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Element 106†

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We have produced element 106 by bombarding ^{249}Cf with ^{18}O ions accelerated by the SuperHILAC. The new nuclide ^{263}106, produced by the $(^{18}O, 4n)$ reaction, is shown to decay by α emission with a half-life of 0.9 ± 0.2 sec and a principal α energy of 9.06 ± 0.04 MeV to the known nuclide ^{259}Rf, which in turn is shown to decay to the known nuclide ^{255}No.

The identification of new elements at the upper end of the periodic table is especially difficult because of extremely low production rates and because there are large uncertainties in predicting their nuclear properties. For these reasons, positive identification requires some means of determining the atomic number directly. Among the proven methods are (1) measurement of distinctive K x rays[1,2] following α decay and (2) establishment of a genetic link between an α emitter of a new element and a previously identified daughter nuclide. Our identification of element 106 is based on the latter method because of its higher sensitivity. This method was also used in discovering α-emitting isotopes of rutherfordium (element 104)[3] and hahnium (element 105).[4] For element 106, we have carried this method one step further by demonstrating that the granddaughter [^{255}No, $t_{1/2} = 3$ min, $E_\alpha = 8.11$ MeV (57%)][5,6,1] is in the chain of α decay of ^{263}106. Thus, our proof for the atomic number of element 106 comes from demonstrating the following decay sequence: $^{263}106 \xrightarrow{\alpha} {}^{259}\mathrm{Rf} \xrightarrow{\alpha} {}^{255}\mathrm{No} \xrightarrow{\alpha}$.

These genetic relationships were established in two ways depending on whether ^{263}106 α particles escaped from their backing surface. (1) When these particles were detected leaving the surface, we observed with a certain probability in a time interval of 12 sec the α's of the 3-sec daughter ^{259}Rf ($E_\alpha = 8.77$ and 8.86 MeV) that also were directed outward; i.e., we observed the decay sequence $^{263}106 \xrightarrow{\alpha} {}^{259}\mathrm{Rf} \xrightarrow{\alpha}$. (2) When ^{263}106 α's were directed into the backing surface (and hence were not detected), the recoil energy imparted to the daughter nucleus allowed it to escape from the surface and to be implanted in the face of an opposing detector. Upon periodically moving these detectors away from the original sources, the α decay of daughter ^{259}Rf and the subsequent α decay of the granddaughter were observed; i.e., we detected the decay sequence $^{259}\mathrm{Rf} \xrightarrow{\alpha} {}^{255}\mathrm{No} \xrightarrow{\alpha}$. Considering the finite thickness (~1 μg/cm^2) of the NaCl deposits containing the ^{263}106 atoms, the considerable recoil energy required to transfer the observed number of daughter ^{259}Rf atoms to the detector faces could be furnished only by a preceding α emitter. We thus were provided with a second genetic linkage to ^{263}106 by α decay.

The ^{18}O beam from the SuperHILAC (average 3×10^{12} ions/sec) was wobbled electromagnetically to prevent localized overheating of the target, which was both edge-cooled by contact with a water-cooled copper block and gas-cooled by helium impinging on the aluminum backing (Fig. 1). The energy of the ^{18}O ions emerging from the target was determined by measuring the energy of these ions scattered from the target into a Si(Au) surface barrier detector placed at 30° to the beam axis.

The target was prepared by subliming 259 μg of ^{249}Cf as CfF_3 onto a 27-μg/mm^2 substrate of

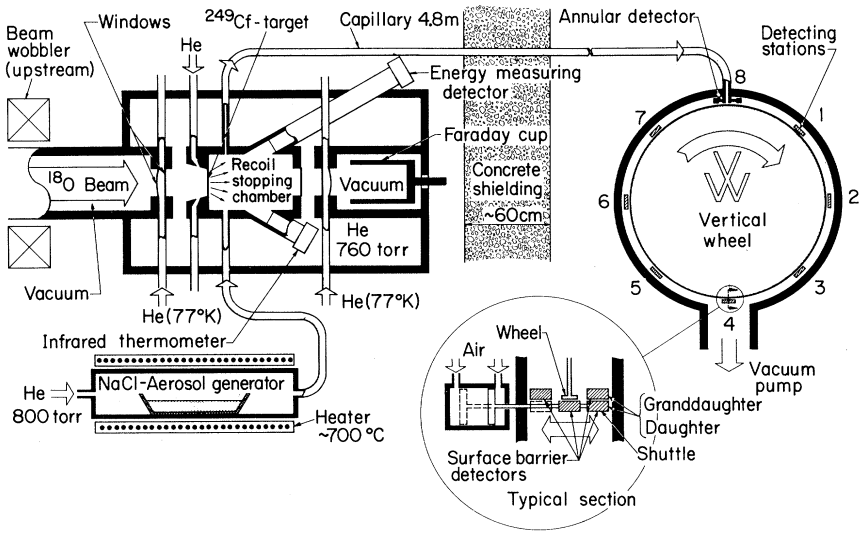


FIG. 1. Schematic representation of the experiment.

99.999% pure Al. The ^{249}Cf, deposited over a 6.3-mm-diam area of average surface density 8.3 μg/mm^2, was covered with a thin (0.3 μg/mm^2) layer of Al to prevent any transport of ^{249}Cf to the detection system.

Atoms of ^{263}106 along with other transmutation products recoiled from the target into a stopping chamber and were swept by a flow of helium (containing NaCl aerosol) through Teflon tubing (4.8 m long, 1.24 mm i.d.) into an adjoining counting area. After a 0.1-sec transit time, the radioactive products were deposited onto the rim of a 45-cm-diam wheel which was rotated 45° each second to collect a new deposit. α particles from the deposits were then examined by a series of seven detecting stations each having 50-mm^2 Si(Au) surface barrier detectors positioned within 0.5 mm of the wheel rim. An eighth 100-mm^2 Si(Au) annular detector analyzed the α activity of the deposit while it was being collected. Thus, each deposit was α analyzed for 7 sec (1 sec at each station) before it returned to the collecting position. Since new deposits were layered over the old, the wheel was advanced by 1.5° every 30 min to reduce the buildup of long-lived radioactivities in the deposits being analyzed.

If an α particle from the decay of ^{263}106 is observed, then another α particle from the decay of its daughter, ^{259}Rf, should follow within a few daughter half-lives. Both events must originate from the same deposit, but they may be observed in separate detectors because the wheel advances the deposit every second. After considering the counting geometry and the decay and gating intervals, we calculated a detection efficiency for these "mother-daughter" pairs of (28 ± 2)% compared to "mother only" events.

In addition to monitoring mother and daughter α decays directly, we used a detector shuttle system (inset of Fig. 1) to detect daughters and granddaughters resulting from α recoils. By moving the detectors away from the wheel, we could distinguish between recoil-implanted and wheel-borne ^{259}Rf and ^{255}No. Much larger amounts of these nuclides were made by direct nuclear reactions than by α decay from ^{263}106 and thus constituted a high background on the wheel. The set of seven detectors monitoring the wheel was shuttled every 6 sec to a low-background position facing seven stationary detectors, while another set of movable detectors resumed the monitoring of the wheel. In the event that a ^{259}Rf daughter had recoiled from the wheel onto a detector and we later observed α decay of this daughter with the detector in the off-wheel position, this detector was not returned to the wheel position until 10 min had elapsed. This time period permitted an adequate opportunity for observing the subsequent α decay of the 3-min granddaughter, ^{255}No.

α and fission pulses from the detectors were amplified and passed through an analog-to-digital converter to a PDP-9 computer. The computer recorded on magnetic tape all the event information, including α energy, time, detector location, and wheel position. The PDP-9 also controlled the operation of the wheel and shuttle systems.

We used off-line computer programs for correlating the arrival time of selected α events with the time, α energy, and detection location of other α events. Using events in the ^{259}Rf energy region to define time origins, the intervals of 0 to 12 sec and 50 to 62 sec preceding these events were scanned for correlated decays. The first time range gave possible mother-daughter correlations; the second provided a good measure of the accidental background.

Earlier experiments performed in the Berkeley laboratory had shown several promising mother-daughter events and daughter recoils. However, because of background radioactivities arising from Pb, Bi, and Be (^{8}Li decay) in the target, these experiments were unable to provide sufficient proof of the atomic number. Our current α spectra are virtually free of these background activities and show prominently only those α emitters produced from the reactions of ^{18}O ions with ^{249}Cf.

The gross α spectrum above 8 MeV, summed using the data from the wheel detectors, is shown in Fig. 2(a). α groups at 8.77 and 8.86 MeV have been identified previously as belonging to ^{259}Rf.[3] After subtracting background, we attribute 73 ± 3 of the 87 events in the groups at 9.06 MeV and near 9.25 MeV to the α decay of the new nuclide, ^{263}106. The distribution of these events around the wheel indicates a half-life of 0.9 ± 0.2 sec.

The 9.06- and 9.25-MeV α's are followed within 12 sec by daughter α's at 8.77 and 8.86 MeV, as shown in Fig. 2(b). We observed 14 time-correlated pairs compared with 20 ± 2 predicted from our estimate of 28% detection efficiency. The singles counting rates indicate that we should have observed an average of only 1 and, within 95% confidence limits, a maximum of only 2.5 accidental correlations among these 14 correlated events. Random α's occurring 50–62 sec before ^{259}Rf decay events are shown in Fig. 2(c). We infer from these data that the new activity decays by emission of 9.06- and 9.25-MeV α particles to ^{259}Rf and, therefore, can belong only to ^{263}106.

Some 22 atoms of recoil-transferred ^{259}Rf were observed to decay in the off-wheel detectors. Shortly after these daughter events, granddaughter ^{255}No α particles were detected from four off-wheel daughter decays. This ratio is consistent with our prediction of twenty off-wheel daughter decays and six granddaughter decays, assuming ~60% counting efficiency and the ~50% electron-capture branching by ^{255}No.[7]

From the rate of producing our ^{263}106 activity,

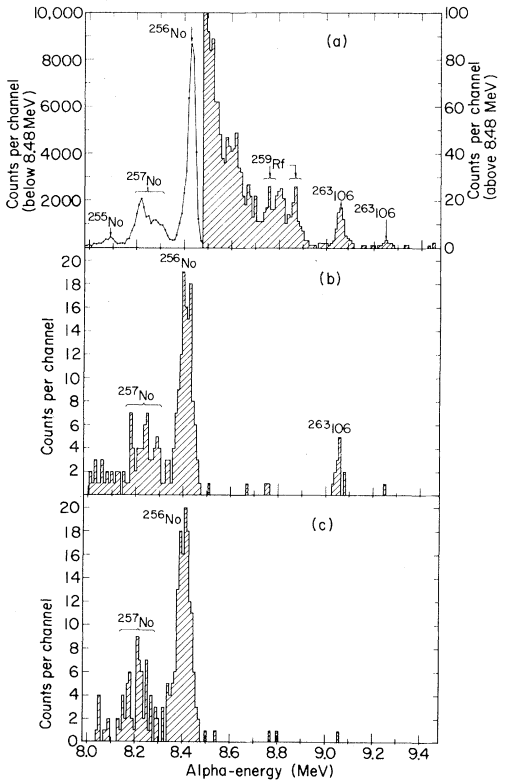


FIG. 2. (a) Sum of α spectra from stations 1 through 7. The integrated beam intensity was 1.34×10^{18} particles of ^{18}O. The peak at 8.81 MeV, which has a long half-life (> 5 sec) and is not time-correlated with any α group above 8 MeV, is probably ^{214}At fed by ^{222}Ac (Ref. 10), produced from trace amounts of Pb in the target. (b) α events in the 0–12-sec interval preceding ^{259}Rf events (8.65 to 8.91 MeV). The 12-sec time interval represents four ^{259}Rf half-lives. Thirteen correlated events were observed at 9.06 MeV and one correlated event at 9.25 MeV. (c) α events in the 50–62-sec interval preceding ^{259}Rf events. A 50-sec time displacement was chosen to determine the accidental spectrum. Only one α event was found within the ^{263}106 energy region, as had been expected from Poisson statistics.

we calculate a formation cross section of ~0.3 nb at an ^{18}O energy of 95 MeV. Very little of this activity was made by ^{18}O ions of ~91 and ~100 MeV, indicating a rather narrow excitation function, consistent with our calculated excitation function for the reaction ^{249}Cf(^{18}O, $4n$), which shows a half-width of 7 MeV and a maximum cross section of 0.2 nb.[8]

Spontaneous fission of ^{263}106 could not be determined because of interference from 2.7-h ^{256}Fm, a spontaneously fissioning isotope produced in the bombardments.

During a recent visit by Soviet scientists to our

laboratory, in which we exchanged information about "106" experiments, G. N. Flerov of the Dubna Laboratory reported the observation of spontaneous fission activities with half-lives of 4–10 msec produced by bombarding ^{207,208}Pb with ^{54}Cr.[9] They attribute these activities to lighter isotopes of element 106. In view of the simultaneity of the experiments at the Dubna and Lawrence laboratories, and their very different nature, we shall postpone suggesting a name for element 106 until the situation has been clarified.

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Gamma Rays Observed from 100-MeV Protons Interacting with ^{56}Fe and ^{58}Ni†

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Gamma radiation from 100-MeV protons incident on targets of ^{58}Ni and ^{56}Fe has been observed. Residual nuclei were identified by using the known γ rays. Some of the strongest γ rays observed involved residual nuclei *equivalent* to the target nucleus minus one to three α particles. These results can be understood on the basis of a pre-equilibrium stage involving an intranuclear nucleon-nucleon cascade followed by an evaporation process.

Several groups[1-5] have observed γ radiation coming from the interactions of fast pions, as well as stopped pions and kaons, with nuclei for $A \lesssim 65$. It was found especially in the case of fast pions that there was particularly strong production of the γ ray corresponding to the first excited state of the nuclei with two protons and two neutrons (an "α" particle), and in some cases several "α" particles, less than the target nucleus. Earlier, Clegg[6] had observed γ rays from nuclei with $A \lesssim 40$ when bombarded with 150-MeV protons. Various authors have observed the similarity of the results in these two classes of experiments, but there has been little quantitative work done in explaining the relative role of direct α knockout, or pre-equilibrium processes,[7] as distinguished from evaporation processes. Since the main features of intermediate-energy processes in nuclei are understood semiquantitatively, we felt that an investigation of proton-induced γ-ray production could shed light on the questions of the connection particularly