Purity of Isospin and its importance in n-rich Systems

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Introduction

In the last eight decades since the discovery of isospin, this quantum number continues to be widely studied in N≈Z nuclei. It is found to be quite pure in light nuclei. Earlier, it was thought that isospin is not of much use in heavy nuclei but in 1962, Lane and Soper [1] gave a theoretical argument that the purity of isospin should increase in neutron rich systems. Fission fragments coming from heavy nuclei are naturally n-rich and a good testing ground for it.

Thus on the basis of conservation of isospin in neutron-rich nuclei, we calculate the relative yields of neutron-rich fission fragments. This work is an extension of our earlier work [2]. In the present paper, we calculate the relative yields of the fragments emitted in ^{238}U(^{18}O, f) and compare it with the experimental work of Danu *et al.* [3].

Our earlier calculations have now been revisited to overcome the ambiguity in assigning the isospin values by using what we call Kelson's conjecture [4]. According to Kelson, *"the tendency to overpopulate highly excited states with $T > T_3$ in the primary fission products, carries largely over to the conventionally referred to Isobaric Analog states (IAS) in the observed products".* We also include in our calculations the weight factors of various n-emission channels by using the estimated neutron multiplicity values from a Gaussian fitting of the data from Bogachev *et al.* [5].

Formalism

Isospin, similar to spin, follow SU(2) algebra. Neutrons and protons are considered to be two members of the same entity, nucleon with t_3= +1/2 and t_3= −1/2 respectively. For a heavy ion induced fusion-fission reaction emitting q number of neutrons,

$$Y(T_Y,T_{3Y})+X(T_X,T_{3X})\rightarrow CN(T_{CN},T_{3CN})\rightarrow$$
$$F_1(T_{F1},T_{3F1})+F_2(T_{F2},T_{3F2})+q$$

Here T_Y, T_X, T_{CN}, T_{F1} and T_{F2} are the total isospin values of projectile, target, compound nucleus (CN), and the two fragments respectively. For the reaction under consideration ^{238}U(^{18}O, f), target and projectile are in ground state which implies that $T_X = T_{3X}$ = 27 and $T_Y = T_{3Y}$ = 1. From the conservation of isospin, $T_{3CN} = T_{3X} + T_{3Y}$ = 28 and $T_{CN} = |T_X - T_Y|$, ………, $(T_X + T_Y)$= 26, 27, 28. But since the total isospin is $T_{CN} \geq T_{3CN}$, we left with a unique value of isospin of CN i.e. T_{CN} = 28. Now, we assign the isospin values to the fragments. For this, we use Kelson's argument that the fission favors the formation of IAS in neutron-rich fragments [4]. We consider three isobars corresponding to each mass number by considering eight lighter and eight heavier fragments in each partition. For each isobaric triplet corresponding to a particular mass number, we choose the T value to be the maximum of the three T_3 values, as this is the minimum T value required to generate all the members of any complete isobaric triplet. Further, we introduce an auxiliary concept of residual CN (RCN) to simplify our problem. The total isospin of RCN is sum of isospin values of the two fragments i.e. $T_{RCN} = T_{F1} + T_{F2}$ and $T_{3RCN} = T_{3F1} + T_{3F2}$. Also it should satisfy,

$$\left|T_{CN}-\frac{q}{2}\right| \leq T_{RCN} \leq \left(T_{CN}+\frac{q}{2}\right)---(1)$$

After the assignment of isospin values, we come to our main task which is to calculate the relative yields of fission fragments. We consider only the isospin part of the total wave function and make all the possible combinations of fragments for each neutron-emission channel. For each possible pair of fragments emitted in nth n-emission channel,

$$|T_{RCN},T_{3RCN}\rangle_n = \langle T_{F1}T_{F2}T_{3F1}T_{3F2}|T_{RCN}T_{3RCN}\rangle|T_{F1},T_{3F1}\rangle$$
$$|T_{F2},T_{3F2}\rangle---(2)$$

where $\langle T_{F1}T_{F2}T_{3F1}T_{3F2}|T_{RCN}T_{3RCN}\rangle$ represent the C. G. coefficients (CGC). The intensity of each fragment in the respective partition for a particular n-emission channel is given by,

$$I_n = \langle CGC \rangle^2 = \langle T_{F1} T_{F2} T_{3F1} T_{3F2} | T_{RCN} T_{3RCN} \rangle^2 - - - (3)$$

We obtain the neutron multiplicity values by Gaussian fitting the data of each partition [5]. We take the average of the width of Gaussian fitted curves and use this averaged value of width to obtain weight factors for various n-emission channels. For example, in Ru-Pd partition, we assume the experimentally dominating 12n emission channel as central value of the Gaussian distribution, we get the neutron multiplicity values as shown in Fig 1.

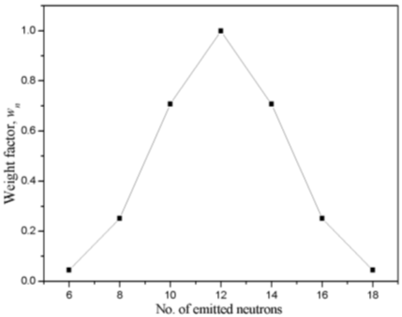

Fig. 1 Weight factor for n^{th} n-emission channel w_n vs. number of neutrons emitted in fission.

Therefore, the final yield of the fragment from all the n-emission channels can be obtained as,

$$I = \sum_n I_n \times w_n = \sum_n \langle CGC \rangle^2 \times w_n - - - (4)$$

Then we normalize the yields of all fragments with respect to the fragment having maximum yield, for lighter and heavier fragments separately. This gives us the relative yields of fragments for a partition. We repeat the same for all the seven partitions.

Results and conclusion

As discussed in the formalism, we calculate the relative yields of all the fragments in all the partitions for ^{208}Pb(^{18}O, f). We compare our calculated values with the experimental data of Danu *et al.* [3]. There is a reasonably good agreement between the calculated and the experimental values (Fig. 2).

There are some deviations in the calculated values from the experimental data. These may be partly attributed due to the presence of long-lived isomers, e.g., ^{124}Sn, ^{136}Xe and ^{136}Ba. Further, there are dips in the yields of fragments due to the shell effects which we do not consider in our calculations. Also, we estimate the neutron multiplicity values from ref. [5] as no direct data are there. Even then, the simple calculations based solely on isospin are able to reproduce the yields of neutron-rich fission fragments reasonably well. This also supports the Lane and Soper's argument [1] that the isospin remains reasonably conserved in neutron-rich nuclei.

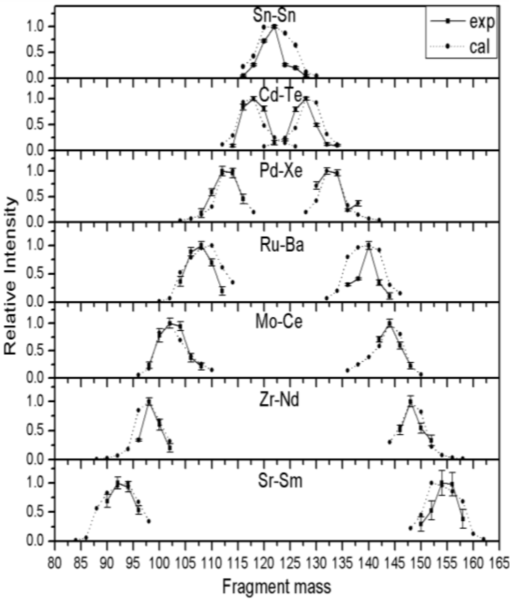

Fig. 2 Relative intensities of neutron-rich fission fragments vs. fragment mass number.

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