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A new alpha-particle–emitting isotope ^{259}Db

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Abstract. An isotope of the element 105 with mass number 259 has been produced via the reaction ^{241}Am(^{22}Ne, 4n)^{259}Db at $E_{\rm lab}$ = 118 MeV. The reaction products were transported and collected using the helium-jet technique and the rotating wheel apparatus. The α-decays of the products and their daughter nuclides were detected by a set of Si(Au) detectors arranged ingeniously. The Z and A of the nuclide have been unambiguously identified by the genetic relationship between the new activity and the known nuclide ^{255}Lr established by α-recoiled milking measurement. The new nuclide ^{259}Db has a half-life of 0.51 ± 0.16 s and decays by alpha-particle emission of E_α = 9.47 MeV. Furthermore, the nuclide ^{258}Db and its daughter ^{254}Lr have also been clearly observed using the same projectile-target combination. Their half-lives and α-particle energies determined in this work are in agreement with previous known data, thus also proving the reliability of our assignment of ^{259}Db.

PACS. 21.10.Tg Lifetime – 21.60.Cs Shell model – 27.90.+b $A \geq 220$

1 Introduction

Early attempts to discover isotopes of the element 105 were made by Flerov in 1968 [1]. He had observed in bombardments of ^{243}Am with ^{22}Ne ions α-activities of E_α = 9.4 MeV, 0.1< $T_{1/2}$< 3 s, and E_α=9.7 MeV, $T_{1/2}$> 0.01 s, which he assigned to ^{261}105 and ^{260}105, respectively. Two years later, a new work on both spontaneous fission as well as α-activities assigned to the element 105 was reported by the Dubna group [2].

In 1970, Ghiorso and coworkers produced ^{260}105, a 1.6 s α-activity, using ^{249}Cf (^{15}N, 4n) reaction [3]. The α-particle groups of 9.06, 9.10, and 9.14 MeV were attributed to the decay of ^{260}105. But they were not able to produce the 9.4 and 9.7 MeV α-activities and hence to confirm the earlier experiment of Flerov *et al.*

In succeeding experiments, Ghiorso *et al.* [4] produced two new α-activities, ^{261}Db and ^{262}Db, via the reactions ^{250}Cf(^{15}N, 4n) and ^{249}Bk(^{16}O, 4n), respectively. The assignments of these two nuclides were based on genetic links to the known 0.6 s ^{257}Lr and 4.5 s ^{258}Lr, respectively. In 1977, Bemis *et al.* [5] have applied the definitive coincident characteristic X-ray method to study the decay of ^{260}Db. They measured the characteristic X-ray of the element 103 in coincidence with the α-particle groups of ^{260}Db. Their results for ^{260}Db completely corroborated and extended the earlier experiments of Ghiorso *et al.* Since that time, there have been several attempts to synthesize ^{263}Db. Up to 1992, Kratz *et al.* [6] carried out ^{18}O bombardments of ^{249}Bk to produce ^{263}Db. After rapid chemical separation, ^{263}Db was found to decay by spontaneous fission (57%) and by α-emission (E_α8.35 MeV, 43%) with a half-life of 27 s.

For the lighter isotopes of the element 105, Münzenberg *et al.* reported that the isotopes ^{258}Db and ^{257}Db were observed from α-decay of ^{262}107 and ^{261}107 [7,8]. Heßberger *et al.* obtained these isotopes directly by bombarding ^{209}Bi targets with ^{50}Ti projectiles via 1n and 2n de-excitation channels [9]. Identification and decay properties of the even lighter isotope ^{256}Db were recently reported by Heßberger *et al.* [10]. But no much information on nuclide ^{255}Db has been published as far as we know. Up to now a blank position for ^{259}Db is still left among the known isotopes mentioned above. Its decay properties are still completely unknown. According to systematics and predictions by Wapstra *et al.* [11] and Möller *et al.* [12], this nuclide should be an alpha-emitter with a short half-life. Therefore, it is the aim of our experiment to close this gap and to study the properties of ^{259}Db nuclide.

The reaction ^{241}Am (^{22}Ne, 4n) was used to produce this new isotope ^{259}Db. Its identification was performed by recoil-milking the 21 s ^{255}Lr daughter. At the same time, its neighboring nuclide ^{258}Db has also been observed in the present work.

We compared the α-decay energy of this new isotope ^{259}Db to the values of the known isotopes in a "Q_α-

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systematics" for isotopes with $Z \geq 98$. It shows that the "Q_α value" for the new isotope ^{259}Db fits quite well into the general trend.

2 Experimental set-up and procedure

A 0.85 mg/cm^2 ^{241}Am target was bombarded with 132 MeV ^{22}Ne ions at the SFC (Sector Focus Cyclotron) of HIRFL (Heavy Ion Research Facility Lanzhou). The ^{22}Ne beam, after passing through a 1.94 mg/cm^2 Havar window and a 1.70 mg/cm^2 Al target backing, had an energy of 118 MeV in the center of the target material. The maximum of the excitation function for the ^{241}Am (^{22}Ne, 4n) reaction is at about 120 MeV, according to statistical evaporation calulations using the Alice Code [13]. The typical beam current of ^{22}Ne was about 0.8 μA.

The ^{241}Am target was prepared by the molecular-plating method and deposited on a 1.70 mg/cm^2 Al backing foil in an area of 0.78 cm^2 [14]. Contaminations from other Am isotopes were lower than 0.1% based on a γ-spectroscopy test.

The reaction products recoiling out of the target were stopped in helium gas at 740 Torr, which had been loaded with NaCl aerosols and were attached to the aerosols and swept out of the target chamber with the gas, then went through a 1.27 mm diameter and 20 cm length capillary into a rough vacuum chamber to impinge upon the periphery of a vertically mounted wheel which acted as a carrier. The experimental set-up is shown schematically in fig. 1. The wheel was periodically rotated by the preset interval to place the collected recoil atoms to the position in front of a series of peripherally mounted Si(Au) surface-barrier detectors in order to measure their alpha-particle spectra.

We note that NaCl aerosols deposited on the wheel can interfere with subsequent α-particle energy measurements. In order to obviate this effect, the deposit of NaCl aerosols was removed at regular interval.

In the present experiment, the detectors were divided into four groups and each group included three Si(Au) surface-barrier detectors. They were arranged around the wheel according to the preset inequal intervals. A schematic representation of the detectors arrangement is shown in the lower-right portion of fig. 1. The wheel-stepping interval is in correspondence with the arrangement of the detectors and controlled by a computer. The operating procedure of the wheel and detectors during the experiment is as follows: when the first collected products source on the wheel is rotated to the front of No. 1-1 detector, the α-decays from products and their daughters collected on the wheel could be recorded by this detector. The second products source is collected and rotated to face No. 2-1 detector and recorded by No. 2-1 detector, while the first products source is rotated to No. 1-2 detector and recorded. In this time No. 1-1 detector due to no product source on the wheel facing it, thus only records the daughter α-particle activities which have recoiled off the wheel into the surface of No. 1-1 detector. Successively the third product source is rotated to No. 3-1 detector, simultaneously the 2nd source is rotated to No. 2-2 detector,

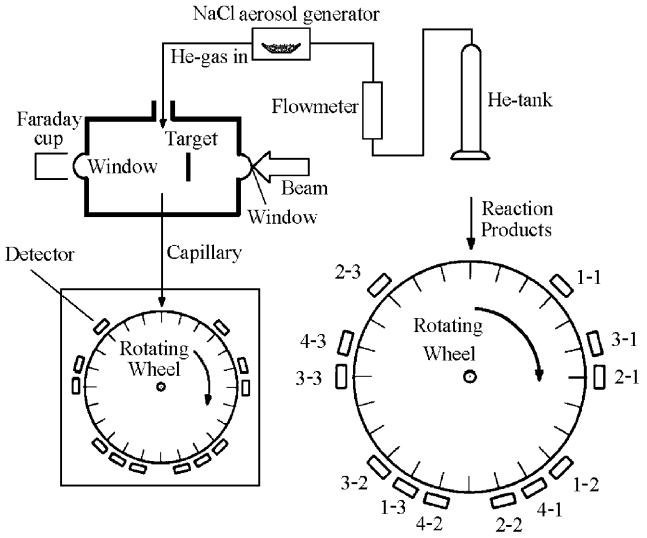

Fig. 1. Schematic diagram of the He-jet target chamber and capillary transport assembly and the rotating wheel collection and detection system. The arrangement of the detectors is shown in the lower-right portion of the figure.

and the 1st source goes to No. 1-3 detector. In this time detectors No. 1-1, No. 1-2 and No. 1-3 recorded the same source (1st source), thus the time sequential spectra could be obtained. When the 4th source is rotated to the front of No. 4-1 detector, the 3rd source is sent to No. 3-2 position; the 2nd source is sent to No. 2-3 position, and the 1st source is returned to the collection position and the 5th source will be collected there. After a cycle of the wheel a new product source will be rotated to face the No. 1-1 detector and a new sequential measurement will be started. By this way the measurement procedure will be repeated and continued up to the end of the experiment. In the process, the measuring time of each detector for every source is equal to the collecting time of this source.

In order to measure the longer and shorter half-lives of the products, two experimental runs with collection times of 3 s and 10 s were performed. A total of 9 s and 30 s time sequential decays in each cycle for 3 s and 10 s collection, respectively, could be obtained.

In the measurement process one can see that there are one time-interval facing the source and three time-intervals not facing the source for each detector. When the detector is not facing the source, only the decays of α-recoils (daughters) on the surface of the detectors are recorded. Furthermore, the detectors of each group are recording the time sequential decays of the products and their daughters when facing the source on the wheel. When the data are processed and analyzed we can accumulate the recorded counts for each detector in accordance with the wanted time-interval so as to obtain the time sequential spectra, the mother and daughter as well as the pure daughter decay spectra. In other words, the time sequential decay could be obtained both from the recorded counts of separated time intervals of each

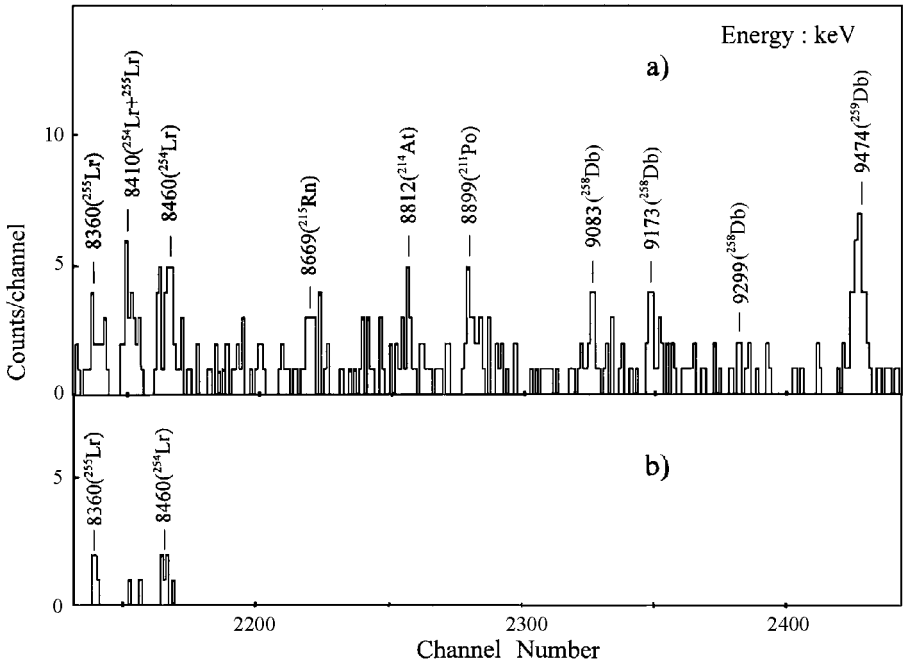

Fig. 2. The α-particle spectra produced by bombardments of ^{241}Am with 118 MeV ^{22}Ne ions. It is the sum counts recorded by No. 1 detector of each group in 3 s collection and measurement time for each cycle. (a) The α-particle spectrum recorded by the detectors when facing the product source. (b) The α-particle spectrum recorded by the detectors during the not-facing the product source period. (The α-spectrum of the recoiled daughter.)

detector and from the recorded counts of the ordinal detectors of each group.

This arrangement of the detectors is much simpler than that with a shuttle system of detectors used by Ghiorso *et al.* [3,4], but our arrangement for the detector without shuttle system has a low efficiency for recording daughter decay.

The information from each of the many detectors was recorded in an event-by-event mode and analyzed using a Multiparameter Data Acquisition System MPA-3. In addition, the position of the wheel and the start time of acquisition data were also recorded. The data processing, such as spectrum fitting, normalizing the gain on the detectors and sorting of the data, was done by a personal computer.

For alpha-calibration the 6.051 MeV (^{212}Bi) and 8.784 MeV (^{212}Po) lines of a Th-source were used. The typical alpha-energy resolution for most of the detectors was 30-40 keV (FWHM).

3 Results and discussion

The α-particle spectra shown in fig. 2 resulted from the bombardment of the ^{241}Am target with 118 MeV ^{22}Ne ions in 3 s collection and measurement time interval by No. 1 detector of each group. The α-spectra recorded by the detectors in facing the product source on the wheel, combined with the α-spectra from the same detectors but not facing the product source, were shown in fig. 2(a) and (b), respectively. In other words, fig. 2(a) represented the α-spectra of the products (including mother and daughter nuclides) on the wheel, and fig. 2(b) was α-spectra from the decay of α-recoil-daughter nuclides embedded in the surface of detectors.

An obvious α-peak with the energy of 9.47 MeV appearing in fig. 2(a) is assigned to ^{259}Db in the present work. Its half-life is measured to be 0.51 ± 0.16 s (as shown in fig. 3). In addition, an α-peak with an energy of 8.36 MeV has a measured half-life of 21 s and thus could be assigned to the previous known nuclide ^{255}Lr. Its second α-peak of 8.40 MeV is just overlapped with another peak of 8.41 MeV. We believe that the nuclide ^{255}Lr is the α-daughter of ^{259}Db . A contribution of ^{255}Lr produced directly in the bombardment is neglected due to a rather small production cross-section for an α4n-reaction expected according to Alice Code calculations.

A complex group of peaks with the energies of 9.08, 9.17 and 9.30 MeV in fig. 2(a) could be assigned to ^{258}Db based on the whole complex group decays with a measured half-life of 4.3 s (as shown in fig. 4). This nuclide arose from the reaction ^{241}Am (^{22}Ne, 5n). According to Alice Code calculations, we expect that at $E = 118$ MeV the 5n cross-section is about a factor of two higher than the 4n cross-section. The α-decay daughter ^{254}Lr of ^{258}Db nuclide presented in fig. 2(a) has an α-peak with an energy of 8.46 MeV. And another 8.41 MeV α-peak of ^{254}Lr nuclide is inter-overlapped with a 8.40 MeV α-peak of ^{255}Lr. The decay curve of ^{254}Lr appeared a growth-decay phenomenon as shown in fig. 4, proving that the ^{254}Lr nuclide arose from the decay of the mother nuclide ^{258}Db but not in the reaction directly. The half-lives of 4.3 s and 13.4 s

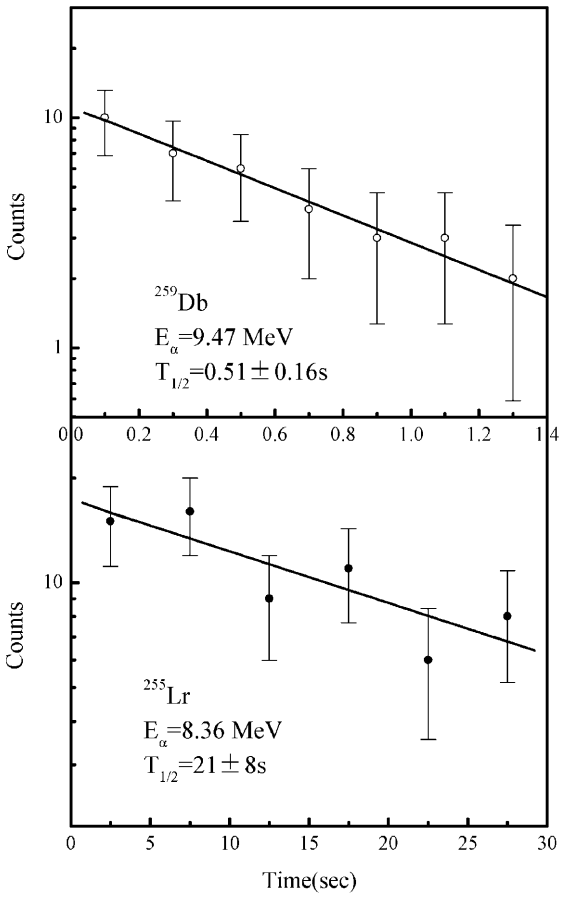

Fig. 3. The decay curves for α-decays of ^{259}Db with α-energy of 9.47 MeV and ^{255}Lr with α-energy of 8.36 MeV when the detectors are facing the product source. For ^{259}Db decay (upper portion) the counts are obtained from the sum counts by No. 1 detector of each group for 3 s collection and measurement time in each cycle, and for ^{255}Lr (lower portion) the decay is obtained from the sequential detectors of each group for 10 s collection and measurement time in each cycle.

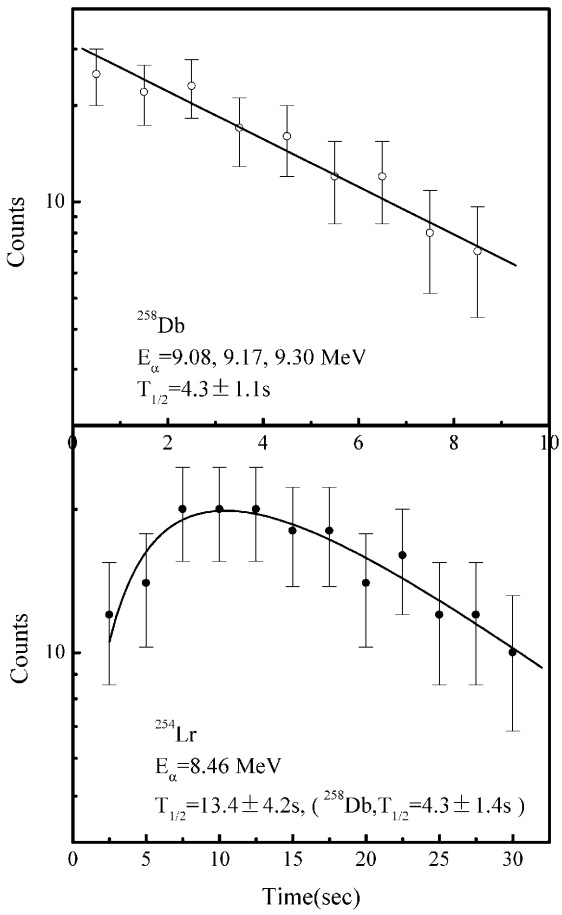

Fig. 4. The decay curves for α-decays of ^{258}Db with α-energy group of 9.08, 9.17, 9.30 MeV and ^{254}Lr with α-energy of 8.46 MeV from the sequential detectors of each group when facing the product source. For ^{258}Db (upper portion) the counts are obtained in 3 s collection time. For ^{254}Lr a growth-decay curve is obtained by 10 s collection time.

deduced from the decay curves of ^{259}Db and ^{254}Lr agree quite well with the known values for these isotopes.

Furthermore, several peaks presented in fig. 2(a) with energies of 8.669, 8.812 and 8.899 MeV should belong to ^{215}Rn, ^{214}At and ^{211}Po, respectively; they are due to bombardment of a small amount of lead impurity in the target with ^{22}Ne ions. These nuclides were produced either in evaporation or in transfer reactions with lead impurity.

Figure 2(b) represented only α-spectra of the recoiled daughter nuclides when the detectors were not facing the products source. In these "daughter" spectra the presented α-peaks have the same energies of 8.36, 8.41 and 8.46 MeV and same half-lives of 13.4 and 21.3 s, respectively, as the values of ^{254}Lr and ^{255}Lr in the "parent" spectra (fig. 2(a)), thus confirming the assignment of the ^{254}Lr and ^{255}Lr, and hence their precursors being ^{258}Db and ^{259}Db.

The ratio of counts in 9.47 MeV peak (^{259}Db) in the mother spectrum to those in 8.36 and 8.40 MeV (^{255}Lr) in the daughter spectrum is 5.2 ± 1.2, which agrees well with the value 5.8 ± 1.0 calculated by taking into account geometry and time factors. Here the efficiency of recording the daughter decay is dependent on detector geometry (∼40%) and the frequency and duration of the wheel.

The production cross-sections are estimated from the yields of ^{259}Db and ^{258}Db α-decays to be 1.6 ± 1.2 nb and 3.6 ± 1.8 nb, respectively. These values result from an assumed 60 ± 10% He-jet transport efficiency, a detection efficiency of 40 ± 10%, and a transport time of 0.2 s for the products from the target chamber to the collection wheel system.

The α-decay energies Q_α of the heaviest elements as a function of neutron number N are plotted in fig. 5. We compared the α-decay energies of new isotope ^{259}Db to the values of the known isotopes in a "Q_α-systematics" for isotopes with $Z \geq 98$. For the Q_α value we took the highest known α-transition energy. The data were taken from ref. [15]. In fig. 5 one can clearly see that the deformed gap of $N = 152$ in the single-particle levels is still observed from elements 98 up to 105. Figure 5 also shows that the

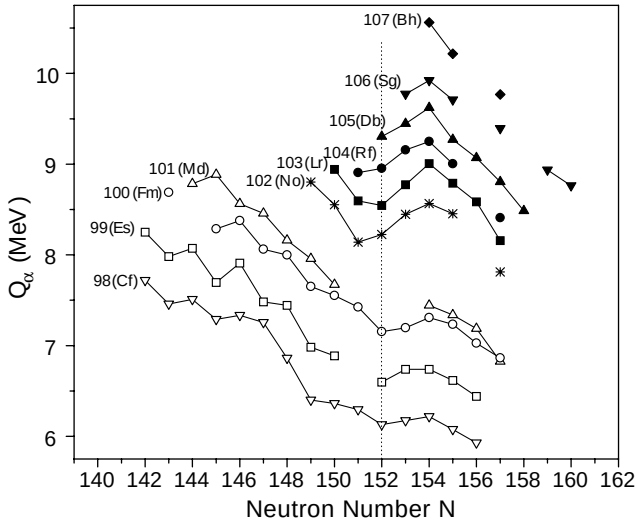

Fig. 5. The systematics of alpha-decay energy Q_α *vs.* neutron number N for isotopes with $Z \geq 98$. The Q_α value for ^{259}Db was derived from the present work. The other data were taken from ref. [13]. For the Q_α value we took the highest known α-transition energy.

Q_α value for new isotope ^{259}Db as compared with the trend for the other $Z = 105$ isotopes, fits quite well into the general trend. ^{259}Db with neutron number $N = 154$ has a higher α-decay energy than the other $Z = 105$ isotopes. Our Q_α value 9.62 MeV for the new isotope ^{259}Db derived from the experiment is in good agreement with the values of 9.60 and 9.61 MeV theoretically predicted by Wapstra [11] and Möller [12], respectively.

In conclusion, a new nuclide ^{259}Db has been produced by bombarding ^{241}Am with ^{22}Ne ions. The identification of this nuclide has been performed by measuring the alpha-particle emission of the mother and daughter nuclides. ^{259}Db has a 0.51 ± 0.16 s half-life and decays by α-emission with the energy of 9.47 MeV. Its Q_α value fits well into the general trend in a "Q_α *vs.* N-systematics" for isotopes with $Z = 105$. Moreover, the nuclide ^{258}Db has been also observed as a by-product in the present experiment and its decay properties are in good agreement with the result reported by ref. [9].

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