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S. HOFMANN, N. NINOV, F.P.HESSBERGER, P. ARMBRUSTER,
H. FOLGER, G. MÜNZENBERG, H.J. SCHÖTT, A.G. POPEKO,
A.V.YEREMIN, A.N. ANDREYEV, S. SARO, R. JANIK, M. LEINO

SW9451

Gesellschaft für Schwerionenforschung mbH
Postfach 110552 · D-64220 Darmstadt Germany

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Short Note

Production and Decay of $^{269}110$

S. Hofmann, V. Ninov, F.P. Heßberger, P. Armbruster, H. Folger, G. Münzenberg, H.J. Schött
Gesellschaft für Schwerionenforschung, D-64220 Darmstadt, Germany

A.G. Popeko, A.V. Yeremin, A.N. Andreyev
Flerov Laboratory of Nuclear Reactions, JINR, 141 980 Dubna, Russia

S. Saro, R. Janik
Department of Nuclear Physics, Comenius University, SK-84215 Bratislava, Slovakia

M. Leino
Department of Physics, University of Jyväskylä, SF-40100 Jyväskylä, Finland

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Abstract: In an experiment carried out to identify element 110, we have observed an α-decay chain, that can be unambiguously assigned to $^{269}110$. In a series of preexperiments the excitation functions of the fusion reactions $^{50}Ti+^{208}Pb\rightarrow^{258}104^*$ and $^{58}Fe+^{208}Pb\rightarrow^{266}108^*$ were measured with high precision in order to get the optimum projectile energies for the production of these heavy elements. The cross-section maxima of the 1n evaporation channels were observed at excitation energies of 15.6 MeV and 13.4 MeV, respectively. These data result in an optimum excitation energy of 12.3 MeV of the compound nucleus for the production of $^{269}110$ in the reaction $^{62}Ni+^{208}Pb\rightarrow^{269}110+1n$. In irradiations at the corresponding beam energy of 311 MeV we have observed a decay chain of 4 subsequent α decays. This can be assigned to the isotope with the mass number 269 of the element 110 on the basis of delayed α-α coincidences. The accurately measured decay data of the daughter isotopes of the elements 108 to 102, obtained in the previous experiments, were used. The isotope $^{269}110$ decays with a half-life of (270^{+1300}_{-120}) μs by emission of (11.132 ± 0.020) MeV alpha particles. The production cross-section is $(3.3^{+6.2}_{-2.7})$ pb.

Introduction

During the first decade of experiments with SHIP at the UNILAC, the new elements 107, 108 and 109 were discovered [1]. The authors proposed to name these elements nielsbohrium (Ns), hassium (Hs), and meitnerium (Mt). The elements were identified from only a small number of decaying atoms produced with cross-sections of 167 pb, 19 pb and 10 pb, respectively. The high sensitivity achieved in the experiments resulted from the following: a) a stable, high current beam from the UNILAC; b) a highly efficient separation of the reaction products by the SHIP velocity filter [2]; c) a sensitive detector system with the feasibility to correlate implanted reaction products with their subsequent radioactive decay chains [3].

Cross-section estimates for the still heavier elements 110 and 111 using lead or bismuth based reactions with projectiles of the $T_z=3$ series, result in values of about 1 pb. Beam times of several months would have been necessary to carry out experiments on this low cross-section level with the experimental set-up used so far. Therefore, considerable efforts were made to further improve the already high sensitivity, so that 1 pb experiments can be carried out routinely [4].

Although the production cross-sections for heavy elements approach the limits of experimental sensitivity, the half-lives for most nuclei that can be produced with stable projectiles and the available targets are predicted to be longer than 1 μs [5-7]. These half-lives are easily accessible in experiments with recoil separators. For the odd-neutron nucleus $^{269}110$ an α half-life of ≈100 μs is estimated from the Q_α values predicted. The fission half-life should be considerably longer following the calculated half-lives for the even-even neighbours and taking into account an odd neutron hindrance factor. The isotope $^{269}110$ should be an α emitter with a negligible fission branching.

Experimental Method

Heavy ion beams of ^{50}Ti, ^{58}Fe and ^{62}Ni were accelerated by the UNILAC to energies sufficient for reactions at the Coulomb barrier. The beams were produced from enriched material. For ^{50}Ti the PIG ion source was used. The projectile ions ^{58}Fe and ^{62}Ni were obtained from an ECR source and accelerated to $1.4\times A$ MeV by an RFQ/IH linac. In both cases, the final kinetic energies were obtained by the Alvarez section plus single resonators of the UNILAC. The relative accuracy of the beam energies was $\pm0.003\times A$ MeV, the absolute energies are accurate to $\pm0.01\times A$ MeV.

Average particle currents of 3×10^{12}/s were used. The consumption of material in the ECR source, metallic iron and nickel heated to ≈1800 K in an Al_2O_3 oven, was less than 4.0 mg/h. The time structure of the beam was determined by a 5.5 ms wide pulse followed by a 14.5 ms wide beam pause.

The targets were produced by evaporation of a 450 μg/cm² lead layer onto a 40 μg/cm² carbon backing. The ^{208}Pb was enriched to 99.0 %. Finally, a thin layer of 8 μg/cm² carbon was evaporated onto the lead [8]. Eight targets were mounted on a wheel of 310 mm diameter. The wheel rotated with 1125 rev./min synchronously to the beam macrostructure.

The produced evaporation residues were separated in-flight by the velocity filter SHIP. Compared to the previous experiments, the distance between target and separator was reduced in order to increase the solid angle. A value of 4 msr was reached, resulting in

a calculated transmission coefficient of 0.4 for the investigated fusion products. The background suppression was significantly improved by an additional dipole magnet allowing to position the detectors at an angle of 7° out of the primary beam direction. Scattered low energy projectiles were the main contribution to the background. The average rate in the stop detector was 10 Hz. The magnetic field strength of the dipole magnet in the $Z = 110$ experiment was set according to the values obtained in the previous experiments for investigation of $Z = 104$ and $Z = 108$.

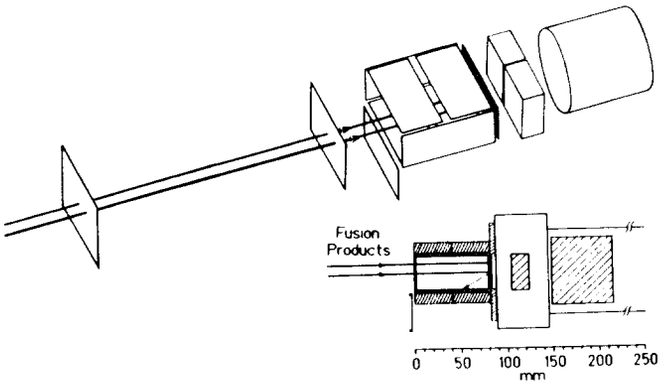

Fig. 1. New assembly of detectors for identification of heavy elements.

The detector system is composed of two time-of-flight detectors, seven identical 16-strip silicon wafers, plus three germanium detectors. A three dimensional view of the detector arrangement is shown in Fig. 1, together with a sectional drawing to scale. In front of the silicon detectors there is a changer for calibration sources and degrader foils (Mylar). In the $Z = 104$ experiment the foils were varied between 3.5 μm and 7.5 μm, in all other experiments a 3.5 μm foil was used.

The active area of one of the silicon strip detectors is 35×80 mm^2. Each strip is position sensitive in the vertical direction with a resolution of 150 μm between α decays of a decay chain. For that reason the stop detector is equivalent to 3700 single detectors of 0.15×5 mm^2, but of 100 % active area. The optimum energy resolution is 14 keV for α's of a ^{241}Am source. Six wafers are mounted in the backward hemisphere facing the stop detector. They measure escaping α's or fission fragments with a solid angle of 80 % of 2π. In case of the backward detectors neighbouring strips are connected galvanicly so that 28 energy sensitive segments are formed. The direction of the escaping α particle or fission fragment can be retraced roughly. The energy resolution obtained by summing the energy loss signal from the stop detector and the residual energy from the backward detector is 40 keV for α particles. All silicon detectors are cooled to 263 K. The germanium detectors measure X-rays or gammas in coincidence with signals from the silicon detectors.

In front of the silicon detectors and degrader stack there are two secondary-electron foil detectors mounted 285 mm apart from each other. The foils are made of carbon of 30 μg/cm^2 thickness. Two foils per detector are necessary. The detector signals are used to distinguish implantations from radioactive decays of previously implanted nuclei. Because of the high efficiency of these detectors ($\geq$99 %) very clean decay spectra are obtained, and the time windows for measuring decay chains are significantly prolongated. The time resolution of the foil detectors is about 700 ps which is small enough to obtain together with the energy signals from the silicon detector a rough mass assignment for the implanted ions.

Results

Excitation functions of the reaction ^{50}Ti + ^{208}Pb → ^{258}104*. The formation of element 104 isotopes was studied within a wide projectile energy range of $(4.52 - 5.10) \times A$ MeV. The measured cross-sections are plotted as function of the excitation energy in Fig. 2a. The error bars are the statistical errors only. The absolute cross-section values are accurate within a factor of two because of systematic uncertainties. Here, and in the following, the excitation energies were calculated for reactions at beam energies in the middle of the target. The known masses of projectiles and targets and the predicted masses of the compound nuclei were used [9,10].

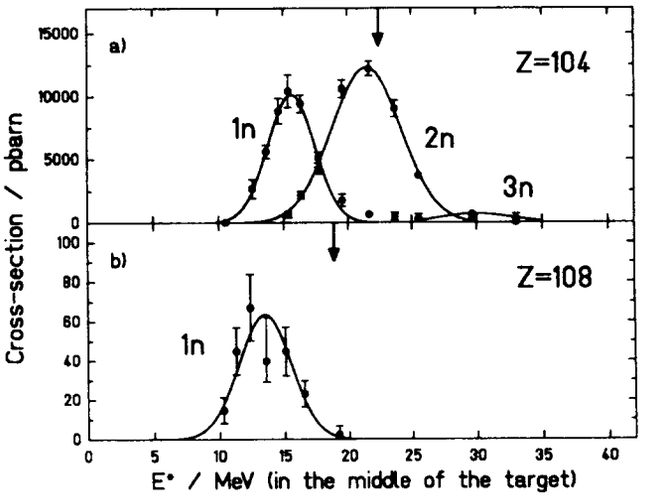

Fig. 2. Measured excitation functions for production of elements 104 and 108 in fusion-evaporation reactions with ^{208}Pb targets. The lines are gaussian curves fitted to the data points. The arrows mark the excitation energies at the Bass barrier [11].

Cross-section maxima were obtained at excitation energies of (15.6 ± 0.1) MeV and (21.5 ± 0.1) MeV for the 1n and 2n channels, respectively; the widths (FWHM) of the excitation functions are 4.3 MeV and 6.3 MeV. These data were obtained from the analysis of $\approx$3000 measured α and fission decays.

Excitation function of the reaction $^{58}Fe + ^{208}Pb \rightarrow ^{266}108^*$ and the decay of $^{265}108$. The measured excitation function is shown in Fig. 2b. The collected beam doses for the 7 data points varied between 0.3 and 1.1×10^{18}. A total beam dose of 4.4×10^{18} projectiles was collected during 4 weeks of irradiation time. In case of the data point at $E^* = 13.6$ MeV we had to double the positive error bar, because the target was partly damaged by a too high beam intensity. A least squares fit of a gaussian curve through the data points results in an energy of $E^* = (13.4 \pm 0.3)$ MeV for the cross-section maximum. The width of the excitation function is (4.8 ± 0.7) MeV. The maximum cross-section value is (63 ± 10) pb.

Altogether we collected 75 alpha decays of $^{265}108$. The assignment was made on the basis of measured α-decay chains via the daughter nuclei $^{261}106$, $^{257}104$ and ^{253}No. Delayed α-α coincidence spectra are shown in Fig. 3. The top spectrum, Fig. 3a, was analysed on the condition, that the α decays were preceded by high energy signals (≈25 MeV) from implantations. These had to be in coincidence with the signals from the time-of-flight detectors.

Two α lines with energies of (10.310 ± 0.020) MeV and (10.578 ± 0.020) MeV could be assigned to $^{265}108$. Within the statistical uncertainty both lines decay with the same half-life of (1.55 ± 0.20) ms. These measurements confirm the previously obtained data, which were made on the basis of 3 observed decay chains resulting in the discovery of element 108.

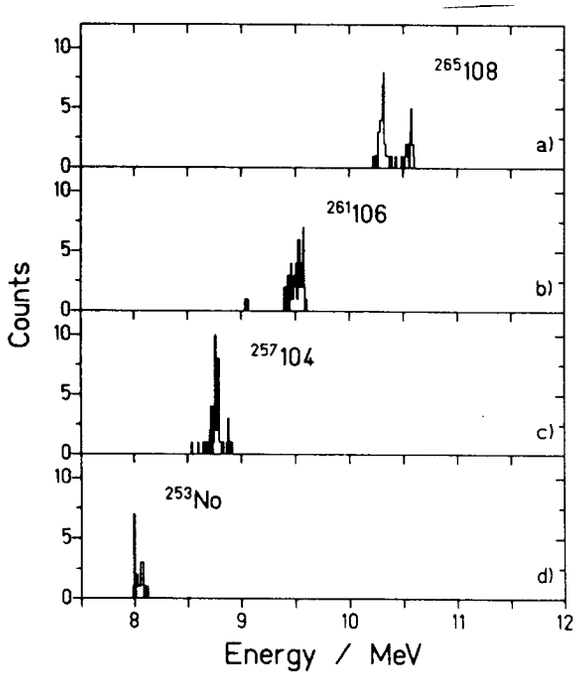

Fig. 3. Delayed α − α coincidence spectra showing four generations of α decays beginning with $^{265}108$. Spectrum a) was accumulated on the condition that an implantation signal occured within a time window of 20 ms before an α decay, and that at least one member of the decay chain followed within time windows of 2 s (b), 20 s (c) and 200 s (d). Common for all spectra was the condition that the signals originate from the same position of the same detector strip.

The 2n-evaporation channel has a cross-section less than 10 pb at $E^* = 19.2$ MeV (Fig. 2b). In spite of the fact that this channel is partly subbarrier in $^{258}104^*$ and open in $^{266}108^*$, it is significantly suppressed compared to $^{258}104^*$. The mean decrease in cross-section per element going from $^{258}104^*$ to $^{266}108^*$ is a factor of 3.5 for the 1n channel and a factor of 6 for the 2n channel. This experiment shows that the maximum production cross-sections are measured at subbarrier energies. Shifts of the barriers resulting from predicted extrapush energies are not observed. The fusion of these heavy nuclei is a very rare, low energy arrangement process. The emission of one neutron cools the system down to a level of excitation energy, which allows the final nucleus to profit fully from the shell stabilisation.

The reaction $^{62}Ni + ^{208}Pb \rightarrow ^{270}110^*$ and the decay of $^{269}110$. A linear extrapolation of the optimum beam energies for the production of $^{257}104$ and $^{265}108$ in 1n-evaporation channels results in $E^* = 12.3$ MeV for the compound nucleus $^{270}110$. The corresponding ^{62}Ni beam energy is $E = 311$ MeV. After collecting a beam dose of 0.24×10^{18}, an α-decay chain was found, that started with a previously not observed α decay with an energy of (11.132 ± 0.020) MeV, 393 μs after an implantation signal of 25 MeV. The observed complete decay chain is shown in Fig. 4 together with its interpretation.

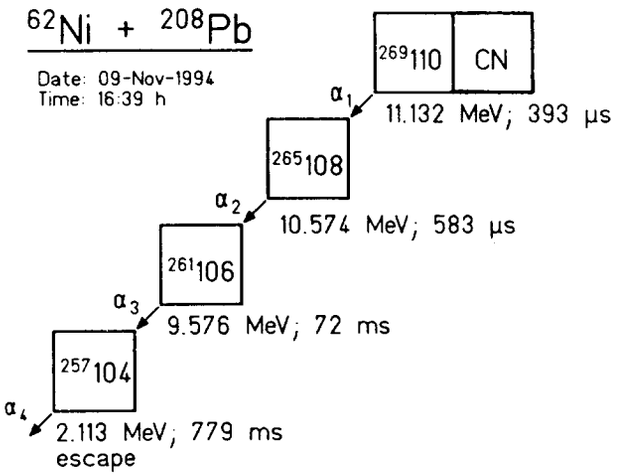

Fig. 4. Assignment of the observed delayed coincidence signals to the α-decay chain of $^{269}110$.

All decay signals from the silicon stop detector originate from the strip of number 10 that is in horizontal direction 7.5 mm from the center of the detector. In the vertical direction, the signals are from positions 1 mm below the center. The full energy α signals are observed within ±270 μm of the position of the implanted nucleus, the escaping α's within ±1.6 mm. The energies of α_1 and α_2 result from α particles stopped completely in strip number 10. The energy of α_3 is the sum of a 0.869 MeV ΔE signal from strip number 10 plus a 8.707 MeV coincident residual-energy signal

from the backward detector. Within 20 keV the full energies of the two α decays subsequent to α_1 agree with the previously measured α energies of ^{265}108 and ^{261}106. Also, the time intervals between $\alpha_1 - \alpha_2$ and $\alpha_2 - \alpha_3$ are in agreement with the half-lives of these two nuclei. The next signal, α_4 results from an escape event, but the measured time interval is in agreement with the half-life of ^{257}104. Proton evaporation is a competitive, energetically possible channel. But this channel would lead into a decay chain with ^{261}105 as daughter product, which has completely different decay characteristics as measured for α_3. We, therefore, assign the observed decay chain to the α-decay of ^{269}110. The half-life is (270^{+1300}_{120}) μs. The resulting cross-section is $(3.3^{+6.3}_{2.7})$ pb. The irradiations are being continued, and we hope to find further decay chains of element 110 already during the experiment still going on.

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Note added in proof. The irradiations for investigation of the reaction ^{62}Ni + ^{208}Pb ended November 20th., 1994. After completion of this paper we observed three more decay chains. The assignment of the measured energy, time and position signals is shown in Fig. 5.

Altogether we observed a number of four decay chains of ^{269}110 within a total measuring time of twelve days. The collected projectile dose was 2.2×10^{18}. The resulting cross-section for production of ^{269}110 is $\sigma = (3.5^{+2.7}_{1.8})$ pb. The average α energy is $E_\alpha = (11.112 \pm 0.020)$ MeV and the average half-life is $T_{1/2} = (170^{+160}_{60})$ μs.

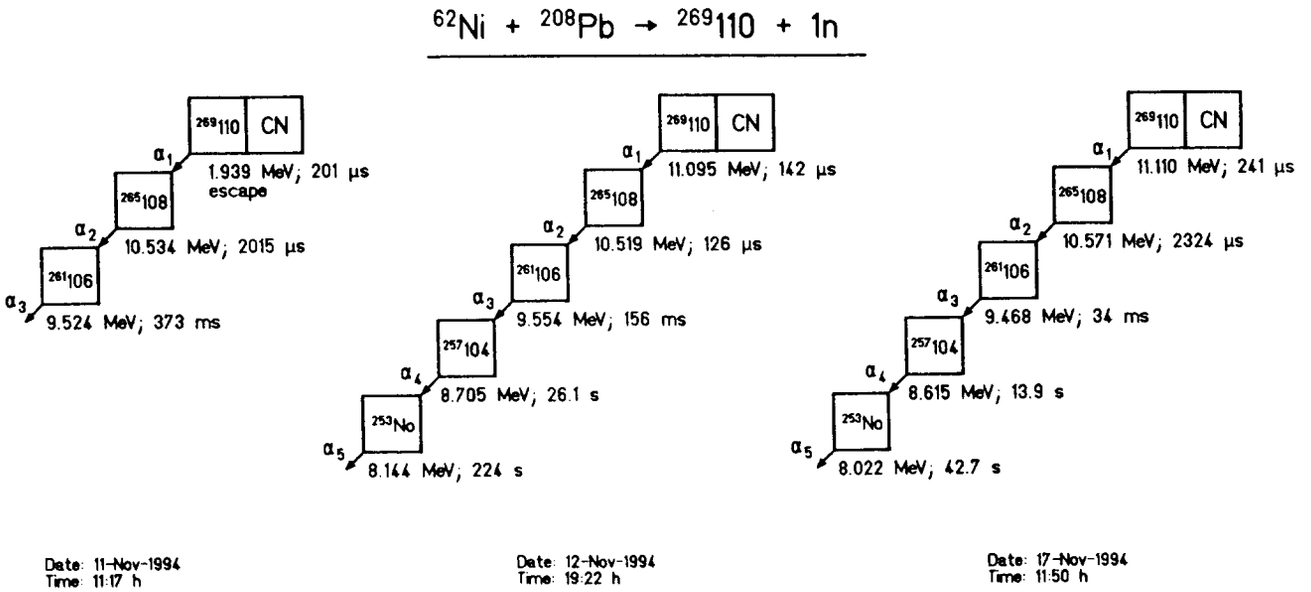

Fig. 5. Last three of the four measured decay chains assigned to ^{269}110.