Role of Isospin in Neutron-rich Fission Fragments

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Introduction

Isospin, a fundamental concept in nuclear physics, was introduced to distinguish between neutrons and protons in the absence of Coulomb force. Due to the charge symmetry in nuclear forces, isospin has been used as a basic quantum number, which plays an important role in deciding the total wave function of nuclei. The concept has provided a simple understanding of many aspects of complex nuclear structure and related phenomena. There have been theoretical suggestions by Lane and Soper [1] that isospin may become a more useful quantum number in the heavier nuclei, particularly for the heavy neutron-rich nuclei as it becomes more pure for these systems.

This motivates one to apply the idea of isospin conservation to nuclear fission, where the neutron-rich fission fragments are emitted. In the present paper, we extend the previous work of Jain *et al.* [4] on the relative yield of the fission fragments by using the concept of the "conservation of isospin". The previous work was mainly focused on the work of Danu *et al.* [3]. In this paper, we focus on the work of Bogachev *et al.* [2], who have measured the relative yields of neutron-rich fission fragments in the heavy ion induced reaction ^{208}Pb(^{18}O,f). They also report the additional information on neutron multiplicity distribution, which we find very useful.

In this paper, we have tried to overcome the ambiguities in assigning the isospin values (T, T_3) and considered all the possibilities allowed by the isospin selection rules. Also, the concept of Isobaric Analog States (IAS) has been used to assign the isospin to each fragment. We also use the neutron multiplicity data for each fission partition as given by Bogachev *et al.* [2], to take into account the weight of various n-emission channels. We are, thus, able to reproduce the total relative yields of fission fragments quite well.

Formalism

For a given (N,Z) nucleus, $T_3 = (N-Z)/2$ and $|(N-Z)/2| \leq T \leq (N+Z)/2$. In a fusion-fission reaction of projectile P, target T, compound nucleus CN, fragments F_1 and F_2,

$$P(T_P, T_{3P}) + T(T_T, T_{3T}) \rightarrow CN(T_{CN}, T_{3CN}) \rightarrow F_1(T_{F1}, T_{3F1}) + F_2(T_{F2}, T_{3F2}) + q$$

where q is the number of emitted neutrons. From isospin selection rules, $|T_T - T_P| \leq T_{CN} \leq |T_T + T_P|$. Since minimum value of $T_T = T_{3T}$ and $T_P = T_{3P}$, the only allowed value of $T_{CN} = T_{3CN} = T_{3T} + T_{3P} = T_T + T_P$.

If T_{F1} and T_{F2} are isospins of two fragments emitted in fission, the minimum value of $T_{F1} = T_{3F1}$ and $T_{F2} = T_{3F2}$, the only possible value of $T_{RCN} = T_{F1} + T_{F2}$, where T_{RCN} is the isospin of a residual compound nucleus, so that $|T_{CN} - q/2| \leq T_{RCN} \leq |T_{CN} + q/2|$.Therefore, the allowed values of T_{3CN} are given by

$$T_{3T} + T_{3P} = T_{3CN} = T_{3RCN} + q/2 = T_{3F1} + T_{3F2} + q/2.$$

We then identify all the available Isobaric Analog States (IAS) in the complete set of experimentally known fission fragments, along with their T_3 values, i.e. T_{3F1}, and T_{3F2} values. For a given isobaric multiplet, we choose the maximum $T_3 = T$, as this is the minimum value required to generate all the members of any complete isobaric multiplet. This allows us to fix the T_{F1} and T_{F2} of the fission fragments for a given partition.

The next step is to obtain the T_{RCN}, and T_{3RCN} values from the assigned T_{F1}, T_{F2} and T_{3F1}, T_{3F2} values by using the isospin selection rules. We can write each possible pair of fragment in a particular partition in terms of the C.G. Coefficients (CGC) as,

$$\left|T_{RCN},T_{3RCN}\right\rangle_n=\left\langle T_{F1}T_{F2}T_{3F1}T_{3F2}\left|T_{RCN},T_{3RCN}\right.\right\rangle \left|T_{F1_1},T_{3F1}\right\rangle\left|T_{F2},T_{3F2}\right\rangle$$

where n corresponds to a particular neutron emission channel. Note that all the required values are now assigned by using the well known selection rules and the concept of IAS in the neutron-rich fission fragments. We may, therefore, find the intensity of each fragment in the respective partition for a particular n-emission channel from as follows

$$I_n=\left\langle CGC\right\rangle^2=\left\langle T_{F1}T_{F2}T_{3F1}T_{3F2}\left|T_{RCN},T_{3RCN}\right.\right\rangle^2$$

Each partition has a different neutron multiplicity of several neutron emission channels. Therefore, the final yield of the fragment from all the n-emission channels can be obtained as, $I=\sum_n I_n\times w_n=\sum_n\left\langle CGC\right\rangle^2\times w_n$

where w_n is the normalized weight factor for n^{th} neutron emission channel from the known experimental data.

We can now calculate the total yield of any isobar simply by adding the individual yields of isobars from each isobaric multiplet. To calculate the relative yield, we further use the renormalization with respect to the maximum yield. We compare these calculated results with the experimental data in the next section.

Results and discussion

For the reaction ^{208}Pb(^{18}O,f), T_{3T} = T_T =22 (^{208}Pb) and T_{3P} = T_P= 1 (^{18}O) so that the T_{CN} = T_{3CN} = 23 (CN). We assign the T and T_3 of each fragment on the basis of identifying the IAS from the experimental data. We then incorporate the experimental data for the neutron-multiplicities [2] to calculate the final total relative yield of each isobar by using the formalism as above.

We plot the calculated results in Fig. 1, and compare them with the experimental data along with error bars. We show the variation of the total relative yields of each isobar available in this reaction with respect to the fragment mass number. The calculated results reproduce the measured values reasonably well, except at the extreme left and right corners, where overestimation in the calculated values can be seen. This, however, confirms that the simple formalism based on the conservation of isospin in n-rich nuclei may explain the yields of the complex fission fragments in the heavy ion induced reaction.

Conclusion

To conclude, we have calculated the relative yields of neutron-rich fission fragments in ^{208}Pb(^{18}O,f) reaction based on the concept of isospin by considering all the possibilities of isospin, as allowed by the isospin selection rules. We also use the concept of IAS to assign the T and T_3 values to the available fragments in this reaction, along with the experimental neutron-multiplicity data. These improved calculations successfully reproduce the experimental trend quite well for the total relative yields of the n-rich fission fragements. We, hence, confirm that conservation of isospin plays a crucial role in explaining the neutron-rich fission fragments, and their respective yields in heavy-ion induced reaction.

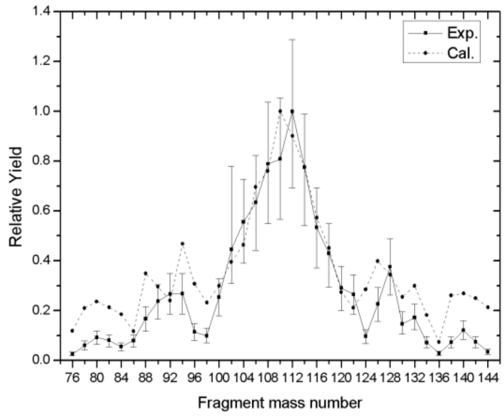

Fig. 1. *Total Relative Yield of fission fragments.*

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