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Observation of the Superheavy Nuclide ^{271}Ds *

ZHANG Zhi-Yuan(张志远)[1,6], GAN Zai-Guo(甘再国)[1**], MA Long(马龙)[1], HUANG Ming-Hui(黄明辉)[1], HUANG Tian-Heng(黄天衡)[1], WU Xiao-Lei(吴晓蕾)[1], JIA Guo-Bin(贾国斌)[1,6], LI Guang-Shun(李广顺)[1,6], YU Lin(郁琳)[1,6], REN Zhong-Zhou(任中洲)[2,5], ZHOU Shan-Gui(周善贵)[3,5], ZHANG Yu-Hu(张玉虎)[1], ZHOU Xiao-Hong(周小红)[1], XU Hu-Shan(徐瑚珊)[1], ZHANG Huan-Qiao(张焕乔)[4], XIAO Guo-Qing(肖国青)[1], ZHAN Wen-Long(詹文龙)[1]

[1]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000*
[2]*Department of Physics, Nanjing University, Nanjing 210093*
[3]*State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190*
[4]*China Institute of Atomic Energy, Beijing 102413*
[5]*Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000*
[6]*Graduate University of Chinese Academy of Sciences, Beijing 100049*

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With the recent commissioning of a gas-filled recoil separator at Institute of Modern Physics (IMP) in Lanzhou, the decay properties of ^{271}Ds (Z = 110) were studied via the ^{208}Pb(^{64}Ni, n) reaction at a beam energy of 313.3 MeV. Based on the separator coupled with a position sensitive silicon strip detector, we carried out the energy-position-time correlation measurements for the implanted nucleus and its subsequent decay α's. One α-decay chain for ^{271}Ds was established. The α energy and decay time of the ^{271}Ds nucleus were measured to be 10.644 MeV and 96.8 ms, which are consistent with the values reported in the literature.

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The liquid-drop model[1] established in 1930s treated the atomic nucleus as a charged drop of incompressible fluid, and predicted that nuclei with more than 100 protons cannot form a bound system and will disintegrate by fission. However, one has realized that nuclear shell effects could enhance the stability of the superheavy nuclei against the spontaneous fission. The nuclear structure models including the shell correction predict the existence of an island of superheavy nuclei around a spherical doubly magic nucleus (Z = 114, 120 or 126 and N = 184).[2–4] In the past half century, nuclear physicists have made their best endeavors to produce and identify the superheavy nuclei, and have achieved great progress. Although the superheavy nuclei up to Z=118[5–7] were synthesized using the heavy-ion induced fusion evaporation reactions, the most neutron-rich nuclei observed experimentally are located far away from the center of the island predicted theoretically. It is a great challenge to get closer to the island of superheavy nuclei.

The existing experimental data on cold fusion reactions shows that the production cross sections of the superheavy nuclei decrease to ∼1 pb exponentially with the increasing proton number. To study the properties of superheavy nuclei, modern separators and single atom identification techniques should be developed. The gas-filled recoil separator is commonly used in the study of superheavy nuclei due to its high transport efficiency and high background suppression ability.[8] A gas-filled recoil separator is newly commissioned at IMP. In this Letter, the observation of the superheavy nucleus ^{271}Ds based on the separator is reported.

The schematic diagram of the gas-filled recoil separator is shown in Fig. 1. It consists of a differential pumping system, a rotating target wheel, a dipole magnet, three focusing quadrupole magnets, and a detection system. As for fusion-evaporation reactions used for the production of superheavy nuclei, the evaporation residues (EVRs) recoiling from the target have a broad charge distribution, and they can reach an equilibrium charge state in a short time after a sufficient number of collisions with the gas molecules. Therefore, EVRs are separated in-flight from the beam particles and other reaction products by the different magnetic rigidities. A series of experiments have been carried out, and the optimum setting of the separator was determined. The separation efficiency for ^{210,211}Ac was measured to be about 14% by using the ^{175}Lu(^{40}Ar, xn) reaction.

The ^{271}Ds nuclide was produced in the ^{208}Pb(^{64}Ni, n) reaction. The ^{64}Ni^{19+} beam was provided by the

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**Correspondence author. Email: zggan@impcas.ac.cn

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sector focusing cyclotron (SFC) of the Heavy-Ion Research Facility in Lanzhou (HIRFL). Based on the measured excitation function in Ref. [9], the beam energy of 317.1 MeV was chosen. The typical beam intensity on the target was 6.6×10^{11} ions/s, and the total dose of the projectile accumulated in the experiment was about 6.4×10^{17} ions. The beam intensity was monitored by detecting the elastically scattered projectiles with four Si avalanche photodiodes mounted at $\pm 30°$ and $\pm 45°$ with respect to the incident beam direction. After passing through the differential pumping system, the beam impinged on the sandwiched ^{208}Pb target. The target was a ~400-μg/cm^2 ^{208}Pb layer with a carbon backing foil of 40 μg/cm^2 thickness. A 10-μg/cm^2-thick carbon was covered on the downstream side of the target to protect the target from sputtering. Ten arc-shaped targets were mounted on a rotating wheel with a 22.4-cm diameter. The wheel rotated at 600 rpm during the irradiation. The energy loss of the beam in the target was estimated to be 6.5 MeV.[10] The beam energy at the center of targets was 313.3 MeV, which corresponds to 14.4-MeV excitation energy of the compound nucleus ^{272}Ds.[11] A beam chopper was used in the experiment to avoid irradiating the target frame. The periodic chopping signal with 6.7 ms for beam-on and 3.3 ms for beam-off was induced by the target wheel and a photo-sensor. It was recorded by a CAMAC system to distinguish the beam-on events from the beam-off ones.

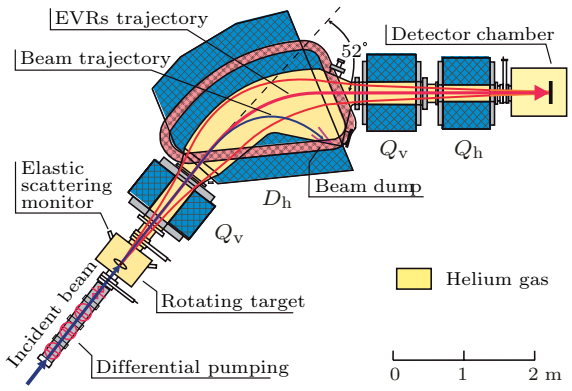


Fig. 1. Schematic view of the gas-filled recoil separator in Lanzhou. D_h denotes the dipole magnet. Q_v and Q_h stand for vertically and horizontally focusing quadrupole magnets, respectively. Typical trajectories of the primary beam and evaporation residues are also indicated.

During the experiment, the magnetic rigidity of the separator was set to be 2.01 Tm. The pure helium gas at a pressure of 0.8 mbar was filled in the space from the target position to the detector chamber (see Fig. 1). Passing through the gas area, the EVRs were implanted into a 300-μm-thick position sensitive silicon detector (PSD) installed at the focal plane of the separator. The implantation depth was estimated to be 10 μm. The PSD with 58×58 mm^2 active area was divided into sixteen independent vertical strips. Two electronics systems were used in the experiment, one for measuring 1–20 MeV α particles and the other for measuring implantation and fission fragments with energies of 5–200 MeV. The detector was calibrated with four α sources, ^{212}Po, ^{212}Bi, ^{241}Am and ^{239}Pu. The average energy resolution of PSD was 50 keV (FWHM) for the 8.785-MeV α particles. Resistive charge division provided 1.5-mm vertical position resolution (FWHM) in each strip of the detector. The probability for observing at least two full-energy events in a five-member α-decay chain was estimated to be 81% if assume 50% geometrical detection efficiency for α particles emitted from the implanted nuclei. A silicon surface-barrier detector with a 50-mm diameter was mounted behind the PSD to provide veto signals for light particles passing through the strip detector. When the PSD was fired, the energy, time, strip number, vertical position, and veto information were recorded.

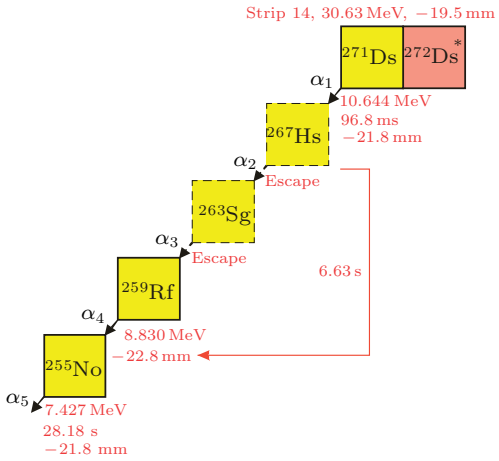


Fig. 2. Observed decay chain in the reaction ^{208}Pb(^{64}Ni, n)^{271}Ds. The measured energies, decay times, and positions are indicated. Two escaped α particles from the decays of ^{267}Hs and ^{263}Sg were not recorded.

With carefully inspecting the data, one correlated α-decay chain was assigned to the decay of ^{271}Ds nucleus. This decay chain is shown in Fig. 2. The implantation event with energy of 30.63 MeV was observed in strip 14 at a position of −19.5 mm (distance below the vertical center of the strip). The implantation energy after corrected for the pulse-height-defect[12] corresponds approximately to the calculated kinematic energy of ^{271}Ds. Following the implantation, an α particle with energy of 10.644 MeV and position of −21.8 mm was observed 96.8 ms later. This energy is very close to 10.681 MeV for the α group of ^{271}Ds reported in Ref. [13]. The lifetime of 96.8 ms is consistent with the half-life (69^{+56}_{-21} ms) of the isomer of ^{271}Ds.[9] The position deviation between the implantation and the decay α particle is slightly larger, and this may be caused by the poor position resolution

of the detector. A subsequent 8.830-MeV α particle can be assigned to the decay of ^{259}Rf. This event should correspond to the known 8.861-MeV α decay of ^{259}Rf.[13] The 6.63-s time interval in the chain is the sum of the lifetimes of the ^{267}Hs, ^{263}Sg and ^{259}Rf nuclei. The escaped α particles from ^{267}Hs and ^{263}Sg were not recorded by the detector since the deposited energies were lower than the 1.0-MeV energy threshold. This is reasonable because the probability for escaping two succeeding α particles is 25%. Following the decay of ^{259}Rf, an α particle was observed at energy of 7.427 MeV, and this event can be tentatively assigned to the decay of ^{255}No.[14] The observed decay energy of ^{255}No is about 300 keV lower than that reported previously.[9] We might assume that this α particle escaped from the front of the detector, and only partial energy was deposited in the detector. In this decay chain, the observed three α particles were all recorded during the beam-on period.

The probabilities of accidental coincidence between the implantation of EVR and individual decays were estimated. The average counting rate in the focal plane detector was about 25 s^{-1} at the beam intensity of 6.6×10^{11} ions/s. In anti-coincidence with the veto signals, the decay events with α energy from 7 to 11 MeV occurred at a rate of 3.5 s^{-1}. With the position window of 3.0 mm and the occurrence times for the three full-energy α particles, the probabilities of accidental coincidence were determined to be 1.1×10^{-3} for EVR-α1 correlation, 7.1×10^{-2} for EVR-α4, and 0.27 for EVR-α5. By multiplying these numbers, the maximum probability of accidental coincidence for the EVR-α1-α4-α5 correlation chain was 2.1×10^{-5}. Based on this analysis, the decay chain shown in Fig. 2 is likely assigned to the nucleus ^{271}Ds.

In summary, one correlated α-decay chain was observed for the nucleus ^{271}Ds using the newly commissioned gas-filled recoil separator at IMP. The measured decay properties of ^{271}Ds are consistent with the values reported by other groups.

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