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GSI-95-05
PREPRINT
JANUAR 1995

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(To be published in Z. Phys. A)

SW95024

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Submitted to Zeitschrift für Physik A,
Dezember 20, 1994

Short Note

The New Element 111

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PACS: 21.10.Dr; 23.60.+e; 25.70.-z; 27.90.+b

Abstract: The new element 111 was produced and unambiguously identified in an experiment at SHIP, GSI Darmstadt. Three nuclei of the isotope ^{272}111 were observed in irradiations of ^{209}Bi targets with ^{64}Ni projectiles of 318 MeV and 320 MeV energy. The cross-sections are $(1.7^{+3.3}_{-1.4})$ pb and $(3.5^{+4.6}_{-2.3})$ pb, respectively. The nuclei decay by α emission into the new and so far the heaviest isotopes of the elements 109 and 107 with mass numbers A = 268 and A = 264. The α-decay chains were followed down to the known nuclei ^{260}105 and ^{256}Lr.

Introduction

In a recent experiment we produced the nucleus ^{269}110 by the reaction ^{62}Ni + ^{208}Pb [1]. In a succeeding experiment we investigated the reaction ^{64}Ni + ^{208}Pb and observed the heavier isotope ^{271}110 [2]. Increasing the projectile neutron number, the produced fusion reaction products approach the center of stabilizing shell effects at Z = 108 and N = 162. The enhanced stability was demonstrated in earlier SHIP experiments [3,4] and was explained theoretically to result from the proton and neutron level structures in a deformed nuclear potential [5-7]. We measured a decreasing Q_α value and increasing α half-life of the two Z = 110 isotopes approaching the N = 162 neutron number in accordance with the predictions [5]. Recent experimental work on the most neutron rich isotopes of the elements 106 [8] and 108 [9] corroborated the stabilizing shell effects at proton number 108 and neutron number 162.

Cross-section systematics of odd and even elements produced in reactions with ^{208}Pb and ^{209}Bi targets and the same projectile result in decreasing values of approximately a factor of three for the next higher odd element. In the reactions with the two different nickel projectiles we measured the production cross-sections for the 1n channels to increase from $(3.5^{+2.7}_{-1.8})$ pb for ^{269}110 to (15^{+9}_{-6}) pb for ^{271}110 with increasing neutron number of the projectile. Therefore, in an attempt to produce the new element 111 we irradiated ^{209}Bi targets with the most neutron rich, stable nickel isotope, ^{64}Ni.

On the basis of the previous results on element 110 we expected a cross-section of ≈5 pb for production of ^{272}111 and α emission as the main decay channel. Although the first three members of the decay chain are not known so far, we hoped to observe with our improved separation and detection method a long and significant α-decay chain down to the known nuclei ^{260}105 [10,11] and ^{256}Lr [12].

Experimental Method

The experimental method was described in Ref. [1]. Therefore, we list here only the modifications compared to the previous experiment.

The ^{64}Ni beam was prepared from metallic nickel enriched to 93.1 %. Projectile ions of the charge state 9^+ were extracted from an ECR source and accelerated by the UNILAC to the energies needed for reactions at the Coulomb barrier. The consumption of ion-source material was less than 4 mg/h at an average beam current of 3×10^{12} projectiles/s.

The bismuth targets were made of material chemically purified to 99.99 %. They were produced by the same method as the previously used lead targets. The thickness of the bismuth-target layer was 450 μg/cm². The target material was evaporated onto a 40 μg/cm² carbon backing and covered by an additional 8 μg/cm² carbon layer. The rotating target wheel was used.

The separation of the fusion products by SHIP and the identification of the α-decay chains by implantation of the reaction products into position-sensitive silicon detectors are identical as in our previous experiment [1].

Results

The reaction ^{64}Ni + ^{209}Bi was studied at three different projectile energies. The energy values were chosen according to the previously investigated reaction ^{64}Ni + ^{208}Pb. In that reaction the isotope ^{271}110 was produced at excitation energies of 10 MeV and 12 MeV. The excitation energies are calculated for the compound systems using the mass tables of Ref. [13]. The excitation energies are used here to compare the energy balance of the various reactions. Details of the ^{209}Bi irradiations are given in Tab. 1. We started with a beam energy of 316.1 MeV that was increased stepwise.

Tab. 1. Summary of the ^{209}Bi irradiations by ^{64}Ni. E^* is the excitation energy calculated for reactions in the middle of the target.

$E_{proj.}$ /MeV	E^* /MeV	Time /day	Ion dose /10^{18}	Observed events	σ/pb
316.1	9.4	5.0	1.0	0	< 2.9
318.1	11.0	5.8	1.1	1	$1.7^{+3.3}_{-1.4}$
320.0	12.5	5.9	1.1	2	$3.5^{+4.6}_{-2.3}$

At the lowest beam energy no event was observed. An upper cross-section limit is 2.9 pb (68 % confidence level) at $E^* = 9.4$ MeV.

The first event chain was measured at a beam energy of 318.1 MeV. This was the only event observed at that energy during an irradiation time of 5.8 days at a beam dose of 1.1×10^{18}. The resulting cross-section is $(1.7^{+3.3}_{-1.4})$ pb.

Two more chains were measured at 320.0 MeV beam energy. The irradiation time and beam dose were similar to the previous irradiation at 318.1 MeV. A cross-section of $(3.5^{+4.6}_{-2.3})$ pb follows.

The three decay chains assigned to element 111 are shown in Fig. 1. The signals attributed to the chains appeared close to the center of the 80 mm wide and 35 mm high detector. Despite of the

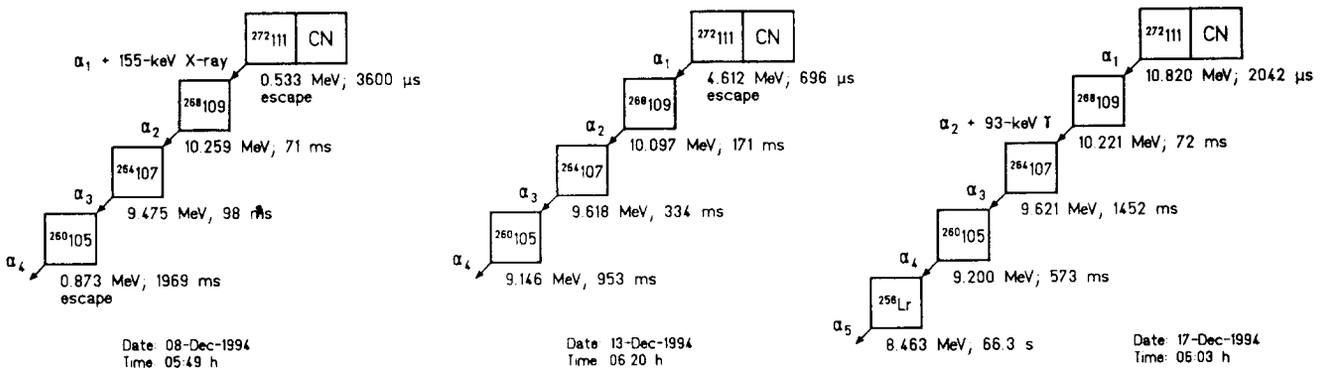

Fig. 1. Decay chains assigned to $^{272}111$

wide range of energies from 25 MeV to 0.5 MeV, all signals belonging to one decay chain appear within a vertical position window of ± 1 mm, 75 % of the signals within ± 0.3 mm. In a final analysis, the position resolution will be further improved using an energy dependent calibration.

All chains start with implantations of ions that are characterized by energy and time-of-flight values within the ranges determined for heavy reaction products in the previous experiments. Altogether, these implantations are succeeded by 13 signals that are assigned to α decays. All signals α2 and α3 were measured during the 14.5 ms wide macropause when the beam is switched off and the background rate is reduced to 0.7 Hz from 35 Hz during the macropuls of 5.5 ms. The other signals were observed within the macropulse, but anticoincident to both time-of-flight detectors. Seven α's were emitted in beam direction deeper into the stop detector and were registered with full energy. Three α energies, α1, α4 and α5 of the last decay chain are summed from ΔE signals of 1.283 MeV, 1.377 MeV and 1.080 MeV in the stop detector and residual energy signals in the backward detectors. The remaining 3 of the 13 α's escaped according to a 20 % escape probability in backward direction, but were registered by a ΔE signal in the stop detector.

The assignment of the three decay chains is based on the following arguments:

1. α4 of chain 2 and α4 and α5 of chain 3 are in excellent agreement with the literature values published in [10-12] for the isotopes $^{260}105$ ($E_\alpha = 9.0 - 9.2$ MeV, $T_{1/2} = 1.52$ s) and ^{256}Lr ($E_\alpha = 8.3 - 8.6$ MeV, $T_{1/2} = 28$ s). In case of chain 1 the half-life of α4 agrees with that of $^{260}105$.

2. The target is monoisotopic and extremely pure. Contaminations resulting in other heavy compound systems as $^{273}111$ can be excluded. Due to the very low excitation energy only n, p, α emission or radiative capture may compete as deexcitation channels. In case of p emission the fissioning nucleus $^{260}104$ would be populated already after three α decays. This possibility can be excluded because fission was not observed. In case of α deexcitation or radiative capture the α decay of the known nucleus $^{261}105$ would occur as α3 or α4 in the decay chains. Because the α-decay energy of $^{261}105$ is below 9.0 MeV [14], we can also exclude this possibility.

The only deexcitation channel left is 1n emission. We assign the three measured decay chains to the previously unknown isotope $^{272}111$. This nucleus is the first one observed of the new element Z = 111.

The transitions α2 and α3 are consequently assigned to the new isotopes $^{268}109$ and $^{264}107$. These are the heaviest known isotopes of the elements 109 and 107. The measured half-lives and α energies of the new isotopes are summarized in Tab. 2.

Tab. 2. Summary of the decay data of the new isotopes. The uncertainty of the α energies is ± 0.020 MeV.

Isotope	E_α/MeV	$T_{1/2}$/ms
$^{272}111$	10.820	$1.5^{+2.0}_{-0.5}$
$^{268}109$	10.097 10.240	70^{+100}_{-30}
$^{264}107$	9.475 9.619	440^{+600}_{-160}

Two of the α decays, α1 of chain 1 and α2 of chain 3 are coincident with signals in one of the two 20 mm thick germanium detectors mounted behind the silicon stop detector. The germanium detectors cover a solid angle of ≈ 15 %. The ratio of chance to true coincidences is 3 %. The energy of the coincident γ signal of chain 1 is (155.0 ± 0.8) keV. The error bar of 0.8 keV for the one event results from the resolution of 1.9 keV (FWHM) of the detector.

The energy of the signal is close to the predicted $K_{\alpha 1}$ energy of element 109, 152 keV [15]. Although the possibility of a chance coincident event is low, an assignment to a Z = 109 X-ray needs confirmation by the observation of further X-ray events with expected energy values and intensity distributions.

We thank the UNILAC staff and the ion-source group for providing an intense and stable beam of ^{64}Ni.

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