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Identification of ^{208}Hg

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This paper describes in detail the procedures used in the identification of the new neutron-rich isotope ^{208}Hg and the measurement of its half-life. The identification included two step chemical separations. The first step was the collection of Hg element products from the irradiated target with high efficiency and good element selectivity, which was realized by means of an off-line melt Pb target device. The second step was to extract periodically the growing Tl element from the collected Hg sample. In the γ spectra of the extracted Tl sample, a 2614.6 keV activity with a half-life of 3 minutes was observed, which may only be assigned to the daughter ^{208}Tl of ^{208}Hg β^- decay.

Key words: neutron-rich nuclei, chemical separation, nuclide identification, β^- decay, γ-activity.

1. INTRODUCTION

The exotic transfer reaction induced by heavy ion projectile on neutron-rich target ^{208}Pb is one possible way to synthesize the unknown isotope ^{208}Hg. The utilizable reaction mechanisms are mainly the nucleon exchange and transfer in dissipative collision process and the directly double charge exchange process between projectile and target. The predicted production cross section of ^{208}Hg is in the range of 10^{-31} to 10^{-29} cm^2 for different projectiles and incident energy. Considering the transfer reaction, especially the double charge exchange reaction may occur in a considerable wide energy range above the Coulomb barrier, intermediate energy (30 MeV/nucleon) ^{12}C was used to collide with

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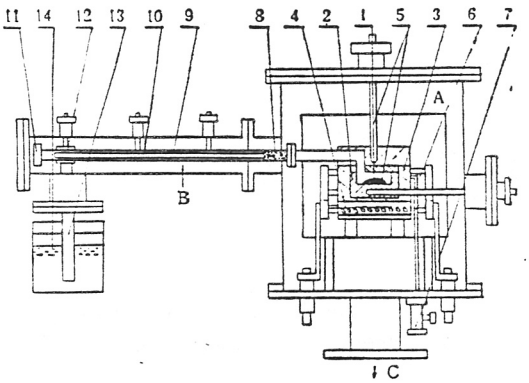

Fig. 1

A schematic view of the off-line melt Pb target device. A: the main vacuum chamber; B: the side vacuum chamber; C: to a turbomolecular pump. 1. target material; 2. graphite box; 3. target oven; 4. heater of helical tungsten filament; 5. thermocouple; 6. capillary; 7. needle valve; 8. quartz wool; 9. Ta foil lined on the inner surface of the transport tube; 10. transport tube; 11. Ag_2O powder collector (filled in a thin foil of foam plastics); 12. cooling ring; 13. copper rod; 14.liquid N_2.

a thick target, which was sufficient to stop the beam in order to increase the yield of the expected ^{208}Hg. Because the energy range is wide and there are a large variety of reaction products, at least hundreds of isotopes of more than ten elements should be considered. It is difficult to unambiguously assign the low cross section product ^{208}Hg. The news about the synthesis of the new neutron-rich isotope ^{208}Hg have already been reported [1]. In this paper, a detail description about the identification procedure of ^{208}Hg is given.

2. EXPERIMENTAL PROCEDURE AND DATA ACQUISITION

2.1. Target Irradiation

A Pb target was irradiated by 30 MeV/nucleon ^{12}C beam from the Lanzhou Heavy Ion Research Facility (LHIRF) at the Institute of Modern Physics with an average intensity of 25 nA. The target thickness was 980 mg/cm^2, which could fully stop the incident ^{12}C beam. The irradiation time was 3 hours.

2.2. The Collection of Hg Element with High Efficiency and High Chemical Selectivity

The irradiated Pb target foils were put immediately in the off-line melt Pb target device for treatment. The detail experimental results about the off-line melt Pb target device can be found in [2]. Here we only give a brief description. A schematic view of this device is shown in Fig. 1. The irradiated target was put into the graphite box of the target oven. Helium gas was flowed with a purity of 99.999% and a flow rate of 1-5 ml/min after the vacuum was established. The heating temperature of the graphite box was controlled between 760°C and 780°C. The products volatilized from the target were collected by a collector, which was placed at the end of the transport tube. The collector is a foam plastics filled with Ag_2O powder. A deep cold point with temperature below -10°C was formed at the end of the transport tube because the transport tube was 60 cm long and a copper rod inserted into a liquid nitrogen vessel was stretched to this end point. This insures that except Hg all the volatile products including Po, Tl and At are deposited along the transport tube. The exponential decrement

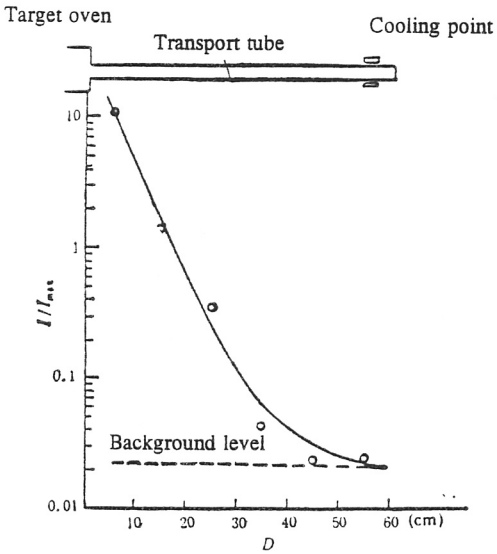

Fig. 2

The deposition and decay of the volatile Tl element along the inner surface of the transport tube obtained by isotope tracer method. The tracer isotope is ^{200}Tl. The horizontal axis is the distance from the measurement point to the target oven.

of these products along the transport tube can be measured by putting a Ta foil on the inner surface of this tube. The decreasing curve of Tl element along the transport tube is obtained by using ^{200}Tl as a tracer isotope and is shown in Fig. 2. In temperature lower than 780°C, Pb and Bi have very low volatility and are difficult to reach the collected point [3]. In Fig. 4(b) of [2] the γ spectra of the directly irradiated Pb target and the collected Hg sample have been compared. The peaks of Pb, Bi and Tl isotopes which are prominent in the spectrum of the direct irradiated Pb target disappear in the spectrum of collected Hg sample. The remained γ rays are produced by Hg isotopes and their β^+ decay daughter Au isotopes. A calibration made by using ^{208}Hg as a tracer isotope shows that the collection efficiency of Hg element by this Ag_2O collector is more than 95% [2].

2.3. Results from Analyzing the Spectrum of the Directly Separated Hg Sample

We failed to directly analyze the time-sequential γ spectra of the collected Hg sample to search the possibly produced ^{208}Hg because the energy of the characteristic γ ray of ^{208}Hg decay daughter ^{208}Tl (2614.6 keV) overlaps that of decay γ ray of ^{192}Au produced by ^{192}Hg β^+ decay, and the latter is much more intense [4]. The intensity of 2614.6 keV γ ray changing with the time shows an almost typical single nuclide growth-decay curve, but we found that the first several data points do not agree with the single growth-decay law of the mother-daughter pair ^{192}Hg→ ^{192}Au. They are obviously too high when fitting the growth-decay curve of 2614.6 keV γ ray with $^{192}\mathrm{Hg}(T_{1/2} = 4.9\mathrm{h}) \xrightarrow{\beta_3} {}^{192}\mathrm{Au}\,(T_{1/2} = 5.03\mathrm{h})$ mother-daughter relation [5,6]. Hence we analyze the relation between the time and the proportion of the intensity of 2614.6 keV γ ray to the intensity of the main decay γ ray of ^{192}Au (316.5 keV). The

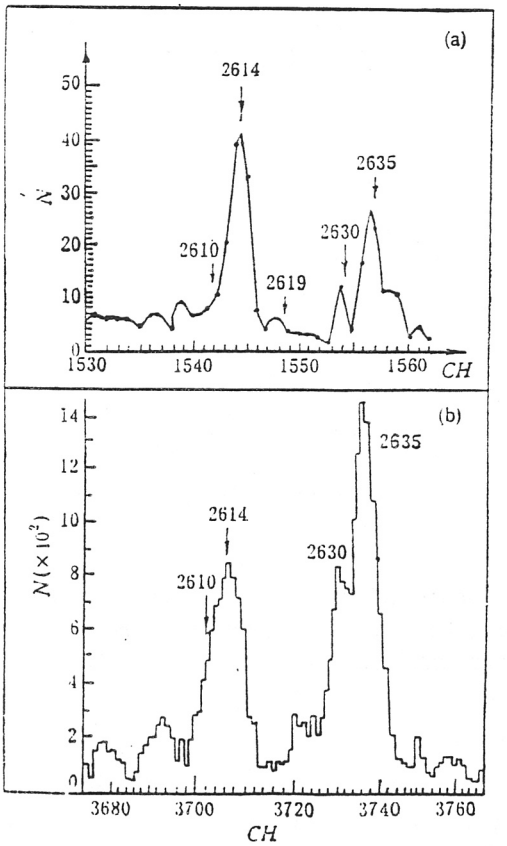

Fig. 3

The γ spectra in the energy range near 2614.6 keV obtained by two different methods. (a) The cumulative spectrum of the 36 γ spectra obtained by measuring the 9 Tl samples extracted periodically from the Hg solution. (b) The direct γ spectrum of the collected Hg sample 5h after the irradiation. The measurement time is 1h.

branching ratios of these two γ ray in ^{192}Au decay are 0.65% and 100% respectively [7]. The proportion of these two γ rays is constant 3 hours from the end of irradiation, is 30% higher 1 hour from the end of irradiation and gradually decreases to a constant value in the following 2 hours. This means the 2614.6 keV γ ray of the collected Hg sample includes a unknown component with a half-life between 0.5 and 1 hour except the decay γ of ^{192}Au. The γ rays of Bi, Tl and Po elements are not observed in the measured spectrum. Even the most intensive γ rays of the easiest measured nuclei ^{202,203,204}Bi do not appear [4]. This excludes the possibility that the unknown component comes from ^{212}Bi α decay daughter ^{208}Tl.

The measurement was performed in a low background Pb chamber. A HpGe detector with a 40% detector efficiency and 2.2 keV energy resolution was used. The background around 2614.6 keV γ peak is 0.83 count/h after a long time measurement.

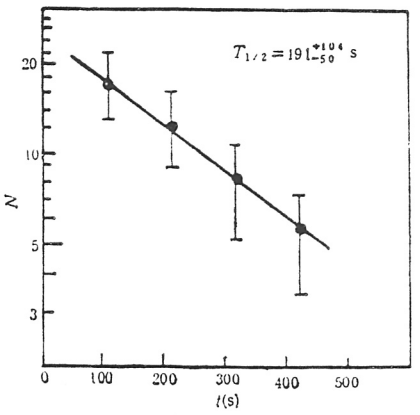

Fig. 4

The decay curve of ^{208}Tl produced by ^{208}Hg decay. The error bar stands for the statistical error only.

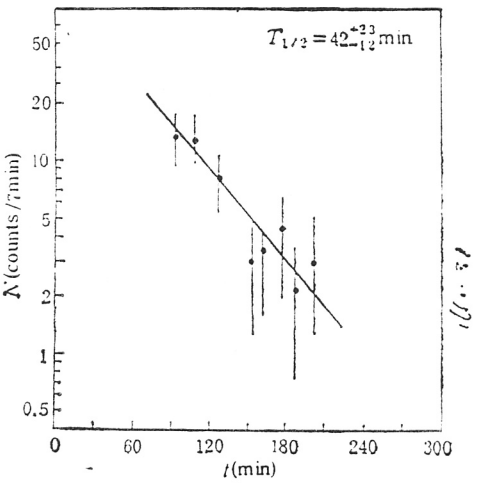

Fig. 5

The decay curve of unknown neutron-rich isotope ^{208}Hg. The zero time corresponds to the end time of irradiation. The error bar stands for the statistical error only.

2.4. ^{208}Tl Was Found in the Tl Element Samples Extracted Periodically from the Collected Hg Product Solution; It Could Only Be Assigned to ^{208}Hg β^-Decay Daughter

Although the above results give us some hope about the synthesis of ^{208}Hg, a clear identification about ^{208}Hg cannot be given immediately. To determine if this short half-life component is the contribution of ^{208}Hg decay daughter ^{208}Tl, the following procedure similar to the so-called "milking" method was used. First, Hg element in Ag_2O powder was extracted and formed a solution. A ^{208}Hg tracer isotope experiment shows the efficiency of this step can reach 90%. Second, the growing Tl element was extracted periodically from the Hg solution. The time gap from the end time of target irradiation to the start time of measuring the first extracted Tl sample is 90 minutes. Considering the equilibrium time of ^{208}Tl grow-decaying from ^{208}Hg was about 2.2 times of the half-life of ^{208}Tl it self ($T_{1/2}$ = 3.05min). 7 minutes is chosen as the growing cumulative time of ^{208}Tl. Tl element was extracted by a fast one-step chemical procedure. Then the γ spectrum of the extracted Tl sample was measured immediately. Several circulations were done as above. The decay of the mother nuclide ^{208}Hg can be deduced from the intensity of the γ ray of the extracted Tl sample. To confirm the synthesis of ^{208}Hg, we must identify whether its daughter ^{208}Tl really exists in the extracted Tl samples. So a multi-scaling data acquisition method was used when measuring the spectrum of the Tl sample. The measurement time of each sample was 7 minutes. Four 2048 channels γ spectra were recorded and each spectrum corresponded to the spectrum of 105 seconds. A total of 36 spectra for 9 samples were obtained. The chemical efficiency of extracting Tl from Hg solution is higher than 95% and the repeatability is better than 5%.

3. DATA ANALYSIS AND RESULTS

Figure 3 shows the comparison of two γ spectra in the energy near 2614.6 keV (see figure caption). In Fig. 3(b), 2610, 2614, 2630 and 2635 keV γ peaks can be attributed to the decay γ of ^{192}Au. Their relative intensities almost agree with the branching-ratios of the corresponding decay γ

of ^{192}Au [7,8]. In Fig. 3(a), 2610, 2630 and 2635 keV γ peaks are much reduced, while the relative intensity of 2614 keV γ peak is obviously higher than others. This indicates that in the periodically growing Tl sample from Hg, there is another source, which can emit 2614.6 keV γ ray except ^{192}Au. If we add the $4 \times 9 = 36$ time-sequential γ spectra acquired by multi-scaling method according to the corresponding time interval, namely we add the intensities of 2614.6 keV γ ray of four γ spectra corresponding to 0-105 s, 106-210 s, 211-315 s and 316-420 s time intervals, respectively, and subtract the contribution of ^{192}Au. The obtained results are shown in Fig. 4. The contribution of ^{192}Au in 2614.6 keV γ peak of the four cumulative γ spectra is subtracted proportionally according to the intensity of the main γ peak 316.5 keV of ^{192}Au in the spectra. A Tl isotope decay-growing from Hg with a half-life of 3 minutes, and a decay γ ray energy of 2614.6 keV is observed. This isotope can only be assigned to ^{208}Tl produced from ^{208}Hg β^- decay. It doubtlessly proves that ^{208}Hg has been synthesized and identified.

The decay γ intensity of ^{208}Tl extracted from Hg solution is proportional to the intensity of ^{208}Hg at the extracted moment. So we add the four γ spectra of each sample and subtract the contribution of ^{192}Au according to the above method. After normalization, the decay curve of ^{208}Hg is obtained and shown in Fig. 5. The half-life of ^{208}Hg 42^{+23}_{-12} minutes is obtained by the least-square fitting of the data. The average production cross section of ^{208}Hg is 1.1 ± 0.5 μb in the energy range of ^{12}C beam from 30 MeV/nucleon to the Colomb barrier 5 MeV/nucleon.

4. CONCLUSIONS

Neutron-rich isotope ^{208}Hg has been synthesized in LHIRF by 300 MeV/nucleon ^{12}C beam colliding with a natural thick Pb target. The identification method includes the chemical separation of Hg element and the determinations of the characteristic γ ray 2614.6 keV for the daughter ^{208}Tl of ^{208}Hg β^- decay. The measured half-life of ^{208}Hg 42 minutes is much longer than the half-life of ^{206}Hg 8.15 minutes. This shows a obvious sell effect. Because the predictions of different theoretical models for the half-life of ^{208}Hg are very different [9-11], the determination of the half-life of ^{208}Hg can provide a significant check to the existing theoretical models.

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