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First confirmation of the discovery of element 106

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September 17, 1993

We have confirmed the 1974 report of the discovery of element 106 by Ghiorso et al. The 0.9-s $^{263}106$ was produced at the Lawrence Berkeley Laboratory 88-Inch Cyclotron via the $^{249}\text{Cf}(^{18}\text{O},4n)^{263}106$ reaction was using a beam of 95-MeV ^{18}O ions. Positive identification of $^{263}106$ was made by observing its α -decay followed closely in time by the α -decay of the ^{259}Rf daughter using our rotating wheel system, with six pairs of detectors, in a special parent-daughter mode. The $^{263}106$ half-life, α -decay energy, and production cross section are consistent with those measured for $^{263}106$ by Ghiorso et al. in their 1974 discovery experiment. The half-life and α -decay energies of the ^{259}Rf daughter events are also consistent with those previously published. Our work constitutes the first confirmation of the discovery of element 106.

Keywords: element 106, alpha decay, half-life,

PACS numbers: 27.90+b, 25.70.Gh

I. INTRODUCTION

Element 106 was first produced in 1974 by A. Ghiorso et al.¹ at the Lawrence Berkeley Laboratory HILAC by bombarding a ^{249}Cf target with an ^{18}O beam to produce the 0.9-s isotope $^{263}106$. The isotope was identified by observing time-correlated α -decays from the parent $^{263}106$ and its 3.1-s daughter², ^{259}Rf . The decay modes, α -particle energies and half lives of $^{263}106$ and its daughter activities are shown in Fig. 1. In the 1974 experiments,¹ a total of 73 events were observed with α -decay energies near 9.06 MeV and 9.25 MeV; 14 of these events were correlated to the 8.770-MeV and 8.865-MeV α -particles² from the decay of the ^{259}Rf daughter. In addition, α -decays of the 3.1-minute granddaughter,³ ^{255}No , were recorded and correlated with the $^{263}106$ and ^{259}Rf decays. Using the correlated events Ghiorso et al. determined the $^{263}106$ half-life to be 0.9 s. The production cross section was estimated to be 0.3 nanobarns. The discoverers have not proposed a name for element 106 pending an independent confirmation of their results which we have now provided.

II. EXPERIMENTAL

The confirmation experiment was performed at the Lawrence Berkeley Laboratory 88-Inch Cyclotron. The isotope $^{263}106$ was produced via the same reaction used by Ghiorso et al.: $^{249}\text{Cf}(^{18}\text{O},4n)^{263}106$. The cyclotron provided a 350 particle-nanoAmpere beam of 114-MeV (lab frame) $^{18}\text{O}^{+5}$ which was focused on the californium target contained in the actinide target system. The beam entered through a 2.4-mg/cm² Be vacuum window, 0.3 mg/cm² of N₂ cooling gas, and the 2.5-mg/cm² beryllium target backing before passing through the 0.8-mg/cm² californium oxide target material. The target was actually a ^{249}Bk target prepared 16 months earlier, and therefore contained 280 $\mu\text{g}/\text{cm}^2$ ^{249}Bk and 520 $\mu\text{g}/\text{cm}^2$ ^{249}Cf . This target was chosen for its small Pb content since interactions of the ^{18}O beam with Pb produce interfering activities. The beam energy was chosen so that the energy loss in the target cell components resulted in an ^{18}O energy range of 96-94.5 MeV

in the californium target, the predicted peak of the $^{263}106$ excitation function,⁴ and very similar to the energy used by Ghiorso et al.¹ The target thickness was near the recoil range of the compound nucleus reaction products, so they could recoil out of the target into the recoil chamber. The recoil collection chamber, located directly behind the target, was a 1.9-cm diameter by 10-cm long cylinder. This volume was continuously swept with a He/KCl aerosol gas jet system at a pressure of 1 atm. and a rate of four liters per minute to collect the fusion products and transport them to the detector array for identification. Since the recoil range of the compound nucleus products in the He is about one centimeter, the 1.6-mm diameter capillary was placed in the recoil collection chamber at a distance of 1.5 cm behind the target. The transport time of the products from the recoil chamber to the detection site 7.6 meters away was approximately 0.25 s.

At the detection site, the MG rotating wheel system and alpha-spontaneous fission detection array⁵ was used to characterize the products. The activity from the gas jet was deposited on 40- $\mu\text{g}/\text{cm}^2$ polypropylene foils mounted near the periphery of 20-inch diameter fiberglass wheels. A stepping motor was used to turn the wheel and position the foils between six pairs of passivated, ion-implanted planar silicon (PIPS) detectors. Each detector, with an active area of 100 mm^2 , had a counting efficiency of approximately 30% for alpha particles and 60% for fission fragments. Off-line detector energy calibrations were obtained by measuring the spectrum of α -particles from ^{212}Bi (6.051 and 6.090 MeV) and ^{212}Po (8.784 MeV) in equilibrium with a ^{212}Pb source.³ On-line energy calibrations were obtained using the α -peaks³ of 0.5-s $^{211}\text{Po}g$ (7.450 MeV), ^{215}Rn (8.674 MeV) in equilibrium with ^{223}Th , and 45-s $^{212}\text{Po}m$ (11.65 MeV), all produced from interactions of the ^{18}O beam with the small amount of lead present in the target. The on-line α -particle energy resolution was 60 keV full-width-at-half-maximum (FWHM) for the top detectors in the parent mode, and 100 keV FWHM for the bottom detectors in the parent mode. In the daughter mode, the energy resolution was 40 keV FWHM. Fission fragment energy calibrations were obtained using ^{252}Cf sources.

For this experiment, a special parent-daughter stepping mode was used to facilitate detection of α - α correlations. As shown in Fig. 2, the polypropylene foils were placed in every second hole in the 80-position collection wheel. The stepping was then programmed to proceed in two modes. Fig. 2(a) shows the parent search mode in which the activity was collected on the polypropylene foils which were then double-stepped between the first, third, and fifth detector pairs at intervals appropriate for the detection of the 0.9-s $^{263}\text{106}$. In this mode, the second, fourth, and sixth detector pairs were not detecting activity from sources. If an α -particle with the $^{263}\text{106}$ decay energy (between 8.9 MeV and 9.2 MeV) was observed in a bottom detector, it was assumed that the daughter nucleus, ^{259}Rf , recoiled out of the KCl deposit on the polypropylene foil, and into the top detector. An event within the software gates in the acquisition system generated a signal to initiate the daughter search mode shown in Fig. 2(b) by causing a single step. In this mode the sources were held between detector pairs two, four, and six, with only holes between detector pairs one, three, and five, for a time interval appropriate for the detection of the 3-s ^{259}Rf . Thus, a search for the correlated α -decay from ^{259}Rf was initiated in a low background environment without the possibility of random events from the collected sources, while the sources were still being counted in the even detector pairs. At the end of each daughter cycle, the wheel was single-stepped to resume the collection of sources from the gas-jet in the parent search mode.

Many events with energies near that expected for $^{263}\text{106}$ were detected, causing the initiation of the daughter search mode. Most were due to pileup of lower energy α -particles from the decays of 0.84-s ^8Li and 0.77-s ^8B (Ref. 3), produced by interactions of the ^{18}O beam with the Be target backing foil. The β^- decay of ^8Li and electron-capture of ^8B populate excited states in ^8Be which then decay into a pair of α -particles emitted at 180° . By limiting the ^{18}O beam intensity to 0.35 μA , and limiting the parent and daughter step intervals to 0.6 s and 7 s, respectively, the fraction of time spent in the daughter search mode was reduced to 15%. To reduce the acquisition system dead-time (to $<1\%$), and to reduce

the volume of data collected from this $A=8$ pileup, only events with energies greater than about 7 MeV were recorded. To prevent the recording of noise, data acquisition was disabled for 100 ms during the wheel steps, creating an additional source of dead time.

To prevent the buildup of long-lived activities on the polypropylene foils, the wheel was replaced at one hour intervals. This also prevented the buildup of large amounts of KCl on the foils, which would degrade the energy resolution in the bottom detectors.

III. RESULTS

The experiment was run for a total of 60 hours of data acquisition time. The spectrum of all α -particle events recorded in the odd-numbered detector pairs during the daughter search intervals is shown in Fig. 3. Only activities which have recoiled onto the top detector surfaces due to the α -decay of a parent activity are present. The ^{252}Fm is present as the daughter of ^{256}No . The long-lived activities on the top detectors were characterized in a 30-hour post-experiment background measurement. In this measurement, the 7.0-MeV α -group was found to decay with the ^{252}Fm half-life of 25.4h. There was also a small component due to the 6.9-MeV α -group of ^{253}Fm , present as the daughter of ^{257}No . ^{211}Po is present on the top detectors from the α -decay of ^{223}Th and its daughter activities. ^{223}Th is produced by the $^{208}\text{Pb}(^{18}\text{O},3n)$ reaction on a small Pb impurity in the ^{249}Cf target. The 7.45-MeV α -group of ^{211}Po decayed with the known 0.52-s half-life for this isotope during the daughter mode intervals. ^{214}Po is present due to the natural content of ^{222}Rn in the air from the decay of $^{\text{nat}}\text{U}$. In the daughter mode spectrum, the region above the ^{214}Po energy is free of activities other than those from the decay of ^{259}Rf and ^{255}No , the daughter and granddaughter of $^{263}106$. We observed nine events in the energy range expected for ^{259}Rf and one in the energy range expected for ^{255}No . It should be noted that the events detected in the bottom detectors in the daughter mode have had their energies corrected by 40 keV, since the energy calibrations for the bottom detectors were

performed through polypropylene foils, while in the daughter search mode, there was no intervening polypropylene foil.

Table I lists the detectors, lifetimes and energies of the nine ^{259}Rf events in the odd detector pairs in the daughter mode. Also listed are the detectors, lifetimes and energies of the $^{263}\text{106}$ events that initiated the daughter search mode intervals for each daughter event. In the first and last events, the daughter search mode was initiated by an unrelated event in a different detector pair. Thus, the $^{263}\text{106}$ parents of these ^{259}Rf events were not detected. Each of these two events can be explained in one of three ways:

- 1) The $^{263}\text{106}$ parent α -particle was emitted in a direction such that it missed the bottom detector and caused the ^{259}Rf to recoil onto the top detector or the top detector holder. The daughter search mode was then initiated by an unrelated event. During this daughter search mode, the ^{259}Rf emitted an α -particle which was detected.
- 2) The $^{263}\text{106}$ decayed in the 100-ms interval around the wheel step during which the data acquisition was disabled, causing the ^{259}Rf daughter to recoil onto the top detector surface. The daughter search mode was initiated by an unrelated event allowing the decay of the ^{259}Rf daughter to be detected in either the top or bottom detector.
- 3) The daughter mode event is due to a long-lived background activity and is unrelated to the decay of any $^{263}\text{106}$ atom.

A statistical analysis based on the number of α - α correlations observed, detection and recoil efficiencies, half-lives, stepping times, and the numbers of parent and daughter mode intervals resulted in the expectation of 0.24 events of type 1) and 0.25 events of type 2). The observation of one long-lived 8.8-MeV event in the post-run background measurement and assuming this background rate applies to the whole experiment would result in 0.40 events of type 3). The total of expected events of type 1), 2), and 3) is therefore 0.89. The observation of two such events in our experiments is not inconsistent with this value.

The daughter α -decay for the seventh event in Table 1 has a lifetime which is longer than the 7-s daughter interval. This can easily be explained by assuming the ^{259}Rf survived the daughter interval initiated by its $^{263}106$ parent. The decay of the ^{259}Rf was then detected during a daughter interval initiated by an unrelated event. A statistical analysis indicates 0.89 of these events is expected, which is consistent with the one event observed.

In the remaining six events in Table 1, both the $^{263}106$ parent and the ^{259}Rf daughter with normal lifetimes were observed. The lifetimes of the seven parent events were used to determine the $^{263}106$ half-life by a maximum likelihood technique⁶, resulting in a half life of $1.1^{+2.8}_{-0.6}$ s. The error limits indicate the half-life limits for which the likelihood drops to one half its initial value while holding the initial activity at the value from the best fit. With the parent stepping interval at 0.6 seconds, the experiment was only sensitive to parent events with lifetimes less than 1.8 seconds, resulting in the large upper error limit. If the covariance with the initial activity is considered, the upper error limit becomes very large. This half-life is consistent with the 0.9 s reported by Ghiorso et al.¹ The distribution of parent energies is consistent with that of 9.06 MeV observed by Ghiorso et al.¹ for the main α -group from the decay of $^{263}106$ after our 100-keV resolution in the bottom detectors during the parent search mode is considered.

Similarly, the lifetimes of the 8 daughter events were used to determine the half-life of the ^{259}Rf . The 10.883-s lifetime of the 7th event in Table 1 could not be used since it was outside the daughter mode interval of 7 s, making it difficult to determine a weighting factor for this event. The maximum likelihood fit⁶ resulted in a half-life of $1.7^{+0.8}_{-0.5}$ s. Again, since the daughter interval was only 7 s, if the covariance with the initial activity is considered, the upper error limit becomes very large. This value is consistent with the 3.1 s previously reported². Alpha-groups at 8.866 MeV (40%) and 8.770 MeV (60%) have been reported for the decay of ^{259}Rf (Ref. 2). The distribution of ^{259}Rf energies in the present work appears to be broader than this, considering the 40-keV resolution in the daughter search mode. There are two reasons for this difference. Since the ^{259}Rf atoms have

recoiled into the face of the top detectors, is possible to detect ^{259}Rf α -particles which are emitted in a direction nearly parallel to the detector surface. The detected energy in these events will be lower due to energy loss in the front window of the detector. Also, any conversion electrons which accompany the α -particles have a 50% probability of depositing some energy in the detector. This conversion electron energy will sum with the alpha particle energy, producing a prominent high-energy tail on the α -peaks. This effect is more prominent than in Ref.2 because in our experiment the Rf atoms are on the detector surface, resulting in a 50% efficiency for conversion electron summing, and since the depletion depth in our detectors is 300 μm (we assume the detectors in Ref.2 had 100- μm depletion depth), conversion electrons can deposit more energy in our detectors.

The gas-jet yield was determined by measuring the ^{252}Fm produced in this experiment and comparing with production rates calculated from cross sections for binary transfer reactions measured previously.⁷ ^{252}Fm production in this experiment was determined by measuring the long-lived α -activities in some of the polypropylene foils after removing the wheel from the detector chamber. The gas-jet yield was determined in this way to be near 30% throughout the experiment. Using this gas-jet yield and the other experimental parameters, we calculate the same $^{263}106$ production cross section of 0.3 nb reported by Ghiorso et al.¹

IV. CONCLUSION

The discovery of element 106 was made in 1974 by Ghiorso et al.¹ using 0.9-s $^{263}106$. The discoverers have not proposed a name for element 106 pending a confirmation of their results. We have produced 0.9-s $^{263}106$ by the $^{249}\text{Cf}(^{18}\text{O},4n)$ reaction and identified it by correlating the 9.06-MeV α -decay of $^{263}106$ with the α -decay of the 3.1-s ^{259}Rf daughter. The activities were detected on a rotating wheel system which was run in a parent-daughter mode which minimized the effect of random parent-daughter correlations. The measured decay energies and half-lives of $^{263}106$ and ^{259}Rf are consistent with those

previously published, as is the $^{263}\text{106}$ production cross section. In our experiment, detection of the 9.06-MeV α -particle from the decay of $^{263}\text{106}$ initiated the daughter search mode, providing a direct correlation between parent and daughter α -decays. In the Ghiorso experiment,¹ detectors were put into daughter mode at preset intervals and an indirect correlation between the parent and daughter α -events was made based on a half-life argument.

This experiment constitutes the first confirmation of the discovery of element 106, thus permitting the discoverers to propose a name for element 106 in accordance with *Criteria for the Discovery of Chemical Elements*,⁸ which states that, "the name for a new element should not be proposed by the discoverers until the initial discovery is confirmed."

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TABLE I. Daughter mode ^{259}Rf events and $^{263}\text{106}$ events which initiated the daughter mode.

Event#	Parent			Daughter		
	Detector	Lifetime (s)	Energy (MeV)	Detector	Lifetime (s)	Energy (MeV)
1				3 bottom	0.717	8.70
2	1 bottom	0.283	8.99	1 bottom	0.717	8.66
3	1 bottom	0.283	9.09	1 top	2.850	8.99
4	3 bottom	1.117	9.00	3 top	1.933	8.93
5	3 bottom	1.183	9.05	3 top	0.267	8.80
6	3 bottom	0.783	9.08	3 top	5.467	8.87
7	1 bottom	0.200	8.95	1 top	10.883	8.90
8	5 bottom	1.733	8.90	5 top	0.517	8.83
9				5 top	4.633	9.10

FIGURE CAPTIONS

FIG 1. The decay of $^{263}\text{106}$ and its daughter activities.

FIG. 2. Schematic of the detection system showing the parent-daughter stepping mode (vertical scale exaggerated). The rotating wheel had 40 mg/cm^2 polypropylene foils interspersed with 18-mm diameter holes in alternating wheel positions. (a) in the parent search mode, the wheel was double-stepped to position the newly collected samples subsequently between detector pairs 1, 3, and 5. Upon detection of a potential $^{263}\text{106}$ α -decay in one of the bottom detectors, it was assumed that the ^{259}Rf daughter recoiled to surface of the top detector. The wheel was then single-stepped to (b) daughter mode, to position a hole between the detector pair in which the parent was detected. The wheel was held in this position to allow the detection of the α -decay of the recoiled ^{259}Rf atom. After an appropriate time interval the wheel was again single-stepped to resume parent search mode.

FIG. 3. The spectrum of all α -particle energies recorded in the odd-numbered detector pairs during the daughter search mode. Note the change in vertical scale at 7.6 MeV.

$^{263}_{106}$ Decay Chain

(a) parent mode

(b) daughter mode

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