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Short Note

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Abstract: The new element 112 was produced and identified unambiguously in an experiment at SHIP, GSI Darmstadt. Two decay chains of the isotope $^{277}112$ were observed in irradiations of ^{208}Pb targets with ^{70}Zn projectiles of 344 MeV kinetic energy. The isotope decays by emission of α particles with a half-life of (240^{+430}_{-90}) μs. Two different α energies of $(11{,}649 \pm 20)$ keV and $(11{,}454 \pm 20)$ keV were measured for the two observed decays. The cross-section measured in three weeks of irradiations is $(1.0^{+1.8}_{-0.4})$ pb.

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Introduction

In recent experiments we investigated the production of new heavy elements in reactions using targets of ^{208}Pb and ^{209}Bi. The isotopes with mass numbers A = 269 and 271 of element 110 and the isotope with mass number 272 of element 111 were identified [1]. These nuclei were produced in fusion reactions by emission of one neutron. The measured cross-sections extended the systematics and did allow to estimate values for the new element 112 by extrapolation. We expected a cross-section between 1 and 3 pb for production of the isotope $^{277}112$ by the reaction $^{70}Zn + ^{208}Pb$ [2].

The decay properties of heavy nuclei were calculated recently [3-5]. In the region of interest longer fission than α half-lives are predicted. Therefore, we expect α decay for isotopes of element Z = 112 near mass number A = 278 and also for the daughter products, allowing a safe identification by correlation methods.

Experimental Method

The beam of ^{70}Zn projectiles was prepared by the high charge injector of the UNILAC. From an ECR-ion source zinc ions of charge state 10^+ were extracted and accelerated. Average beam intensities on target were between $(2.8 - 3.1) \times 10^{12}$ ions/s. The selected specific beam energy was 4.912 MeV/u. The energy was measured by time-of-flight methods with a relative accuracy of ±0.003 MeV/u. The absolute accuracy is ±0.01 MeV/u.

The targets were prepared by deposition of a 450 $\mu g/cm^2$ thick layer of ^{208}Pb, enrichment 99.0 %, onto 50 $\mu g/cm^2$ carbon foils. The lead was covered by 15 $\mu g/cm^2$ carbon [6]. Eight targets were mounted on a wheel that rotated with 1125 rpm through the beam. The distance from the axis of the wheel to the beam spot was 310 mm.

The reaction products were separated in-flight by the velocity filter SHIP. The identification of α-decay chains by a position-sensitive silicon-detector array is essentially the same as in our previous experiments. For improvement of the anticoincidence conditions, we added a third large area foil detector in front of the silicon detectors. Before implantation the ions were degraded further by a 3.0 μm thick mylar foil in order to avoid high implantation signals. The counting rate of a projectile background below 10 MeV was 90/s, the rate of implanted lead recoil nuclei plus a small fraction of transfer products at (17 – 29) MeV was 30/s, and a projectile background in the energy range (30-320) MeV had a rate of 9/s and was highest at the low energy portion of the spectrum. The given rates were measured during the 5.6 ms wide beam pulse on the stop detector. During the 14.4 ms beam pause the background rate above 0.2 MeV was 0.02/s.

The α energies were calibrated utilizing the α emitting transfer products ^{213}Rn and ^{211}Po and the previously implanted long-living activities of ^{210}Po and ^{208}Po. The energy resolution for α lines was 17 keV (FWHM), the absolute error of the α energy is determined by systematic uncertainties and amounts to ±20 keV.

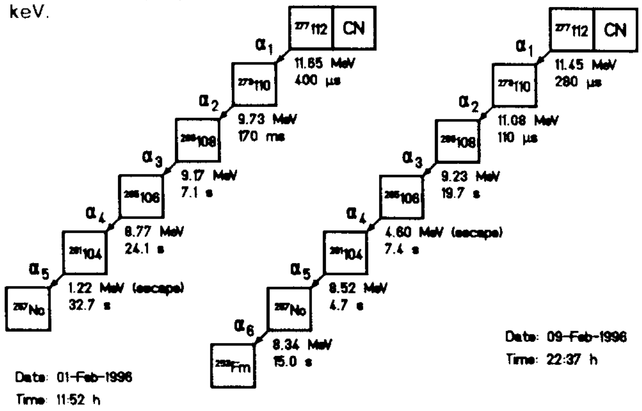

Fig. 1. The two observed decay chains during irradiations of ^{208}Pb targets by ^{70}Zn projectiles and assignment of the measured signals to the α decay of $^{277}112$.

Results

The irradiations with a ^{70}Zn beam started on Jan. 26, 1996. The first event chain was measured on Feb. 1, the second on Feb. 9. Both chains are presented in Fig. 1. Until Feb. 18, the total number of collected projectiles was 3.4×10^{18}. From these data, together with the target thickness and a calculated total efficiency of 45 %, results a cross-section value of $(1.0^{+1.8}_{-0.4})$ pb. The given error bars represent statistical uncertainties only. The values are correct relative to our previously measured cross-sections, but are uncertain within a factor of two on absolute scale due to estimated systematic deviations.

The beam energy for the production of $^{277}112$ was selected according to our previous systematic investigations of reaction cross-sections [2]. At a specific beam energy of 4.845 MeV/u calculated for reactions at half of the target thickness, the free energy is 10.1 MeV, using a Q value for the reaction of 243.7 MeV following from the mass predictions of Refs. 3 and 8.

The second chain turned out to be more complete than the first one. A number of six α decays was measured within an interval of 47 s since implantation. Therefore, we discuss the measured properties of this chain first.

The chain started with an implantation signal of 32.0 MeV, which was in coincidence with signals from all three time-of-flight foil detectors. Implantation energy and measured flight times corresponded to a heavy-element fusion product. Subsequent to the implantation, two α decays were measured with energies of 11,454 keV and 11,083 keV in time intervals of 280 μs and 110 μs, respectively.

Subsequent, the α decays number 3 to 6 were measured, with energies and time intervals as given in Fig. 1. The α's with numbers 3, 5, and 6 occured during beam pause, α4 during beam pulse. All signals were measured in strip number 15, that is 32.5 mm from the center in horizontal direction. In vertical direction, the mean position of all signals, except that of the escaped α, was 0.40 mm above center. The positions were distributed within a window of ±0.23 mm. The position resolution measured with higher statistical accuracy using transfer products was 276 μm (FWHM). The position for the escaped α was measured 0.6 mm below the average. The position information of all events, both in x and y direction allows to assign the sequence of signals to one and the same decay chain.

Candidates for an assignment of the chain must be searched for in the region of γ, n, 2n, p, pn or α emission channels due to the very low free energy of 10.1 MeV. Of those, the channels γ, 2n and α must be excluded, because α-decay chains would populate the fissioning nuclei ^{260}104 and ^{262}104 already after 4 or 3 α transitions, respectively. Also a chain starting after 1p emission would end after 4 α decays in the fissioning nucleus ^{261}Lr. The very long living ^{262}Lr ($T_{1/2} = 4h$) would be populated after 4 α's in case of a γ channel plus electron capture. The chain starting after pn emission is equivalent to the chain starting with 2n emission including electron capture. In that chain the long living nuclei ^{260}Lr ($T_{1/2} = 3m$) and ^{256}Md ($T_{1/2} = 77m$) would be populated after 4 and 5 α decays. The measured lifetimes as well as the α energies disagree with the measured data for α transitions 5 and 6. Therefore, the observed chain must be assigned to the isotope with mass number A = 277 of element Z = 112, produced by fusion of ^{70}Zn and ^{208}Pb and emission of one neutron. This chain represents the first unambiguous identification of the new element Z = 112. The isotope ^{277}112 is the heaviest nucleus known so far.

After assignment of the decay chain to ^{277}112, we can compare the decay properties of the daughter nuclei with literature data. These nuclei are relatively neutron rich and difficult to produce. The nucleus populated by the decay α6 (see Fig. 1) is ^{253}Fm. This nucleus has a half-life of 3 d, an α-decay branch of only 12 % and ends the decay chain. Alpha decay of ^{253}Fm could not be detected. Only the nuclei ^{257}No and ^{261}104 are known since longer time [7]. But, also for these nuclei, details of the α-decay pattern are known insufficiently, especially, when the nuclei are populated by preceding α decays. Nevertheless, the half-lives of ^{261}104 and ^{257}No and the α energy of ^{257}No agree well with literature data. Our measured ^{261}104 α-decay energy of 8.52 MeV is higher by 0.24 MeV than the literature value, but fits better into Q-value systematics [8].

Experimental data on the α decay of ^{265}106 were obtained only recently [9,10]. Alpha energies between (8.7 – 8.85) MeV and a half-life of ≈7 s were measured. Data on the α decay of ^{269}108 and ^{273}110 are scarce. An α energy of ^{273}110 of 11.35 MeV was reported by the Dubna-Livermore group [11].

The decay chain measured first (see Fig. 1) is shorter and ends with an escape α emitted by ^{261}104. Subsequent signals, that could arise from a decay of ^{257}No, were observed in the low energy portion of the spectrum during beam on intervals. They could not be assigned definitely because of too long correlation times for these low energetic signals.

Implantation and all decays of the chain, except the escape α, appeared within a position window of ±0.08 mm at the center of strip number 13, which is 22.5 mm from the axis in horizontal direction. Although the implantation energy of 18.6 MeV is close to that of the transfer products, an assignment of the 11.65 MeV α decay to ^{212}Po must be excluded because of the short lifetime and the subsequent four α decays. The two decays α2 and α3 were measured during beam off intervals. No subsequent fission was observed, which is the argument to assign also this chain to ^{277}112 produced by 1n emission.

The decay data of isotopes below ^{273}110 of the first chain agree well with the data of the second chain, respectively literature values in case of the ^{265}106 α energy. Significantly different compared to the result of the second chain is the decay of ^{273}110. The measured α energy is 1.35 MeV less and the lifetime is 1545 times longer. Because of this large lifetime difference, the two transitions must be assigned to different levels in ^{273}110. Calculated lifetimes result in values of 67 μs and 175 ms, respectively, both for Δl = 0 transitions. These values compare well with the measured lifetimes. We conclude that both transitions are unhindered and connect analogous states in parent and daughter nuclei.

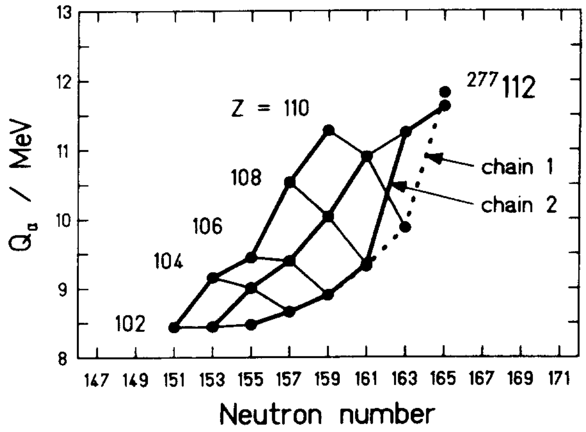

Fig. 2. Systematics of measured Q_α values. The thick lines connect members of α-decay chains starting with ^{269}110, ^{271}110 and ^{277}112.

In a first attempt for an explanation we show the systematics of Q_α values in Fig. 2. It is obvious, that chain 1 demands higher shell correction energies for the α transition between ^{277}112 and ^{273}110, whereas chain 2 demands the higher energy between ^{273}110 and ^{269}108. Comparing these results with mass calculations, we find nearly perfect agreement between chain 1 and the predictions by Möller et al. [5] and, similarly, agreement between chain 2 and the predictions by Smolanczuk and Sobiczewski [3]. Both calculations agree in case of Q_α(^{269}108) and Q_α(^{277}112), but differ by 1.0 MeV in case of Q_α(^{273}110). The Q_α values of odd isotopes were obtained by interpolation from the even neighbors in case of Ref. 3.

The measured energy difference of 200 keV between the two observed α transitions of ^{277}112 suggests that two parallel running decay chains, one through the ground state and the other through a high energy isomer, are already initiated by the reaction process populating two different levels in ^{277}112 both of similar half-life. But, as long as these considerations are not confirmed, we present only one value of the half-life of ^{277}112. From the two measured chains we obtain as average value (240^{+430}_{-90}) μs.

At present, the experiment is continued in order to increase the statistical accuracy of the production cross-section and the half-life of ^{277}112, and to confirm the two α branches.

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