Production and Decay Properties of $^{266}$Bh and its daughter nuclei by using the $^{248}$Cm($^{23}$Na,5n)$^{266}$Bh Reaction

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Introduction

Motivation of this work

Until now, two decay chains of $^{278}_{113}$ were observed by using $^{209}_{97}$Bi + $^{70}_{28}$Zn. Both Chain consist of four alpha decays and ended by spontaneous fission of $^{262}_{113}$Db.

Because the decays of $^{266}_{113}$Bh and $^{262}_{113}$Db are known nuclei already reported, we claimed that the $^{278}_{113}$ were clearly determined with Z and A.

However

The statistics of the report of $^{266}_{113}$Bh are not enough.

1 events: ($^{249}_{97}$Bk + $^{22}_{10}$Ne -> $^{266}_{113}$Bh), LBNL, P. A. Wilk et al., Phys. Rev. Lett. 85, (2000)

4 events: ($^{243}_{95}$Am + $^{26}_{13}$Mg -> $^{266}_{113}$Bh), IMP, Z. Qin et al., Nucl. Phys. Rev. 23 (2006) (Chinese journal in English)

Motivation of this work is to increase the statistics of the decay of $^{266}_{113}$Bh and $^{262}_{113}$Db. Confirm the connection to the known nuclei for element 113.

Candidate of the reactions

- $^{249}_{97}$Bk, $^{243}_{95}$Am target: Not available in RIKEN
- $^{205}_{81}$Tl($^{70}_{28}$Zn, n)$^{274}_{113}$Rg: small cross section 1 event/30days
- $^{248}_{95}$Cm($^{23}_{12}$Na, 5n)$^{266}_{113}$Bh: rotating $^{248}_{95}$Cm target was just available large cross section 10 events / 30days
\[ ^{209}\text{Bi} + ^{70}\text{Zn} \rightarrow ^{278}\text{113} + \text{n} \]

**23-July-2004 18:55 (JST)**

1st chain

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\[ \sigma = 23 \text{ fb} \]

**2-APRIL-2005 2:18 (JST)**

2nd chain

Ref.1

\[ ^{249}\text{Bk}(^{22}\text{Ne,5n})^{266}\text{Bh} \]

Ref.2

\[ ^{243}\text{Bk}(^{26}\text{Mg,3n})^{266}\text{Bh} \]
Cross section systematics

![Graph showing cross section systematics](image)
Experimental setup

GARIS (Gas-filled recoil ion separator)

Primary beam
Differential pumping
He inlet
He gas

Primary beam
Beam stopper (Ta)

Rotating Cm targets
Beam Intensity monitor

D1 Q1 Q2 D2

Evaporation Residues

0 1 2 (m)

SSD box
PSD
Focal plane setup

- small recoil energy $\rightarrow$ remove TOF detector (impossible to passing through Mylar foils)
- large counting rate during Beam-On $\rightarrow$ use beam ON/OFF method

- Z=113 search (Cold fusion)
  - $L = 29.5$ cm
  - Full-time beam on

- $^{266}$Bh search (Hot fusion)
  - Beam ON/OFF (3s)
Beam ON/OFF structure

Macro structure

ON
Beam ON
Beam OFF
OFF

3s
3s
100s

266 Bh like

100s extended Beam OFF

Micro structure

ON
5.5 ms
2 ms
OFF

100 mm
Rotating $^{248}$Cm target

- Purification with ion exchange
- Electrodeposition
  - 0.54 mg of $^{248}$Cm in 20 $\mu$L of 0.2 M HNO$_3$ + 5.5 mL 2-propanol
  - 1000 V x 11 mA/cm$^2$ for 10 min
  - $\rightarrow$ 350 $\mu$g/cm$^2$ $^{248}$Cm$_2$O$_3$
  - on 2.0 $\mu$m Ti backing foil

- Water-cooled cell for electrodeposition

- Deposition area: 2.04 cm$^2$

- $^{248}$Cm$_2$O$_3$ target

- $^{248}$Cm$_2$O$_3$ target
Summary of Experimental conditions and Experimental results

**Experimental conditions:**

- **Method:** Focal plane Silicon Box + Beam On/Off method
- **Target:** $^{248}\text{Cm}$, $350 \mu \text{g/cm}^2$, 10cm diameter, 1000rpm
- **Beam intensity:** $^{23}\text{Na}$, 4.4 p $\mu$ A, average 1p $\mu$ A (duty 27.5%)
- **Beam Energy:** 126, 130, 132 MeV
- **On/Off:** 3s On – 3s OFF
- **Daughter mode:** 100sec
- **GARIS pressure:** 33 Pa
- **GARIS (B $\rho$):** 2.07, 2.19 Tm, (estimated by the results of $^{248}\text{Cm}^{(^{22}\text{Ne},5n)^{265}\text{Sg}}$ exp.)

**Experimental results:**

- **Total beam dose:** $1.9 \times 10^{19}$
- **Counting rate:**
  - Beam ON: $3 \times 10^4$ /s
  - Beam OFF: 5-10 /s
- **Observed events:** 32 (Correlated events)
- **Cross section:** 50pb for $^{266}\text{Bh}$ and $^{267}\text{Bh}$ (included the events of tentative assignment)
Decay chains observed in this experiment
(result of ±2 mm and 300 s correlation analysis)

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^a Bp of GARIS was set to 2.19
^b Bp of GARIS was set to 2.07
^s Sum of PSD and SSD signals

Example of the observed decay chains of $^{266}$Bh

- $^{266}$Bh
  - $^{262}$Db
    - $^{258}$Lr
      - $E=8.60$ MeV (PSD)  
        - $\tau=9.4$ s  
        - $P=49.6$ mm
  - $E=8.74$ MeV (PSD)  
    - $\tau=13.7$ s  
    - $P=42.5$ mm
  - $E=9.12$ MeV (PSD+SSD)  
    - $\tau=1.19$ s  
    - $P=46.0$ mm

- $E=9.09$ MeV (PSD+SSD)  
  - $\tau=4.23$ s  
  - $P=26.3$ mm

$\alpha$ extension beam off timer = ON
Singles spectrum (beam off period)

16.4 h, $3.1 \times 10^{17}$ beam dose
A: $^{266}\text{Bh} \rightarrow ^{262}\text{Db} \rightarrow \text{SF}$
B: $^{266}\text{Bh} \rightarrow ^{262}\text{Db}$
C: $^{262}\text{Db} \rightarrow ^{258}\text{Lr}$
D: $^{267}\text{Bh} \rightarrow ^{263}\text{Db}$

$E_{\text{SF}}$ (Daughter) [MeV]

$E_{\alpha}$ (Daughter) [MeV]

$E_{\alpha}$ (Mother) [MeV]

$T_{1/2} = 31^{+41}_{-11}$ s
Ref.: 34±4 s

$T_{1/2} = 24^{+14}_{-7}$ s
Ref.: 34±4 s

Observed in $^{278}113$
Comparison of $^{266}$Bh decay, from $^{278}$113 and present data

Decays observed in $^{278}$113 synthesis
Decays observed in the present work

$^{278}$113 + $^{70}$Zn $\rightarrow$ $^{279}$113$^*$

One $n$ evaporation

$^{266}$Bh $\rightarrow$ five $n$ evaporation

$^{248}$Cm + $^{23}$Na $\rightarrow$ $^{271}$Bh$^*$

$9.08$, $9.77$ MeV
$8.82$, $9.05$ - $9.23$ MeV
8.40 – 8.74 MeV (79 %)
$T_{1/2}$: 24.0$^{+14}_{-7}$s

$8.57$ – $8.80$ MeV
$T_{1/2}$: 4.0$^{+22}_{-2.0}$s

S.F. (21%)

40.9s, 0.787s
Summary of result

32 correlation events were observed in total.
14 events were assigned to the decay from $^{266}\text{Bh}$

$^{266}\text{Bh}$
- $E_\alpha$: 8.82 and 9.05–9.23 MeV
- consistent with one of the $E_\alpha$ observed in the $^{278}\text{Hgl13}$ decay chain $E_\alpha$

$^{262}\text{Db}$
- $E_\alpha$: 8.40 – 8.74 MeV
- Branch: $\alpha$-decay: 11 events (79%), S.F.: 3 (21%)
- consistent with the decay time observed in the $^{278}\text{Hgl13}$ decay chain

$^{258}\text{Lr}$
- $E_\alpha$: 8.57 – 8.80 MeV, $T_{1/2}$: 4.0$^{+2.2}_{-2.0}$ s
- R. Dressler et al., 8.565, 8.595, 8.621 MeV, 3.92$^{+0.35}_{-0.42}$ s

A state in $^{266}\text{Bh}$, which decays by $\alpha$-emission with the energies ranging from 9.05 – 9.23 MeV, feeds a state in $^{262}\text{Db}$, which decays by $\alpha$-emission and by SF with a previously known half life.

The result provided a further confirmation of the production and identification of the isotope of the $^{278}\text{Hgl13}$, studied by RIKEN.
Future Plan of new element search

$^{76}\text{Ge} + ^{208}\text{Pb} \rightarrow ^{283}114 + n$

$^{209}\text{Bi} + ^{70}\text{Zn} \rightarrow ^{278}113 + n$

P. A. Wilk et al., PRL85, 2697 (2000)

$^{249}\text{Bk}^{(^{22}\text{Ne},5n)}^{266}\text{Bh}$

Z. Qin et al., Nucl.Phys.Rev.23(2006)

$^{243}\text{Bk}^{(^{26}\text{Mg},3n)}^{268}\text{Bh}$

and