FIRST OBSERVATION OF ^{162}Hf DECAY: COMPLETION OF AN α-DECAY CHAIN

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Abstract

The new isotope ^{162}Hf ($T_{1/2}$=(37.6±0.8)s) was produced in a ^{142}Nd (^{24}Mg,4n) reaction. The activities produced in this reaction were transported to a measuring station by use of a He-jet system. Decay properties were observed with α-, γ-, and γ-γ - spectroscopy. The Z-assignment of the new isotope was based on a cross bombardment on ^{141}Pr target and on the results of a γ-X-ray coincidence measurement. The mass assignment was deduced from excitation function measurements. From the measured α-decay energy E_α = 4308 (10) keV new mass values were derived for ^{162}Hf, ^{166}W, ^{170}Os, ^{174}Pt, and ^{178}Hg. These new mass values make it possible to establish systematics of two-proton and one-proton binding energies far from stability.

I. Introduction

During the last decade new heavy ion beams have made possible detailed studies of neutron-deficient isotopes in the medium-weight mass region. For the very neutron deficient isotopes between the rare earth and the lead region, α-emission has been shown to be the predominant decay mode. Since the detection of α-particles offers a convenient method of establishing decay properties of new isotopes, many new α-emitters have been studied. Their spectroscopic properties have been reviewed some time ago by Gauvin et al.[1] and more recently by Rytz[2] and Toth[3].

By studying chains of Q_α-values and linking these chains to known mass values (usually close to stability) it has been possible to extend the known masses to exotic nuclei[4]. While in general it is possible that the α-decay doesn't feed the daughter ground state, this does not occur for chains of α-emitters consisting of only even-even nuclei since the $0^+ \rightarrow 0^+$ ground state α-branch is always by far the strongest transition.

There are two fairly long chains of even-even α-emitter in the medium-mass region based on the N = 82 isotones ^{146}Gd and ^{148}Dy. Recently, the ^{148}Dy chain was linked to stable masses values by Spanier et al.[5] and Schmidt-Ott et al.[6] who determined the mass of ^{148}Dy by measuring the ratio of EC/β+ for its β^+-decay. The ^{146}Gd chain was linked to stable mass values by Pardo et al.[7] and Alford et al.[8] by determining the mass of ^{146}Gd via reaction Q-values. Decay studies of ^{146}Gd and ^{150}Dy confirmed their results[9].

Before this study the ^{146}Gd chain consisted of the two unconnected fragments: (^{146}Gd, ^{150}Dy, ^{154}Er, ^{158}Yb) and (^{166}W, ^{170}Os, ^{174}Pt, ^{178}Hg). The missing link is ^{162}Hf. The measurement of its Q_α-value would result in five new mass values, completing the chain from ^{146}Gd to ^{178}Hg, 22 neutrons away from the line of stability. The search for the α-decay of ^{162}Hf was therefore the goal of this study.

Although the use of on-line mass separation would have been desirable in order to demonstrate unambiguously the mass number, hafnium is a difficult element for any ion source, because of its low vapour pressure. We therefore used the He-jet technique to transport the activity to a well shielded counting location.

II. Experimental Method

The experiments were carried out at the upgraded MP tandem accelerator at the Chalk River Nuclear Laboratories. A He-jet system[10] was coupled to a fast tape-transport system similar to that described in ref. 11. Self supporting targets of ^{142}Nd (enriched to 96.24%), Pr, and CsI, having thickness of 2.5 mg/cm^2, were bombarded with 105 to 133 MeV ^{24}Mg beams at a typical beam intensity of 10^{11} s^{-1}. Recoiling atoms from the target were thermalized in helium gas (pressure: 80 kPa). The helium was saturated with NaCℓ aerosol generated by passing the gas through an oven containing NaCℓ crystals heated to about 620°C.

The gas was swept out from the target chamber through a 7 m long teflon capillary (inner diameter 1.7 mm) to the tape system, which was located in a low background area. Samples were collected on the tape and periodically moved to a counting position where α-particles were detected with a 300 mm^2 silicon surface barrier detector (thickness: 100 μm). For half-life determinations, each particle event was tagged by the time elapsed since the last tape movement. That time and the α-particle energy were recorded event by event on tape. A mixed source of ^{239}Pu, ^{241}Am, and ^{244}Cm served as a standard for α-energy calibration of the detector.

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The He-jet technique has a possible disadvantage for α-particle measurements caused by self absorption in the accumulated aerosol material at the collection spot. Thus an energy shift between off-line calibration and on-line measurement can result. Therefore the known α-emitters[2)] $^{151-153}Ho$, and $^{151,152}Dy$ were produced in the ^{133}Cs + ^{24}Mg reaction, and α-peak position and line shape as well as He-jet transport efficiency were scanned for different oven temperatures. The adopted temperature setting provided sufficient transport efficiency while maintaining an acceptable line width (FWHM) of less than 30 keV. At this setting the mean energy loss in the salt deposit for α-rays between 4 and 5 MeV was determined to be (13 ± 2) keV.

Low energy γ-rays were detected concurrently by an intrinsic Ge-detector positioned behind the α-detector. The γ-events were stored in multispectrum mode either as 4 by 2048- or 8 by 1024- channel spectra.

Dead-time corrections for particle and γ-spectra were established by feeding pulser signals into both spectra. In a different set-up, coincidences between γ and X-rays were measured by moving the source into a counting position between two intrinsic Ge-detectors (crystal size: 1) 200 mm^2 x 7 mm, 2) 1000 mm^2 x 15 mm). Energy signals were stored together with TAC signals on magnetic tape.

The energy and efficiency calibrations of the γ-detectors were obtained with standard sources of ^{152}Eu and ^{133}Ba.

III. Results

In the ^{142}Nd + ^{24}Mg reaction a new activity was observed emitting γ-rays with a half-life of $T_{1/2}$=(37.6 ± 0.8)s. Because the activity was not observed in the cross bombardment ^{141}Pr + ^{24}Mg, it was concluded that these γ-rays were emitted following the β-decay of Hf isotopes. The coincidence experiment provided confirmation since the strongest new γ-lines were observed in coincidence with Lu-X-rays as well as with 511 keV annihilation radiation.

Excitation functions were measured for both the ^{142}Nd + ^{24}Mg and ^{141}Pr + ^{24}Mg reactions, under the same experimental conditions (compare fig. 1). The two reactions are characterized by similar compound-nucleus Q-values and similar nucleon binding energies for the evaporation process[12)]. Thus similar excitation functions can be expected.

The ^{141}Pr + ^{24}Mg reaction produced the isotopes $^{161,160}Lu$, first observed and identified with on-line mass separation[13)]. We used the reported γ-rays from these two isotopes to establish excitation functions for ^{160}Lu and ^{161}Lu. The excitation functions for the most intense γ-rays are presented in fig. 1.

Also given in fig. 1 is the excitation function for the strongest γ-line,

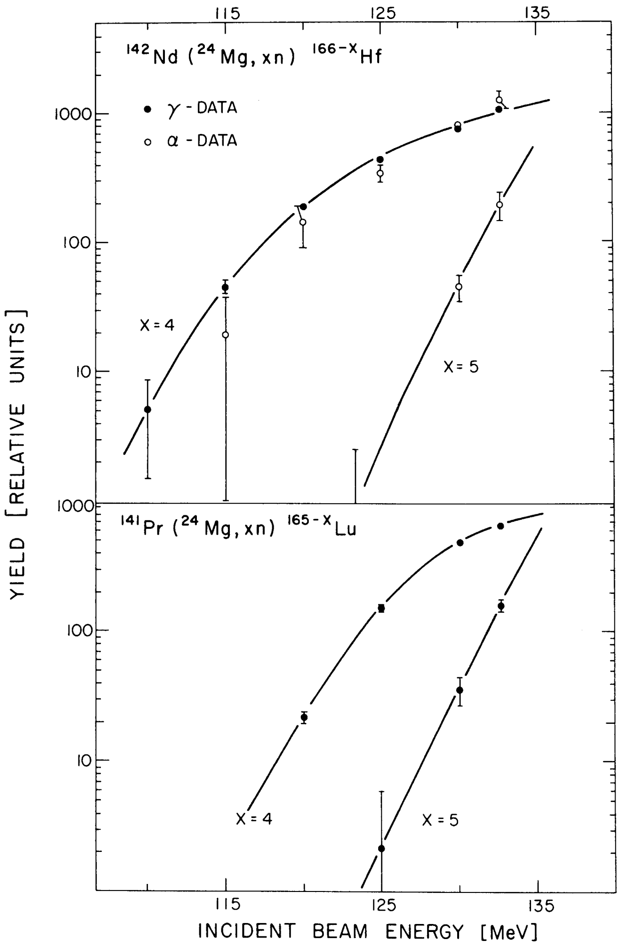

Fig. 1: Excitation functions measured for the bombardment of ^{142}Nd and ^{141}Pr targets with ^{24}Mg beams.

E_γ = 174 keV, of the new Hf activity produced from the ^{142}Nd target. Because of its similarity to the 4n reaction curve from the ^{141}Pr target, it was concluded that the new activity was also produced by a 4n reaction, and thus concluded it to be ^{162}Hf.

During the bombardment of ^{142}Nd two fairly strong α-lines appeared in the particle spectrum (fig. 2). The measured results for energy and half-life are listed in table 1 together with the average half-life of the γ-rays from ^{162}Hf. Also given is the only previous result from ^{161}Hf[14)].

We assign the new α-particle line at 4308 keV to ^{162}Hf because
a) the excitation function measured for this line parallels that for the production of γ-rays from β-decay of ^{162}Hf. (cf. fig. 1)
b) the half-life measured from the decay of the α-line is in agreement with the half-life measured for the γ-rays from ^{162}Hf (compare fig. 3).
c) this α-line was not observed during a cross bombardment on ^{141}Pr targets.
This line represents the groundstate to groundstate transition between the even-even nuclei ^{162}Hf and ^{158}Yb. Results from detailed γ- and γ-γ studies of the β-decay

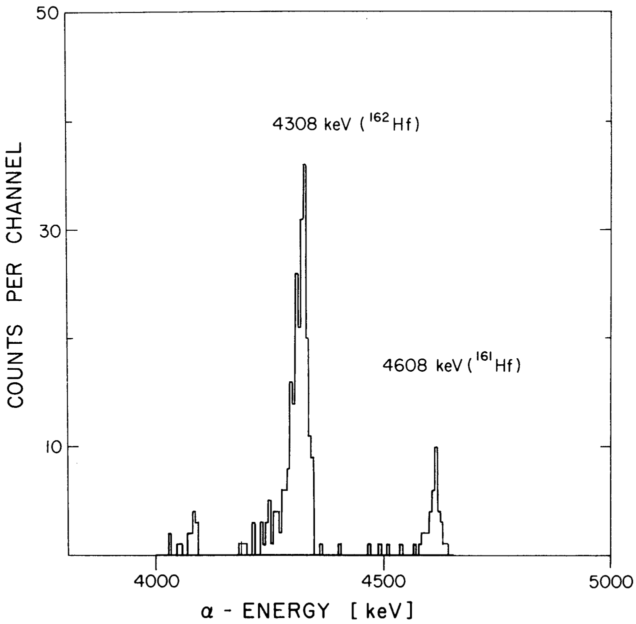

Fig. 2: A section of the α-spectrum measured during a 3h bombardment of ^{142}Nd (integrated beam intensity: $5 \cdot 10^{14}$ particles). The weak line at 4070 keV stems probably from a slight Cs contamination of the target or the decay of the ^{158}Yb, the daughter of ^{162}Hf. The collection and the measurement time for each individual sample deposited by the He-jet was 80 s.

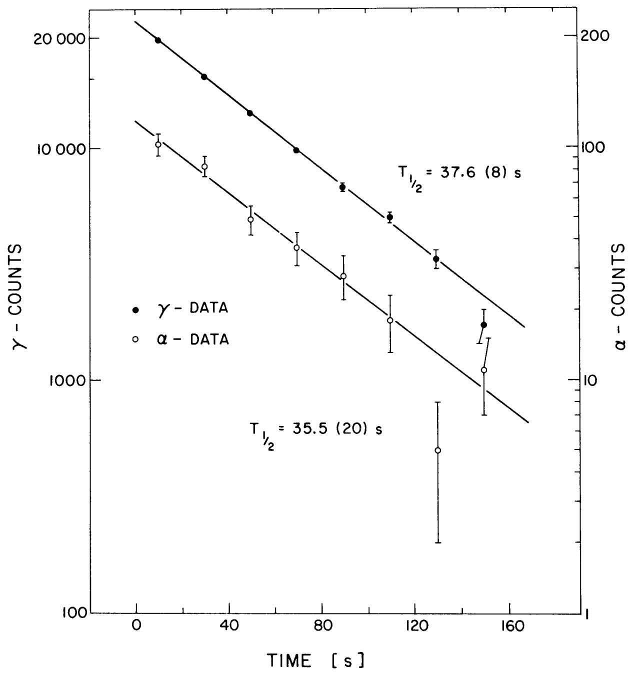

Fig. 3: Comparison of the decay curves for ^{162}Hf γ- and α-rays obtained during a 7h measurement. Collection and measurement time for each sample was 160 s.

of ^{162}Hf shall be presented in a later communication.

IV. Discussion and Conclusion

We have obtained new mass values for ^{162}Hf, and implicitly for ^{166}W, ^{170}Os, ^{174}Pt, and ^{178}Hg, by combining the α-decay energy of ^{162}Hf with previous reported mass values and α-decay energies. The mass excess data and corresponding Q_α-values are given in table 2. Comparison of the new data with theoretical mass values indicates a fair agreement with predictions based on the droplet model (Myers (see ref. 19) and Groote et al.,(see ref. 19)) and also with the semi-empirical shell model (Liran and Zeldes, (see ref. 19)). A more detailed discussion will be presented in another contribution to the conference[18].

From the extended knowledge of atomic masses, information about one- and two-proton binding energies for some nuclei far from stability can be extracted. In fig. 4 we have plotted the 2p binding energies for a

Table 1

Results from Particle Measurements

Nuclide	Present Work E_α [keV]	$T_{1/2}(\alpha)$ [s]	$T_{1/2}(\gamma)$[b] [s]	Reaction Process[c]	Previous Work[a] E_α [keV]	$T_{1/2}(\alpha)$ [s]
^{161}Hf	4608(10)	19(2)	–	^{142}Nd(^{24}Mg,5n)	4600(10)	17(2)
^{162}Hf	4308(10)	35.5(20)	37.6(8)	^{142}Nd(^{24}Mg,4n)	–	–

a) Ref. 14.

b) Weighted mean of $T_{1/2}$ for the 174, 196 and 410 keV γ-lines of ^{162}Hf.

c) Identified by excitation function.

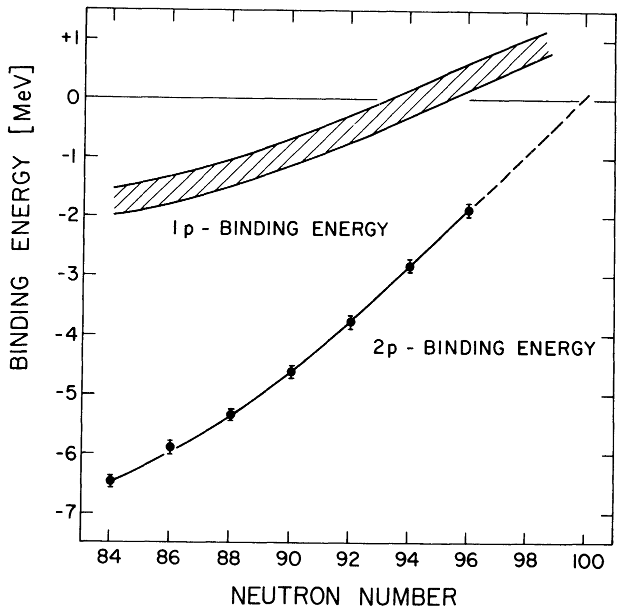

Fig. 4: Experimental two-proton binding energies for members of the α-decay chain ending with ^{148}Dy. One-proton binding energies for the odd-even decay chain based on ^{147}Tb. The ^{147}Tb mass value is extrapolated from systematics.

chain of nuclei from ^{148}Dy to ^{172}Pt, derived from the mass difference between the ^{148}Dy[6] and ^{146}Gd α-decay chains (table 2). An extrapolation of the curve beyond ^{172}Pt indicates one would not expect 2p unbound nuclei for elements lighter than lead. It should be noted, however, that the closed proton shell at Z = 82 limits the validity of this extrapolation since the shell closure lead to a decrease of the 2p binding energy.

Similarly, knowledge of mass values for the α-decay chain based on ^{147}Tb would give one-proton binding energies for the members of this chain up to the lightest known gold isotope, ^{175}Au. Although it is not proven that the ground state is fed for every α-decay of this odd-even chain, systematic considerations, similar to those used by Wapstra[20], suggest that excited state feeding would be small. In any case, even if the measured α-energies for this chain are somewhat lower than the actual mass differences, the calculated 1p binding energies would be upper limits.

So far, the ^{147}Tb α-decay is not linked to stable mass values, and one member, ^{163}Ta, is missing. We have therefore started a search for the α-decay of ^{163}Ta.

In the meantime, it is tempting to extrapolate the ^{147}Tb mass value using the information now available for neighbouring masses[7,18]. This extrapolation and our preliminary result for ^{163}Ta α-decay leads to the conjecture that ^{175}Au and also ^{171}Ir are probably proton unbound, having positive proton binding energies of E_p = 800(200) keV and E_p = 400(200) keV, respectively (compare fig. 4). A measurement of ^{147}Tb mass would be desirable in order to confirm this expectation.

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Table 2

Auxiliary Data on α-Decay Energies and New Mass Excess Values

Nucleus	E_α (keV)	Ref	Q_α (keV)	Mass Excess (MeV)
^{146}Gd	–	–	–	-76.09(2) a)
^{150}Dy	4232(3)	[2]	4348(3)	-69.32(2)
^{154}Er	4166(3)	[2]	4277(3)	-62.62(2)
^{158}Yb	4069(10)	[15]	4175(10)	-56.02(2)
^{162}Hf	4308(10)	Present Work	4417(10)	-49.18(3)
^{166}W	4739(5)	[2]	4856(5)	-41.89(3)
^{170}Os	5400(10)	[16]	5530(10)	-33.94(3)
^{174}Pt	6035(10)	[17]	6177(10)	-25.34(3)
^{178}Hg	6430(6)	[17]	6578(6)	-16.33(3)

a) Weighted mean of ref. 7,8,9

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DISCUSSION

J. Jastrzebski: What was the Mg energy spread in the target? (The excitation curves look very broad.)

E. Hagberg: The energy spread of the Mg beam in the ^{142}Nd target was typically 25 MeV at 130 MeV incident energy.

W.-D. Schmidt-Ott: The α-branching ratio of ^{162}Hf must be extremely small. Do you have a number or an estimate on that?

E. Hagberg: We did, indeed, do an experiment where we annihilated positrons from the decay of ^{162}Hf in a localized geometry. We have not analyzed that data yet but as a preliminary estimate I would say that the α-branching ratio is of the order of 10^{-5}.