Journal of Advances and Scholarly Researches in Allied Education
Vol. 12, Issue No. 2, January-2017, ISSN 2230-7540

A Study on the Evidence for Octupole Correlations in ^{140,142}CS

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Abstract:- The present Paper, entitled "A Study On The evidence for octupole correlations in 140,142Cs", Focuses On The Evidence for octupole correlation. For nuclei with a small number of valence particles (N < 85), octupole effects were explained due to octupole phonon excitations. In nuclei with a larger number of valence particles, one expects stronger octupole correlations, which will eventually cause octupole deformations of the nuclear potential. At N = 85, the number of valence particles may not be large enough to cause an octupole instability of the nuclear mean field, yet sufficient for numerous octupole excitations to appear. To check the stability of octupole excitations in 140Cs, Nuclear shapes in these neutron-rich Cs isotopes are expected to change gradually from a spherical shape in 137,138,139Cs to a weak deformed shape in 140,141,142Cs and then to a well deformed shape in 143,144,145Cs . Octupole correlations were observed in 141Cs and 143Cs .

Keywords:- Octupole, Phonon Excitations, Nuclear Potential, Nuclear Mean, Octupole Correlations etc.

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INTRODUCTION

Neutron-rich Cs (Z = 55) isotopes with mass numbers from 137 to 145 have five protons beyond the 50 proton major shell and the neutron number is located between the 82 and 126 neutron closed shells. High-spin states in these nuclei have been studied from the spontaneous fission of ^{248}Cm , ^{252}Cf , and deep inelastic transfer reactions. Nuclear shapes in these neutron-rich Cs isotopes are expected to change gradually from a spherical shape in ^{137,138,139}Cs to a weak deformed shape in ^{140,141,142}Cs and then to a well deformed shape in ^{143,144,145}Cs. Octupole correlations were observed in ^{141}Cs and ^{143}Cs . In this work, octupole correlations are extended to ^{140,142}Cs from the analysis of ^{252}Cf spontaneous fission data. The odd-odd isotopes ^{140}Cs^{85} and ^{142}Cs^{87} have three and five neutrons outside the N = 82 cloesd shell, respectively, and are close to the octupole deformation/correlation region centered around Z = 56, N = 88 . Possible octupole deforma-tions were proposed in the Cs isotopes at N = 85 − 88 in Ref., based on the observation of inverted staggering of the odd-even effect in the differential radii in the Cs isotopes. Urban *et al.* reported the observation of octupole correlations in ^{143}Cs and tentative results in ^{141}Cs . Recently our group proposed parity doublets in ^{141}Cs, with the simplex quantum numbers s = +i and s = −I The decay of ^{140}Xe and fission of ^{252}Cf have been used to populate excited states in ^{140}Cs. Many transitions at low excitation energy were observed in the β decay of ^{140}Xe . A few high-spin levels were identified in ^{140}Cs in the spontaneous fission of ^{252}Cf by Hwang *et al.*. In this work, we report a new level scheme for 140Cs based on the results in Ref. . We observe seven new transitions at low and moderate spin and thirteen at high spin. The new structure is proposed to be related to octupole correlations . A high-spin level scheme of ^{142}Cs was reported in Ref. involving six transitions of energies 97.3, 205.6, 404.7, 544.9, 699.9, and 787.0 keV out of the yrast band and seven other transitions. No nuclear structure was discussed further by the authors. By means of our new and higher-statistics data, a new level scheme for ^{142}Cs is proposed. Spin-parities are assigned to levels based on some angular correlation measurements and systematics of neighboring nuclei. The new level structure of ^{142}Cs shows evidence for the existence of octupole correlations. In a reflection-asymmetric nuclear mean field, an electric dipole moment D^0 may occur as a difference of the interference terms between quad rupole Y^{20} and octupole Y^{30} shape vibrations for protons or neutrons. One expects to see significantly larger D^0 in nuclei with octupole correlations than those without octupole correlations. It is of interest to compare the D^0 values for the Cs isotopes with octupole correlations with those for other neighboring isotopes with octupole deformations/correlations. The D^0 values for ^{140,142}Cs are determined using the corresponding branching ratios from the same spin states. A dramatic decrease of D^0 with increasing neutron numbers in the Cs isotopic chain is found, as proposed in Ref. [6].

REVIEW OF LITERATURE

Haralson, Mitchel, Jr.(2009) investigated the influences the neutron Pt spectra were also measured at lower energies, as shown in figure 11 .They show essentially the same behavior. However, a difference can be seen in the spectra with heavy (high-Z) targets. The neutron distribution from the ^{142}Cs +C ->n +^{141}Be +Xreaction shows no narrow peak, because ^{141}Cs is one neutron halo and the neutron is scattered by the reaction. However, a narrow peak rapidly develops when the target becomes heavier. the probability of exciting the projectile by a strong interaction is relatively.

Haralson, Mitchel, Jr.(2008) finding was not consistent with the present result an extraction of the strength of the correlation was first attempted by means of a comparison of the one- and two neutron octupole correlationss. Although this analysis was performed using the observed neutron and fragment octupole correlationss, it turned out not to be meaningful because the observed neutron octupole correlations reflects not the internal motion, but the decay Q value, as discussed above. Because of this complexity, no determination has so far been made for the internal neutron octupole correlations, therefore this method cannot be applied.

Another method is to compare the fragment octupole correlations and the halo density distribution. Suzuki *et al* analyzed the octupole correlations of ^{140}Cs. They calculated the octupole correlations of a 4He fragment using the Glauber - type model. Firstly, a cluster-orbital shell-model wave function that fitted the observed nuclear radius was used. The calculated octupole correlations is much broader than the observed one, as shown in figure 1.2. On the other hand, a di-neutron cluster wave function(L =0; S =0),in which neutrons are strongly correlated, gives a distribution that is narrower than that in the experiment. By making a hybrid model, which is a linear combination of the cluster orbital shell model and the di-neutron model, they were able to fit the experimental data quite well.

JS Shrauger (2010) who explored, the microscopic three-body calculation is expected to provide accurate information, because the core ^{4}Cs is extremely tightly bound. Such a calculation

Has been reported by many authors; they all reproduce the octupole correlations of the He fragment well. Here, as an example, the results of three-body calculations by Zhukov *etal* are presented. Figure 1.3 shows a two-particle correlation density plot of ^{141}Cs. The two-neutron density shows two separate peaks: one corresponding to a cigar-like geometry and the other to a di-neutron configuration. Although no direct information about such a correlation has yet been obtained, it would be an interesting experiment to see whether such configurations are mixed in a nucleus. In the same figure the calculated Pt distribution of ^{141}Cs from a fragmentation of ^{142}Cs is shown (solid curve). This shows quite a good fit to the data.

RESULTS

^{140}Cs

The level scheme of ^{140}Cs proposed by Hwang *et al.* was solely based on the observation of an 80.1-keV transition in the fission data, which has the same energy as the one found in the previous β-decay studies of ^{140}Xe to ^{140}Cs. Here, a measurement is undertaken to firmly establish the mass number of the transitions proposed in Ref. [9], as reported in Subsection 5.3.1. The level scheme of ^{140}Cs reported in Ref. [11] is extended and a side-band is proposed. The coincidence spectrum, created by double gating on the 80.1- and 563.6-keV transitions, is shown in Fig.1 In addition to previously known transitions in Tc isotopes and ^{140}Cs, one clearly sees five new transitions of energies 35.5, 54.8, 90.3, 551.2, and 552.6 keV, the latter two forming a doublet. To further confirm the existence and positions of the above five new transitions, two spectra are obtained, as presented in Fig. 1.1, where the gate transitions are indicated. Figure 1.2 (a), gated on the known 594.3- and 640.9-keV transitions in ^{140}Cs, shows the coincidence relationship among known transitions in 107,108,109Tc and ^{140}Cs, and the newly observed transitions, such as the 35.5-, 54.8-, and 90.3-keV transitions and two others of energies 472.5 and 702.2 keV. The spectrum, gated on the new 551.2-keV and known 563.6-keV transitions, is given in Fig.1.1 (b), where the new transitions of energies 35.5, 552.6, 652.6, and 876.5 keV are seen. Note that the new 54.8-keV transition seen in Fig.1.2 (a) is not found in Fig.1.2 (b). This observation is very important for us to place newly observed transitions in the level scheme of ^{140}Cs.

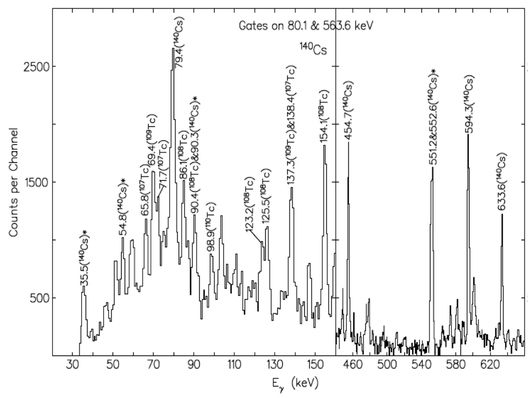


Figure 1.1: Coincidence spectrum double gated on the 80.1- and 563.6-keV transitions in ^{140}Cs . The new transitions are marked with an a sterisk.

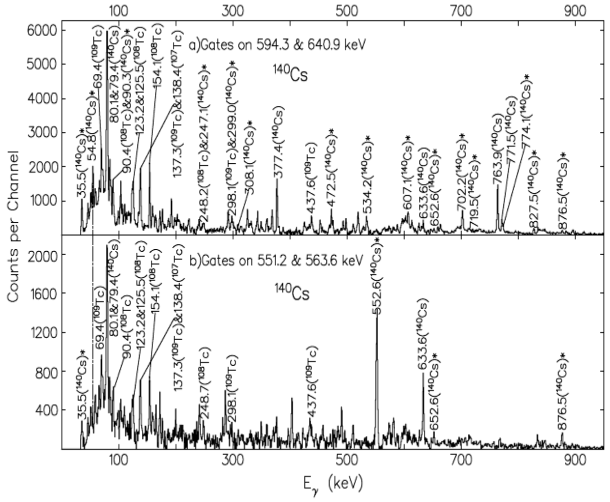


Figure 1.2: Coincidence spectra double gated on transitions in ^{140}Cs. The newly identified transitions are marked with an asterisk. A dashed line is drawn to illuminate the position of the 54.8-keV transition.

Careful cross-checking of numerous coincidence spectra leads to the final transition identifications and placements in the level scheme of ^{140}Cs. Eight new excited levels with thirteen new de-exciting transitions at high spin and three new excited levels with seven new deexciting transitions at low and moderate spin are observed. The level scheme of ^{140}Cs is presented in Fig. 1.3, where excited states are extended up to 3794 keV with a new side-band (band 3).

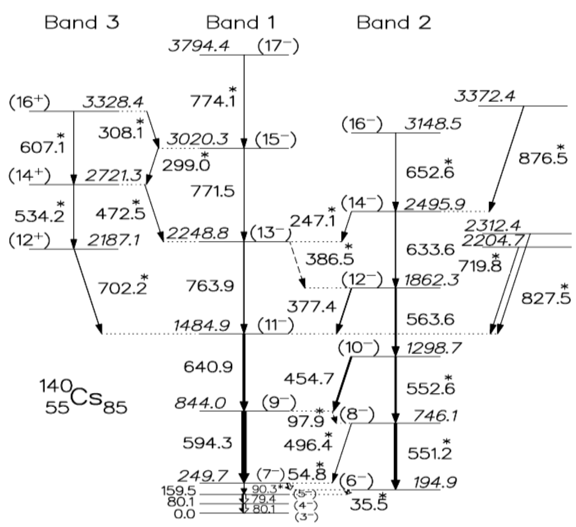


Figure 1.3: The new level scheme of ^{140}Cs. Energies are in keV and the width of the arrow is proportional to the corresponding -ray intensity. The newly observed transitions are marked with an asterisk. The level energies are relative to that of the (3−) state.

Angular correlations are measured for some strong transitions in Fig. 1.3. The measured A2 and A4 values for the 640.9 → 594.3- and 454.7 → 594.3-keV cascades are shown in Fig. 1.4, respectively. These data are consistent with a βI = 2 character of the 594.3- and 640.9-keV transitions and a βI = 1 character of the 454.7-keV transition [3, 5], which allow us to assign spin-parities to levels relative to Iβ of the 249.7-keV level, populated by the 594.3-keV transition.

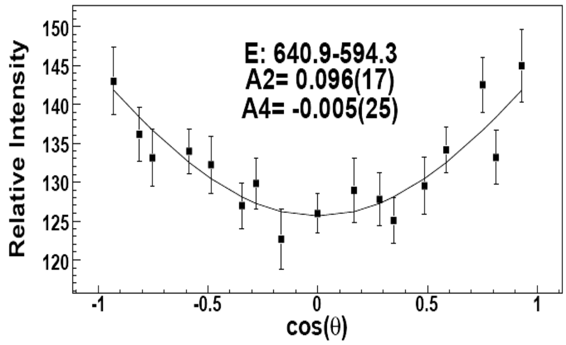


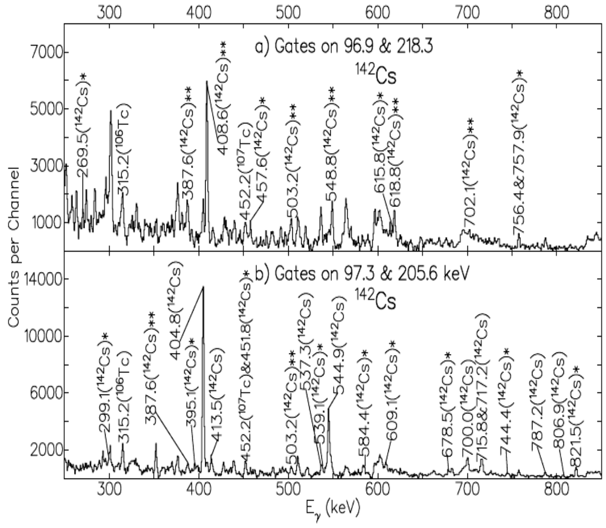
Figure 1.4: Angular correlation for the 640.9 → 594.3-keV cascade in ^{140}Cs.

It is assumed that spin values increase with increasing excitation energies, as commonly observed in fission products at high spin. We argue that the 594.3- and 640.9-keV transitions have a stretched E2 multipolarity and the 454.7-keV transition has an E2/M1 mixed multipolarity. Consequently, multipolarities of other upper crossover transitions above the 194.9-keV level in bands 1 and 2 are proposed to be stretched E2, whereas those of the linking transitions are E2/M1, by considering the multipolarity of the 54.8-keV transition as E2/M1. As will be discussed the very probable I_ assignments for the 249.7- and 194.9-keV levels are 7− and 6−, respectively. So, spins and parities can be assigned to the levels above the 249.7-keV level, as present in Fig. 7.3, based on their multi polarites proposed above and the detailed systematics analysis below. Spins and parities are assigned to the levels in band 3, according to the proposal in Subsection 7.3.1 that band 3 along with band 1 forms an octupole s = +1 doublet.

^{142}Cs

As argued the nuclear structure of ^{139}Cs, a group of transitions previously assigned to ^{139}Cs by Hwang *et al.* belong to ^{142}Cs. This assignment is based on the measurement that yields the fission yield ratio of 107Tc to 108Tc in the 218.6/408.6-keV double gate, 0.49(7), consistent with the value of 0.47(7) for ^{142}Cs.

Careful examinations and back-ground subtractions of several coincidence spectra reveal that the peak observed around 97 keV in the 408.6/218.3-keV gate is 96.9 keV, not the same as the one of energy 97.3 keV observed in the 404.8/205.6-keV gate. The coincidence spectra double gated on the 218.3/96.9- and 205.6/97.3-keV transitions show the newly identified transitions, especially these of energies 269.5, 757.9, 299.1, 821.5, 744.4, 457.6, and 584.4 keV, as present. Two additional spectra are shown to provide more evidence for the new transitions. The observation of the 457.6-keV transition in helps us to properly place the transitions previously assigned to ^{139}Cs.



We learned of the work of Rz, aca-Urban *et al.* on the level scheme of ^{142}Cs , where two low-energy transitions of energies 25.3 and 26.4 keV were observed.

CONCLUSION

The nuclear structure of the odd-odd, N = 85 nucleus 140Cs has been re-investigated. A measurement has been performed to firmly assign the mass number 140 to the pre- viously known transitions. Eight new excited levels with thirteen new de exciting transitions at high spin and three new excited levels with seven new deexciting tran- sitions at low and medium spin are observed to enable us to establish the level scheme of 140Cs. Spins and parities of levels in 140Cs are tentatively assigned on the basis of angular correlation measurements, systematics of N = 85 isotones, and the proposal of the existence of octupole excitations. The structure of 140Cs has been discussed and the newly identified side-band (band 3) along with band 1 is proposed to form an s = +1 octupole doublet. Further examinations indicate that octupole excitations are more of vibration character in 140Cs. A new level scheme of 142Cs has been established. Spin-parities have been ten-tatively assigned to levels in 142Cs based on angular correlations and systematics of neighboring nuclei. Two sets of alternating-parity doublets are extended to indicate more definite octupole correlations in 142Cs. The average electric dipole moments for 140,142Cs are measured and compared with 141,143Cs and other neighboring nuclei observed with octupole correlations. A remarkable decrease in D0 in the Cs isotopic chain with increasing neutron numbers found, which may be analogous to the drop of D0 in 146Ba. The pronounced drop of D0 in the Cs isotopes may have a similar origin to that in the Ba isotopes. More theoretical efforts are needed to interpret what we have found in the Cs isotopes with octupole correlations. The present dissertation is accomplished mainly by analyzing our fission exper- imental data collected in 2000. A large amount of -ray coincidence events were accumulated with the Gammasphere detector array for further detailed analysis of properties of neutron-rich nuclei produced in the spontaneous fission of 252Cf. A few nuclei in three different mass regions have been studied. They are:

(a) 114,115Rh in the A = 110 region, where triaxiality plays an important role in the nuclear structure;

(b) 134I, 137I, 139Cs, and four N = 83 isotones beyond the doubly- magic core 132Sn, where the shell model is suitable for describing their properties;

(c) 140Cs and 142Cs near the region centered on Z = 56, N = 88, where octupole deformations/correlations were proposed.

The first identification of high-spin excited states in 114,115Rh provides very im- portant information on the structure of Rh nuclei in the more neutron-rich region. A _I = 1, negative-parity yrast band and a side-band in 114Rh are found. The signa-ture inversion of the yrast bands of 106,112,114Rh is observed at 13.7 ~ for 106Rh, 12.5~ for 112Rh, and 10.6 ~ for 114Rh. The triaxial deformation is proposed to result in the signature inversion. The level scheme of 115Rh is established with an yrast band and an yrare band. The large signature splitting and the yrare band show features of a typical triaxial nucleus. Preliminary calculations based on the rigid-triaxial-rotor- plus-quasiparticle model have been performed to predict triaxiality of = 28◦ for

^{115}Rh.

A new high-spin level scheme of ^{134}I has been established for the first time. This high-spin level scheme is proposed to be built on the 8− isomeric state. Shell-model calculations have been performed and good agreement with experiment is found for both level energies and spin-parity assignments. Two N = 84 isotones ^{137}I and ^{139}Cs have been studied. The high-spin structure of ^{139}Cs is investigated, by extending its level scheme to 4670 keV. Spins and parities of levels in ^{139}Cs are firmly assigned up to 25/2+ experimentally. High-spin states in ^{137}I are extended as well. The level patterns of these two isotones indicate the important role that the two major shells Z = 50 and N = 82 play in their structures. Realistic shell-model calculations have been carried out to interpret the structures of ^{137}I and ^{139}Cs, by choosing 132Sn as a closed core. The calculations provide a very satisfactory description for both isotones, with discrepancies not exceeding 150 keV for most of the states up to 3.5 MeV. This shows that the interpretation of the low- to medium-energy levels in 137I and ^{139}Cs is well within the shell-model framework. However, for levels higher than 33/2+ in both ^{137}I and ^{139}Cs, larger discrepancies are found, which may indicate that excitations outside the chosen model space play an important role for such states. The present work indicates that the shell model can be used for neutron-rich nuclei as far as Z = 55 and N = 84. The g-factor of the 15/2− state in ^{137}Xe has been measured for the first time to extend our knowledge of g-factors in nuclei having several nucleons beyond the doubly- magic core ^{132}Sn. The measured value is in good agreement with the theoretical prediction from the shell model. Based on observed angular correlations, spins and parities are assigned to several levels in four N = 83 isotones ^{135}Te, ^{136}I, ^{137}Xe, and ^{138}Cs. These assignments are supported by the present shell-model calculations, which also show configuration mixing in these nuclei caused by one more neutron than their corresponding N = 82 isotopes and increasing proton numbers. The nuclear structures of the odd-odd ^{140}Cs and ^{142}Cs have been re-investigated. A new level scheme with a new side-band is built in ^{140}Cs. Spins and parities of levels in ^{140}Cs are tentatively assigned. The structure of ^{140}Cs has been discussed and the new side-band (band 3) along with band 1 is proposed to form an s = +1 octupole doublet more of vibration character. A new level scheme of ^{142}Cs has been established. Spin-parities have been tentatively assigned to levels in ^{142}Cs. Two sets of alternating-parity doublets are built to indicate octupole correlations in ^{142}Cs. The average electric dipole moments for ^{140,142}Cs are measured and compared with neighboring nuclei. A striking decrease in D_0 in the Cs isotopic chain with increasing neutron numbers is found. The pronounced drop of D_0 in the Cs isotopes may have a similar origin to that in the Ba isotopes at N = 90. In a word, the present dissertation enriches our knowledge of nuclear structures of neutron-rich nuclei produced in the spontaneous fission of ^{252}Cf. The current studies involve three important mass regions, which are of great interest in both theory and experiment.

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