The Odd-Even Z Isospin Anomaly In The Yields From High-Energy Reactions

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The expression "odd-even Z isospin anomaly" – introduced by L. B. Yang et al. [1] in 1999 – indicates the experimental evidence that the elemental even-odd effect decreases with increasing neutron-richness of the system. Since 1999, the analysis of experimental production cross-sections of final products of several nuclear reactions at very different energies confirmed the existence of this effect. An example of this effect is depicted in ***Figure 1*** (left panel), where the elemental yields produced in the reactions ^{136}Xe+Pb and ^{124}Xe+Pb at 1 *A* GeV are compared. The experiment was performed at the GSI, Darmstadt [2]. The projectile fragments from ^{124}Xe+Pb (N/Z = 1.30 for ^{124}Xe) show a stronger even-odd staggering than the products from the neutron-richer ^{136}Xe+Pb system (N/Z = 1.52 for ^{136}Xe). The difference in the strength of the even-odd staggering is shown in ***Figure 1*** (right panel).

We worked out that odd-even Z isospin anomaly is a direct consequence of the de-excitation process by particle evaporation occurring in the hot remnants of the nuclear reaction. In particular, the characteristics of the odd-even Z isospin anomaly can be reproduced providing that two effects are properly considered: 1) the *memory effect*, which express the fact final fragments hold some reminiscences of the primary impinging nuclei, and 2) the effect of pairing, which is responsible for the even-odd staggering in the yields.

The memory effect is reflected in the experimental observation that for each Z the mean values of the isotopic distributions of the final fragments produced in the two reactions do not coincide: if the original system was neutron rich the distribution is more shifted to the neutron rich side (see figures 9 and 11 of Ref. [2]).

The even-odd staggering in the yields correlates strongly with the lowest particle separation energy of the final experimentally observed nuclei, but it does not correlate with their binding energy, contrary to what at first one is tempted to think [3]. The lowest particle separation energy staggers among the isotopes of a given Z; the strength of the staggering is stronger along even-Z chains (see figure 5 of Ref. [3]). This is why in the experimental yields we observe a stronger even-odd staggering in the isotopic distributions of even elements.

Once the two effects discussed above are considered, the odd-even Z isospin anomaly is just a consequence of a mathematical game: take two Gaussians (isotopic distributions), shift them by a certain amount (memory effect), modulate them with a given staggering (pairing), make the integrals (elemental yields) and finally make the ratio of the integrals. The strength of the staggering has to be stronger if the two Gaussians represent the isotopic distributions of an even element. In this way, one can reproduce a pattern like that of Figure 1 (right panel). The memory effect is important, because if the were not a shift among the Gaussian, the integral would be always constant, independently of the staggering. The stronger staggering in the lowest particle separation energy of even-Z nuclei is important because it modifies the value of the integral (thus the value of the elemental yield) more for even-Z than for odd-Z.

With a statistical model without structural effects (pure liquid-drop-model) we calculated the isotopic distribution of the products of ^{136}Xe+Pb and ^{124}Xe+Pb at 1 *A* GeV. The model is correct enough for the present purpose because the distributions show a memory effect. We applied the very simple idea of lowest separation energy to get the even-odd staggering in the cross sections. We made the ratio of the elemental yields, and the result is presented in Figure 2. The result of out crude calculation shows that the calculated staggering qualitatively agrees with the experimental one, proving the validity of our simple idea.

To conclude, our study shows that it is precisely the memory effect combined with the characteristics of the lowest particle separation energy which determine the "isospin anomaly".

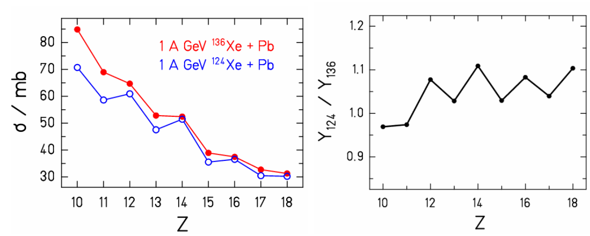

Figure 1: Left panel: Experimental elemental production cross-sections for the reactions 1 *A* GeV ^{136}Xe+Pb (dots) and ^{124}Xe+Pb (circles) [2]. Right panel: Ratio of cross sections for each element produced in the two reactions.

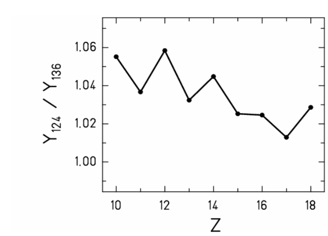

Figure 2: Calculated ratio of elemental cross sections for 1 A GeV ^{124}Xe+Pb and ^{136}Xe+Pb.

References

[1] L. B. Yang et al., Phys. Rev. C 60 (1999) 041602
[2] D. Henzlova et al., Phys. Rev. C 78 (2008) 044616
[3] M. V. Ricciardi et al., submitted to Phys. Rev. C (2010), arXiv:1007.0386