Formation and decay of neutron-deficient nuclei Po and Pb

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Abstract A study of α-decay for ^{192,194}Po and ^{188,190}Pb was performed in the reaction of ^{36}Ar on ^{160}Dy at 176 MeV. The formation cross section was obtained to be 5.0±0.2 μb for ^{192}Po and 11.6±0.3μb for ^{194}Po. The resulting reduced α width δ^2 was 38(5) keV for ^{188}Pb and 25(3) keV for ^{190}Pb, which further confirmed the magic characteristics for neutron-deficient nuclei of Z=82.

Keywords Neutron-deficient nuclei, Formation cross section, Reduced α widths δ^2

1 Introduction

The study on formation and decay of nuclei far from β-stable line is one of the active fields in the frontiers of nuclear physics. It is a very interesting subject whether the magic number (shell closure) still remains magic for those isotopes far from β-stable line both in rich and in deficient-neutron sides. The magic characteristics for Z=82 can be systematically surveyed by reduced α widths δ^2, since α-decays are the main decay models for these nuclei and have the striking relation between α-decay rates and α-decay energies known as Geiger-Nutall laws.

δ^2 values of ground state to ground state transitions for even-even nuclei with Z from 78 to 100 have been plotted as a function of both neutron number N and atomic number Z by Toth *et al.*[1], which exhibited a regular behavior of shell closure at Z=82, N=126 and N=152, but in the range of N=104-110 a contrast to an expected shell effect for Z=82 i.e. δ^2 of lead (Z=82) are larger than those of mercury (Z=80) with the same neutron numbers. Based on this anomaly, Toth *et al.* first concluded that Z=82 is not magic for light Pb isotopes, resulting in an intriguing interest in both theories and experiments. Reproducing of the α-decay widths has been a challenge for theory over many years. To calculate the reduced α width Buck *et al*[2] developed a simple cluster model and Yoshida *et al*[3] used a deformed relativistic mean field approach. Both their results yielded a conclusion that some of the neutron-deficient isotopes having proton number Z=82 do not behave as good magic nuclei. The α branching ratios of ^{192,190,188}Pb were measured using mass-separated sources with α-β and α-γ(X) methods by Wauters *et al*[4] and the results showed that the δ^2 for ^{190,188}Pb were not larger than those for mercury, which might question the above conclusion made by Toth *et al.* Later on, they compared the reduced widths of the α-decays to the ground and 0^+ excited states for these nuclei and showed a strong variation at Z=82 which can be an experimental proof for the stability of the Z=82 magic at the very neutron-deficient side[5].

Obviously, these important conclusions are

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mainly based on α branching ratios. The α branching ratios measured with α-β or α-γ(X) methods had a large experimental uncertainty due to the difference of efficiencies between two detectors and the decay scheme-dependency. The present work was proposed to study the α-decay of mother nuclei ^{192,194}Po and daughter ^{188,190}Pb in the same detector system with α-α method.

2 Experimental

The facilities for the experiment were arranged as Fig.1, the same as Ref.[6]. Bombarding a 510 μg/cm^2, 79% enriched ^{160}Dy target with an 176 MeV ^{36}Ar beam delivered by the Argonne Tandem-Linac Accelerator System (ATLAS), ^{192,194}Po were formed as the fusion evaporation residue nuclei through the 4n and 2n reaction channels, ^{160}Dy(^{36}Ar, 4n) and ^{160}Dy(^{36}Ar, 2n) respectively. The recoiling nuclei were passed through the fragment mass analyzer (FMA) to separate them from the primary beam and then disperse them in mass/charge (A/q) at the focal plane. The FMA was tuned so that both 17$^+$ and 18$^+$ charge states of A=192 and 194 recoils can be detected at the focal plane. A parallel grid avalanche counter (PGAC) was used at the focal plane to provide horizontal and vertical positions of ions resulting in A/q, timing and energy-loss informations. After passing through the PGAC the ions were implanted in a double-sided silicon strip detector (DSSD) located 45 cm behind the PGAC, where their subsequent charge-particle decays were detected. The DSSD has a thickness of 65μm, an area of 16$\times$16 mm^2 and consist of 48 horizontal strips on its front surface and 48 vertical strips on its back surface, resulting in 2304 pixels. Each event in the DSSD was time stamped and identified as either an implanted ion or a decay particle depending on its coincidence or anti-coincidence with a signal from the PGAC. Signals from scattered beam particles, which move with higher velocities than reaction recoils, were rejected from the analysis by gating on the implant-ion events in the two-dimensional spectrum of time-of-flight between PGAC and DSSD versus implantation energy in DSSD. Data were accumulated for 48 h with an average beam intensity of 3.75 nA particles.

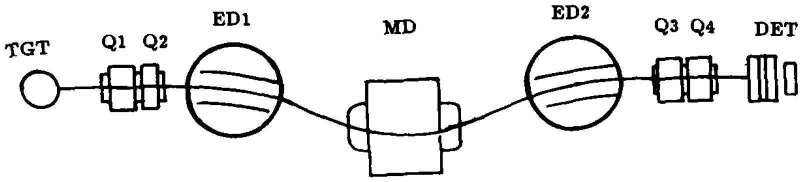

Fig.1 The schematic layout of the experimental arrangement
TGT = target, Q = quadrupole singlet, ED = electric dipole, MD = magnetic dipole, DET = detector. The overall length is 8.2 m

3 Results and conclusions

Fig.2 shows the total α-particle spectrum recorded in the DSSD. The assignment of α-lines to nuclei labeled were mainly based on the α-particle energies. The 7.169 MeV to ^{192}Po, 5.98 MeV to ^{188}Pb and 6.845 MeV to ^{194}Po, 5.58 MeV to ^{190}Pb were further identified by the correlation between α-decays of mother and daughter nuclei. Correlating the subsequent α-decays within the same DSSD pixel, the α-branching ratios can be deduced from the number of α-particles from mother nuclei and the number of daughter's. Out of the ^{194}Po-^{190}Pb and ^{192}Po -^{188}Pb correlation, a value of 0.25% was deduced for ^{190}Pb and 7.9% for ^{188}Pb. The beam was monitored with a monitor detector near the target for the scattered beam from the target. The beam intensity was online calibrated with the monitor counts. The formation cross section can be calculated from the observed intensity of ^{192}Po and ^{194}Po, the

α-branching ratio of 95% for ^{192}Po and 93% for ^{194}Po taken from the Nuclear Data Sheets (NDS), the monitor counts and the efficiency of the detector system $\varepsilon_{\mathrm{FMA}}$. $\varepsilon_{\mathrm{FMA}} = f_1 \cdot f_2 \cdot f_3 = 0.046$, where f_1 is the transmission of 38% for (17^+ and 18^+), f_2 the correction of 60% for dispersion, f_3 the DSSD detection efficiency of 20% for the solid angle. Then we obtained a cross section 5.0±0.2μb for ^{192}Po and 11.6±0.3μb for ^{194}Po at beam energy of 176 MeV.

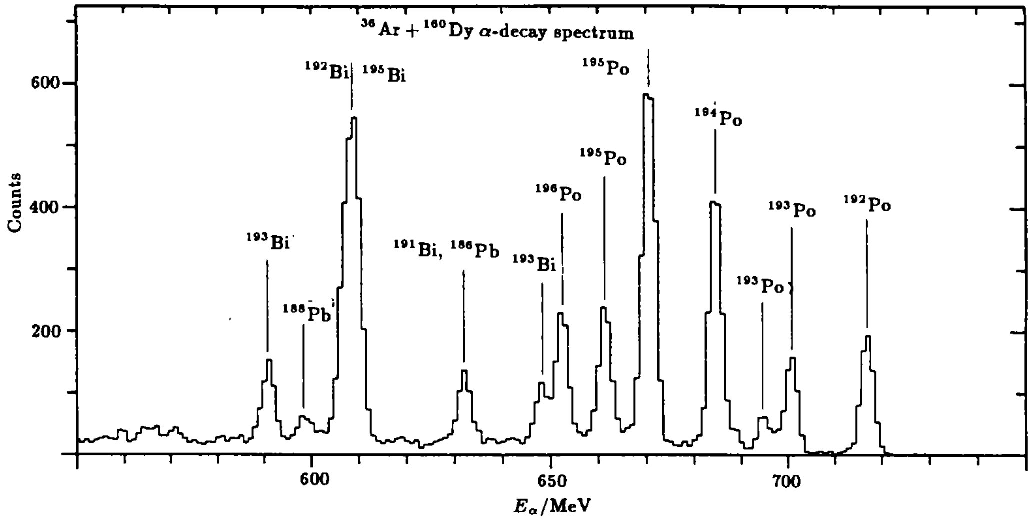

Fig.2 The total α-particle spectrum from ^{36}Ar + ^{160}Dy recorded in the DSSD

The reduced α width is a very useful tool for studying nuclear structure, $\delta^2 = (\lambda h)/p$, where λ is the α-decay rate, h is the Plank constant and p is the penetration factor for the α particle to tunnel through the Coulomb and centrifugal barriers, which can be experimentally extracted from the α-decay half-life, branching ratio b_α and α particle energy E_α using the method developed by Rasmussen[8].

Table 1 The properties and reduced widths of α-decays

N	Pb	E_α/MeV	$T_{1/2}$/s[NDS]	b_α/%	δ^2/keV	δ^2(Pb)/keV[4]	δ^2(Hg)/keV[4]
104	^{186}Pb	6.335	4.7	45[7]	39(18)	<97	62(35)
106	^{188}Pb	5.980	24	7.9	38(5)	15-51	59(+22,-20)
108	^{190}Pb	5.580	72	0.25	25(3)	50(7)	41(+11,-10)

The results and the experimentally extracted reduced α widths are listed in Table 1. The α-branching ratio of ^{186}Pb is just renewed 45(20)% instead of 100% reported by Batchelder *et al.*[7] It can be seen from Table 1 that the present reduced α widths δ^2 for Pb(Z=82) are smaller than that for Hg(Z=80) and directly confirm the conclusion of Z=82 still being magic in the neutron deficient side.

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