Wide range $T_\alpha-Q_\alpha$ formula for real time application

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Abstract

A new wide-range formula $T_\alpha = f(Q_\alpha)$ to operate with the new DGFRS2 analog spectrometer installed at the DC-280 cyclotron facility is presented. The main goal of this formula application algorithm is to search the optimal time correlation recoil-alpha parameter directly during the execution of the C++ acquisition code. Note that the spectrometer operates together with the $48 \times 128$ strip DSSD (Double Side Strip Detector) detector and low-pressure pentane-filled gaseous detector. Comparison with others known formulas is performed for $Z=119, 120$ nuclei.

1. Introduction

With the discovery of the fission of uranium by Hann and Strassmann, the boundary of existence of nuclei was physically defined for the first time as a limit of stability of nuclei with spontaneous fission (SF) [1]. According to the theory [2] the fission barrier will rapidly decrease with growing $Z$ ($Z>92$). In the macroscopic theory (liquid drop model) the situation with zero barrier occurs for the element with $Z>100$. The situation is changed in 1962 after observing the short SF half-life $T_{SF} \approx 0.014$ s in $^{242}$Am known to have $T_{SF} > 3^{12}$ y in the ground state[3]. It means that nuclear structure does not disappear with increasing deformation but evolves and maintains an important role in nuclear fission process [4]. Elements with $Z>100$ were produced in the reactions induced by charged particles. In the beginning of present century new $Z=114-118$ elements were synthesized using the Dubna Gas-Filled Recoil Separator (DGFRS) [5-10]. That discovery confirmed the main role of shell effects in stability of superheavy nuclei. A key question relating to the discovery of new element and isotope is the probability $P_{err}$ that the event sequence observed is due to a random correlation of unrelated events. The magnitude of this probability allows readers and experimenters to judge the validity of the interpretation. Present work aimed to a consideration of wide-range formula to predict half-life time of new isotopes of superheavy elements. Namely, these estimates are used in “active correlation” method to provide a reasonable choice for $ER(Evaporation\ Residue)-\alpha$ time interval to provide a radical suppression of background signals [11].
2. Formulae for prediction of time properties of superheavy nuclei

In [12] different formulae are presented to predict properties of alpha decaying nuclei. These formulae deal with $Z$, $Q_{\alpha}$ and $A$ as independent variables. From the other hand, in [13] the same predictions are made using only $Z$, $Q_{\alpha}$ parameters. In this paper parameter $d$ of the formula was varied to satisfy data presented in [5] for SHE as following: $T_{\alpha}^{calc}=T(Z)$, where $F(Z)=(aZ+b)\cdot Q_{\alpha}^{-1/2} +c\cdot Z +d$. In [14] experimental and theoretical data for $Ac$ isotopes are presented, and the comparison of these results with one which estimated using above formula is shown in the Fig.1. These data are fitted well with optimal parameter $d=-27.5928$. In the Table 1 an arbitrary choice of isotopes are presented with lower $Z$.

Table 1. $d$- Parameters for wide range of $Z$.

| Isotope | $Z$ | $T_{1/2}$  | $Q_{\alpha}$, MeV | $d$    |
|---------|-----|-----------|------------------|------|
| $^8$Be  | 4   | 0.082 fs  | 0.184            | 18.154        |
| $^{10}$Te | 52  | 3.1 ms    | 4.0846           | -24.65124     |
| $^{108}$I | 53  | 36 ms     | 4.25676          | -23.47449     |
| $^{110}$Xe | 54  | 93 ms     | 4.0214           | -24.72388     |
| $^{144}$Nd | 60  | 2.29 $\cdot 10^{15}$ y | 1.96088 | -23.14566   |
| $^{146}$Sm | 62  | 6.8 $\cdot 10^{7}$ y | 2.600 | -24.31563   |
| $^{152}$Eu | 63  | 1.7 $\cdot 10^{18}$ y | 2.01853 | -22.40255 |
| $^{148}$Gd | 64  | 71.1 y    | 3.36209          | -25.0482      |
| $^{152}$Dy | 66  | 3 $\cdot 10^{6}$ y | 3.02356 | -24.7324    |
| $^{154}$Ho | 67  | 2.7 min   | 4.62916          | -26.42281     |
| $^{154}$Tm | 69  | 8.1 s     | 5.2288           | -26.07        |
| $^{152}$Hf | 72  | 2.85 s    | 5.54509          | -26.75256     |
| $^{160}$Os | 76  | 21 ms     | 6.64097          | -26.74        |
| $^{176}$Hg | 80  | 20.3 ms   | 7.0597           | -27.06        |
| $^{190}$At | 85  | 290 ms   | 7.4927           | -26.553       |
| $^{210}$Rn | 86  | 45 mcs    | 8.352            | -28.20686     |
| $^{207-209}$Ac | 89 (AverYang) | - | - | -26.72 |
| $^{236}$U  | 92  | 2.34 $\cdot 10^{7}$ y | 4.6517 | -27.99773 |
| $^{238}$U  | 92  | 4.47 $\cdot 10^{9}$ y | 4.3427 | -28.03537 |
| $^{241}$Am | 95  | 432.6 y   | 5.76298          | -27.6253      |
| $^{252}$Fm | 100 | 1.06 d    | 7.26808          | -27.9061      |
| $^{264}$Sg | 106 | 3.6 ms    | 10.054           | -28.42474      |
| $^{276}$Ds | 110 (aver. [17]) | - | - | -28.318 |
| Fl | 114 (aver. [13]) | - | - | -28.0928 |
Fig.1 Measured [14] and calculated (triangles) dependences against half-life values of Ac isotopes.

Note, that in the positions of Ac, Ds and Fl the averaged values of d parameters are shown.

The wide range d parameter dependence against Z is shown in the Fig.2. Best fit is shown as power function $d = -28.73672 + 74.1551 \cdot 0.95105^Z$.

Fig.2 Dependence of d-parameter against Z. ($a = -28.73672; b = -74.1551; c = 0.95105$)
3. Calculation of Z=119, 120 nuclei half life values

We calculated $T_\alpha$ values for the elements with $Z=119,120$. We plan to synthesize these elements at the DGFRS2 setup [16] in a nearest future. $Q_\alpha$ values were taken from [13]. The results are presented in Table 2.

Table 2. $T_\alpha$ values calculated for $Z=119,120$ nuclei.

| Z  | $Q_\alpha$, MeV | $T_{1/2}$ (This paper) | $T_{1/2}$ [13] | $T_{1/2}$ [Royer] |
|----|----------------|------------------------|---------------|------------------|
| 119| 12.338         | 38 $\mu$s              | 107.89 $\mu$s | 509.2 $\mu$s     |
| 120| 12.7           | 11 $\mu$s              | 31.4 $\mu$s   | 16.6 $\mu$s      |

It should be noted, that $T_\alpha$ values calculated by Royer’s formulae were performed for $A=294, 296$ respectively. Known isotope properties were taken from [18].

4. Summary

New four parameter formula for $T_\alpha=f(Q_\alpha)$ dependence is obtained. The $T_\alpha$ values were calculated for $Z=119,120$ nuclei. Comparison with Royer’s formulae as well as reported in [13] has been performed. We plan to apply these results as a base for application of “active correlations” method in the area of unknown isotopes synthesized in heavy ion induced complete fusion nuclear reactions at the DGFRS2 setup. One general extra conclusion can be drawn here: namely, the described $T_\alpha=f(Q_\alpha)$ dependence can be used to predict reasonable value of unknown alpha decay parameters in the area with the lowest $Z$ values.

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5. References

[1] O.Hahn, F.Straßmann, Naturwissenschaften 27, 11(1939)
[2] L.Meitner, O.R.Frisch, Nature 143,239 (1939)
[3] S.M.Polikanov, et al. Zh. Eksp. Teor. Fiz. 42, (1962) 1464
[4] V.M.Strutinsky, Nucl. Phys. A 95, (1967) 420
[5] Yu.Ts. Oganessian, V.Utyonkov, Nucl. Phys. A 944 (2015) 62-98
[6] Yu.Ts.Oganessian, V.K.Utyonkov rep. Prog. Phys. 78, (2015) 036301
[7] Yu.Ts. Oganessian et al., Phys.Rev. C 87, (2013) 034605
[8] Yu.Ts.Oganessian et al., Phys.Rev.Lett. 108(2012) 022502

[9] Yu.Ts.Oganessian et al., Phys. Rev. C 74, (2006) 044602

[10] Yu.Ts. Oganessian et al., Phys.Rev. C 83 (2011) 054315

[11] Yu.S.Tsyganov, D.Ibadullayev, A.N Polyakov et al., Acta. Phys. Polonica B 14, Proc. Suppl. (2021)767-774

[12] Zhishuai Ge, Cheng Li, Jingjing Li et al., Phys. Rev. C 98 (2018) 034312

[13] D.Ibadullayev, Yu.S.Tsyganov, A.N.Polyakov et al. Eurasian. J. of Phys. and Functional Materials. (2022), 6(1),18-31

[14] H.B.Yang, Z.G.Gan, Z.Y.Zhang et al. // Phys.Rev. C (in print)

[15] D.Ibadullayev, Yu.S.Tsyganov , A.N Polyakov, A.A.Voinov// (2022) To be submitted to IEEE TNS on Nucl. Sci.

[16] Yu.Ts.Oganessian, A.G.Popeko, V.K.Utyonkov et all. Nucl. Instrum. and Meth. In Phys. Res. (2022),A 1033, 166640.

[17] Yu.Ts. Oganessian, V.K.Utyonkov et al. //2022. Submitted to Phys. Rev.C.

[18] http://nrv.jinr.ru/nrv/webnrw/map/