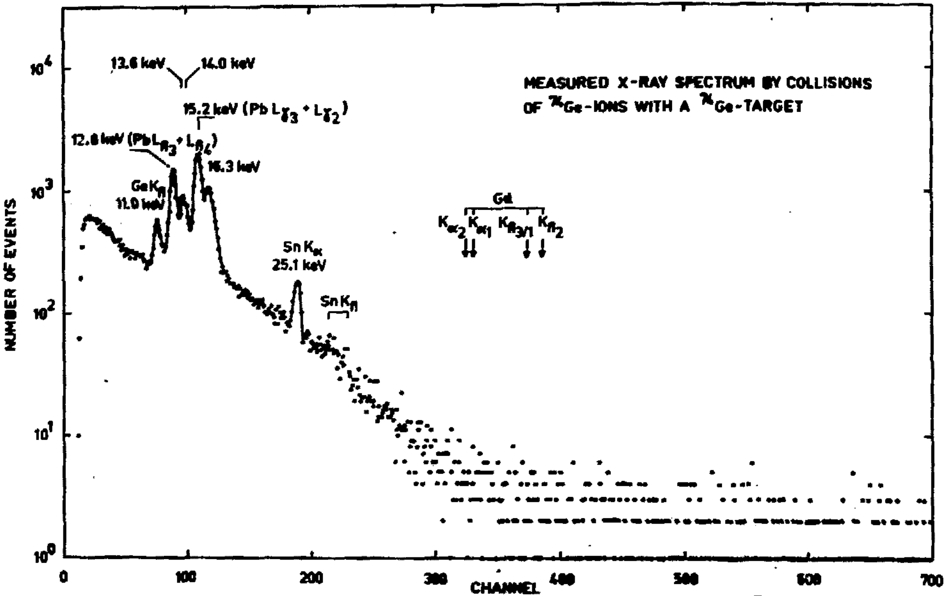

Fig. 3. Measured X-ray spectrum of an enriched ^{74}Ge target bombarded by 81 MeV - ^{74}Ge ions.

ratio of the continuum area to the Ge $K_\beta X$ -ray amounts to

$$\frac{N_{\text{cont.}}}{N_{K_\beta}} = 3.7 \times 10^{-4}$$

for the natural germanium target. For the enriched ^{74}Ge target the value 9×10^{-4} was obtained, which is possibly exaggerated by a lead LX-ray pile-up contribution to the lower part of the quasimolecular continuum.

Taking into account the K_β / K_α intensity ratio * for germanium /11/, we obtain

$$\frac{N_{\text{cont.}}}{N_{K_\alpha + K_\beta}} = 4.4 \times 10^{-5}.$$

This value can be compared with the yield per beam K vacancy given by Meyerhof et al. /10/ if we take the fluorescence yield ω_K into account and consider the number of beam vacancies to be a half of the total number of K vacancies. For ω_K we took the tabulated value /11/ $\omega_K = 0.49$ because ω_K weakly depends on the outer-shell ionization state /12/. In this way we obtained the yield of quasimolecular radiation per beam K vacancy of

$$\frac{N_{\text{cont}}}{N_{K,\text{beam}}} = 3 \times 10^{-5},$$

which is considerably lower than the value 10^{-4} of Meyerhof et al. /10/ for the system KBr + Br.

In the measurement with the natural $_{29}Cu$ target a weak twofold continuum was also obtained, where the maximum energy of the upper part corresponded nearly to the KX-ray energy of $_{61}Pm$.

In order to identify unambiguously the found continua as quasimolecular KX-radiation, further experiments are in preparation. To avoid the E1-bremsstrahlung contribution completely, pure symmetric (i.e., monoisotopic) systems such as $^{93}_{41}Nb + ^{93}_{41}Nb$ are to be preferred.

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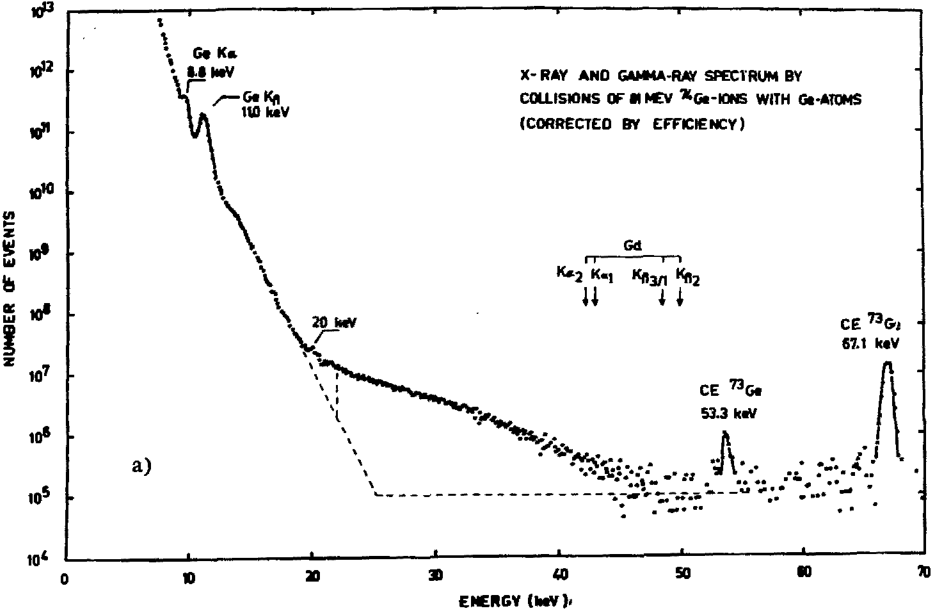
*For heavy ion excitation this ratio is mostly found to be smaller than that for electron excitation, due to the additional outer shell ionization. The given intensity ratio may, therefore, be overestimated.



X-RAY AND GAMMA-RAY SPECTRUM BY
COLLISIONS OF MEV Ge-IONS WITH Ge-ATOMS
(CORRECTED BY EFFICIENCY)
Ge Kα
8.8 keV
Ge Kβ
11.0 keV
20 keV
Gd
Kα2 Kα1 Kβ3/1 Kβ2
CE 73Ge
53.3 keV
67.1 keV
a)
NUMBER OF EVENTS
ENERGY (keV)

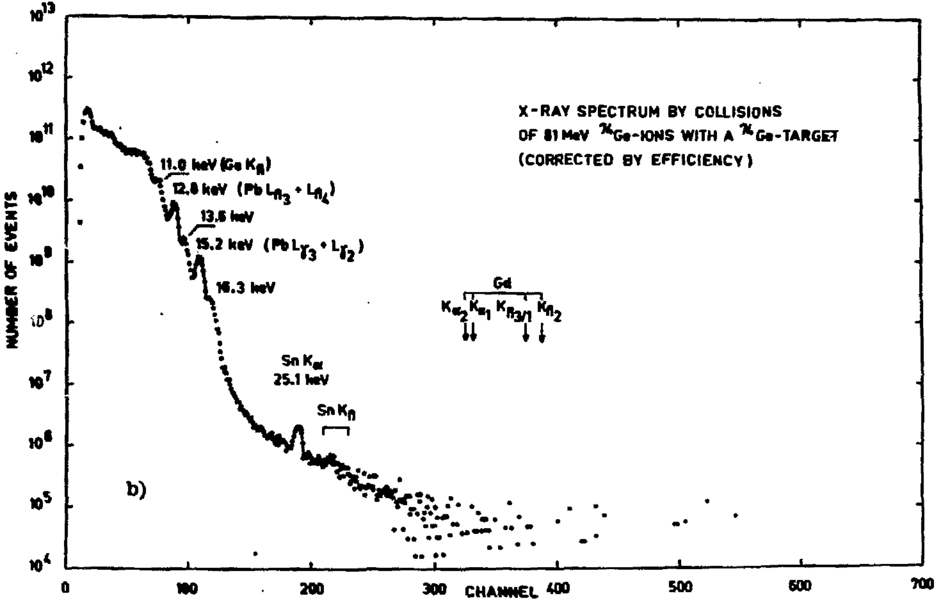


Fig. 4. X -ray spectra, corrected for the detector efficiency, obtained by bombardment of a natural Ge target (a) and an enriched ^{74}Ge target (b) with 81 MeV - ^{74}Ge ions.

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