Turkish Journal of Nuclear Sciences, 10 (1983) 24-33

MACROSCOPIC IMPLICATIONS OF DIVERSE MECHANISMS FOR DINUCLEAR (N-Z) EVOLUTION

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ABSTRACT

Discrete Random Walk calculations of the (N-Z) evolution of a liquid drop dinucleus are reported for various assumptions about the trasfer dynamics. Transition probabilities are assumed which correspond to the transferred nucleon's being able to reach (a) any energy conserving state of the final dinucleus, (b) any energy conserving state more complicated by not more than 1p and 1h than the initial state, and (c) any one-particle one-hole excitation of the initial state. Physically these assumptions correspond to restricting the transfer, not at all, somewhat, and totally to be a pure one-body process. In every case, the Pauli exclusion principle is honored in the allowed final states. One finds that the assumption (c) generally leads to predictions easily distinguishable from those of (a) and (b), which do not differ substantially.

ÖZET

Gelişigüzel yürüme modelinin çiftçekirdek'in (N-Z) evrimindeki parçacık taşınma dinamiği çeşitli varsayımlarla çalışıldı. Parçacık taşınma olasılıklarında taşınan parçacığın (a) çiftçekirdek'in enerji korunumunu sağlıyan herhangi bir enerji düzeyinde olması, (b) enerji düzeyinin bir öncekinden ancak 1p-1h kadar daha karışık olduğu, (c) ilk enerji düzeyinin 1p-1h kadar yükseltgenmesi gözönüne alınmıştır. Fiziksel olarak bu varsayımlar, sırasıyla hiçbirşekilde, kısmen ve tamamen tek-gövde işlemine karşılıktır. Yukarıdaki her durum için Pauli kısıtlaması kuralı enerji düzeylerinin sayımında gözönüne alınmıştır. (c)

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varsayımının (a) ve (b) ninkilerden kolaylıkla ayırtedilebilir olduğu fakat (b) ve (c) nin çok farklı sonuçlar vermediği görülmüştür.

INTRODUCTION

In the discrete random walk description of nucleon transfer in heavy ion collisions /1-3/ all of the physical properties of the q^{th} nucleon transfer event are summarized in the transition probabilities $T_\alpha(N,Z,q)$, and in the specification of the associated change in total kinetic energy for the emergent fragments. Thus any sharp physical conjecture about the transfer mechanism which can be reduced to a specific set of transition probabilities and energy losses may be converted into an implied (N-Z) evolution and compared with the experimental observations. In such a process one seeks not so much to obtain "a fit" to the data, but to learn which aspects of the physical mechanism most affect which features of the observations, and especially whether (and when) more than one plausible assumption might equally well describe them.

CALCULATIONS

Here we report calculations based on three assumed forms of transition probability, corresponding to degrees of independence for the transferred nucleon which vary from extreme to minimal. In every case, the Pauli exclusion principle is honored[1] in the allowed final states.

(A) From the most extreme independent particle viewpoint, we assume that a nucleon tnasferred across the neck of the dinucleus leads to a one-particle, one-hole final state of excitation energy $\Delta q(\alpha)$ (equal to the increase in E^* due to the transfer, α), and that the state of every other nucleon remains unaltered. The corresponding transition probability,

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[1] *The Pauli principle is sometimes discussed as though it were co-extensive with the assumption of extreme independent particle motion, whereas in fact it can, and must, be honored no matter how strong the effects of residual two-body interactions might be. The Pauli principle is considered in such an independent particle context /4-7/.*

proportional to the weighted density of such final states, is given by

$$T_\alpha^{PH}(N,Z,q) \propto \rho_{PH} = g^2\Delta\left|\exp(\Delta/2\tau)\right|/\mathrm{Sinh}(\Delta/2\tau), \quad (1)$$

where $\tau_q = \tau_q\left|E_q^\star(N_\alpha,Z_\alpha)\right|$ is the temperature of the system before the transfer event in the final state nucleus, (N_α,Z_α). This assumption must be augmented implicitly by the further assumption that before the next transfer event the energy Δ_q is spread into a new equilibrium distribution characterized by the temperature, τ_q.

(B) Our intermediate assumption is that during each nucleon transfer event one additional particle and one additional hole may be created, and that all the previously created particles and holes may be rescattered into new states. Then the transition probabilities are proportional to the "pre-equilibrium" level density, as follows:

$$T_\alpha^{PE}(N,Z;q) \propto \rho_{PE} = \sum_{s=1}^{q} \rho_{ss}\left|E_q^\star(N_\alpha,Z_\alpha)\right|, \quad (2)$$

where ρ_{ss} is the density of s-particle s-hole states /8,9/. Since for large q, this pre-equilibrium density approaches the total ("Exponential") level density assumed in (C) below, the implications of this assumption are expected to converge to those of assumption (C) below for large q, or large TKEL, values. (And, in fact, does so, as the present results show.)

(C) Our third assumption specifies that in the process of transfer, as many other nucleons may scatter into new states as are necessary to reach any final state of the system. Then the transition rate is proportional to the total (here taken to have the exponential form, whence the label "EX") level density, as follows:

$$T_\alpha^{EX}(N,Z;q) \propto \rho_{EX}\left|E_q^\star(N_\alpha,Z_\alpha)\right| \propto (E^\star)^{-5/4}\ \mathrm{Exp}\left|gE^\star\right|^{1/2}. \quad (3)$$

Here $E^\star = E_q^\star(N_\alpha,Z_\alpha)$. This is the form used in the earlier analyses /2/.

(D) The Eqs. 1-3 above refer only to the transition probabilities for nucleon transfer (i.e., $\alpha = 1,2,3,4$). In addition, earlier analyses /1,2/ have shown that a finite (and substantial) value should also be assigned to the probability, T_0, that no transfer actually occurs during the trasfer event, or q-step This probability, T_0, then describes an event in which kinetic energy is lost into excitation energy by some mechanism not associated with the transfer of a nucleon. In the present calculation we have assumed that T_0 has in each reaction a fixed constant value, γ , corresponding to an alternative energy dissipation process which is independent of N, Z, and E_q^*; then the four other transition probabilities at each (N,Z) are normalized to a total of $(1-\gamma)$. Physically, this assumed independence of specific details corresponds well (e.g.) to the assumption that the excitation of giant collective states is the dissipation mechanism.

We note that the constant T_0^γ assumption differs from the form, $T_0^\beta = \beta\rho(E^*)$ used in earlier calculations /1,2/ whose dependence upon the level density (whichever one is assumed) implies that the process leading to this no-step probability is of the same generic type as the assumed transfer process. Although in general the implications of T_0^β and T_0^γ are similar, in certain respects, which will be detailed elsewhere /9/ the T_0^γ conforms better, although not decisively so, with the observed patterns.

For each of the reactions analyzed /11-13/ (Ca+Cl (270 MeV), Fe+Fe (464 MeV), Fe+Ho (464 MeV), and Fe+U (464 MeV)), the behavior of the overall width in A, ${\sigma_A}^2$, was first fit as well as possible by a specific choice of γ, which then was retained unchanged. This process is recommended by the fact that the behavior of ${\sigma_A}^2$ is most sensitive to the value of γ, and quite insensitive to the choice of level density (as one can see in Figs. 1a, 2a, 3a, 4a), and also by the fact that our precise knowledge of the alternative excitation processes is meager.

For Ca+Cl and Fe+Fe, the best value of γ is zero (see Figs. 1a, 2a) implying that the energy dissipation rate by nucleon transfer alone is sufficient. This is qualitatively agreeable with the fact that, as compared with Ho and U targets, these light nuclei have greater giant resonance eigenenergies, and therefore are less easily subject to direct excitation. The description of σ_Z^2 for these reactions, not shown here, is similar to that of σ_A^2.

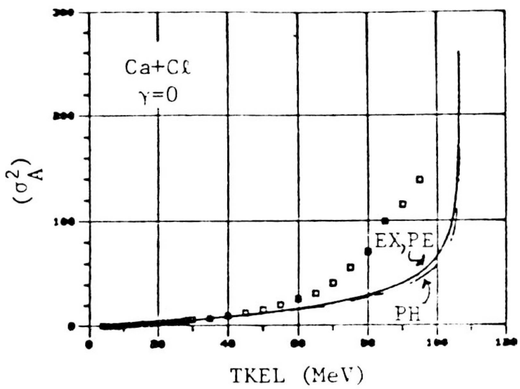

Fig. 1a. Ca+Cl (270 MeV): σ_A^2

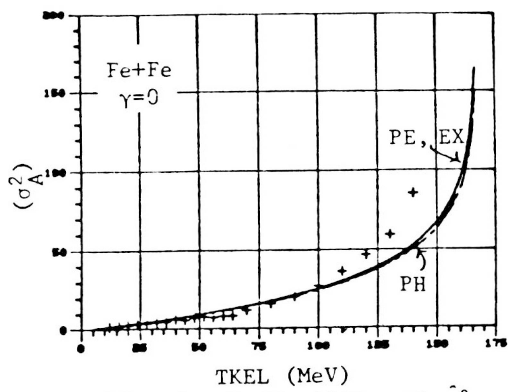

Fig. 2a. Fe+Fe (464 MeV): $\tilde{\sigma}_A^2$

In these same reactions the comparison of the calculated and observed values of the fixed-A cut width in Z, $\sigma^2_{Z/A}$, shows (Figs. 1b, 2b) that the EX and PE results are rather similar, and quite easily distinguished from the extreme PH results. /We note that recent calculations /13,14/ suggest that neutron and proton emission from the emergent fragment (not included in the calculations reported here) may significantly reduce the calculated values of $\sigma^2_{Z/A}$ and $\sigma^2_{A/Z}$. One should therefore not summarily reject the PH results here./

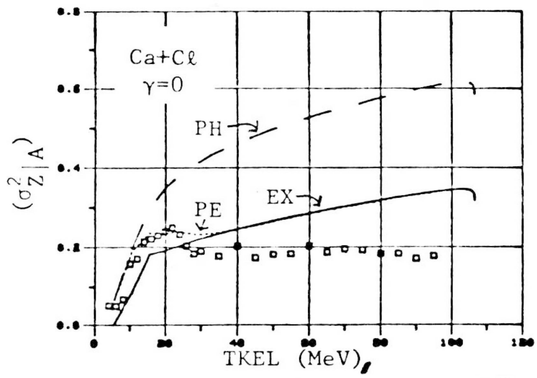

Fig. 1b. Ca+Cl (270 MeV): $\sigma^2_{Z/A}$

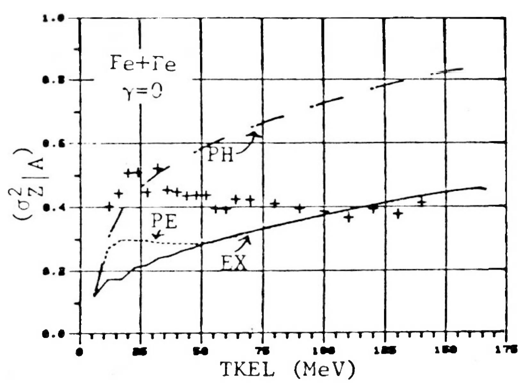

Fig. 2b. Fe+Fe (464 MeV):$\sigma^2_{Z/A}$

In Fe+Ho and Fe+U, the best values of γ are found to be 0.67 and 0.82, respectively. Figs. 3a,4a show that these choices provide an excellent fit to σ^2_A, independent of the level density assumed. Figs. 3b, 4b show that σ^2_Z, is also reasonably well described, but with somewhat more dispersion among the various level densities, which, however, does not strongly favor any particular choice.

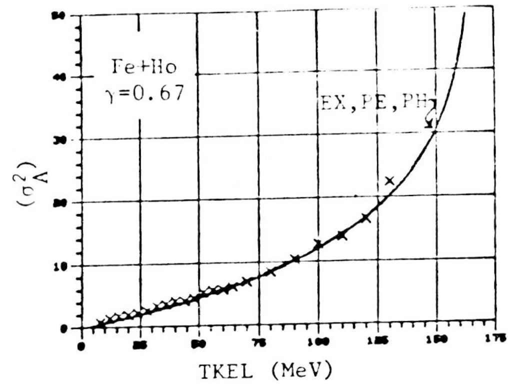

Fig. 3a. Fe+Ho (464 MeV): σ^2

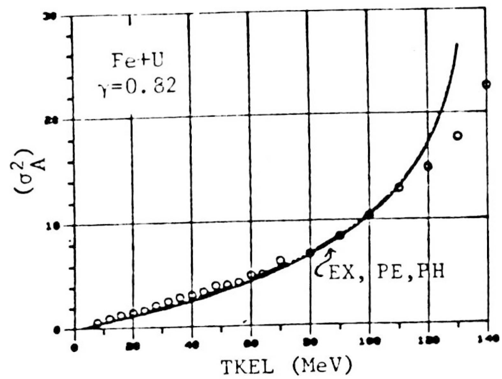

Fig. 4a. Fe+U (464 MeV): σ_A^2

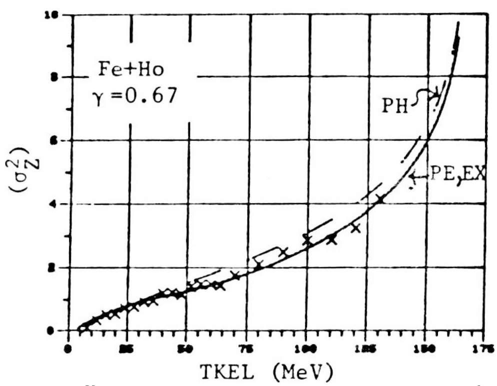

Fig. 3b. Fe+Ho (464 MeV): σ_Z^2

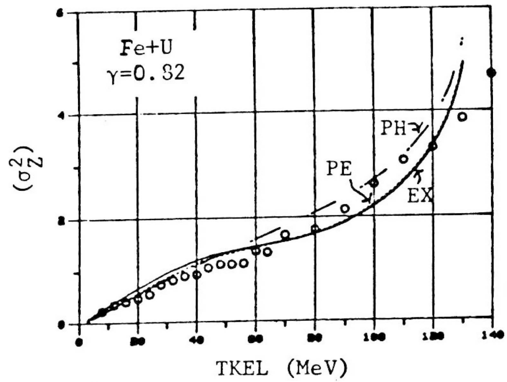

Fig. 4b. Fe+U (464 MeV): σ^2_Z

For the cut-widths, Figs. 3c, 3d, 4c, 4d show $\sigma^2_{Z/A}$ and $\sigma^2_{A/Z}$ for Ho and U, respectively. Again one finds that the EX and PE assumptions yield nearly the same predictions, whereas the PH density differs substantially except for the smallest TKEL values. The caution offered above about the possible effects of nucleon emission on $\sigma^2_{Z/A}$ and $\sigma^2_{A/Z}$ is also operable here.

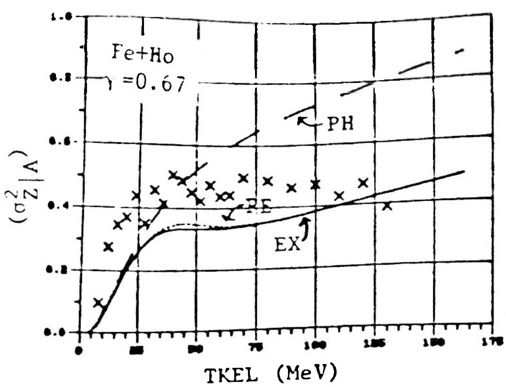

Fig. 3c. Fe+Ho (464 MeV): $\sigma^2_{Z/A}$

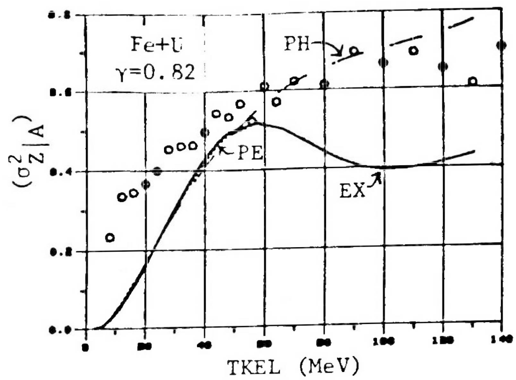

Fig. 4c. Fe+U (464 MeV): $\sigma^2_{Z/A}$

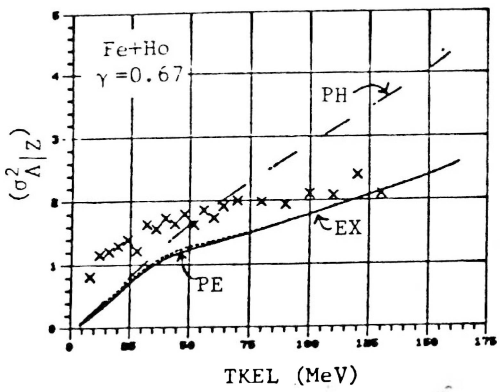

Fig. 3d. Fe+Ho (464 MeV): $\sigma^2_{A/Z}$

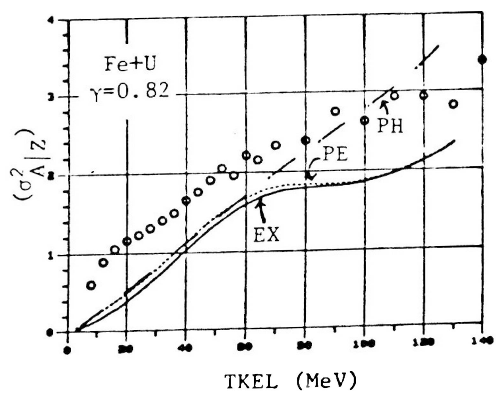

Fig. 4d. Fe+U (464 MeV): $\sigma^2_{A/Z}$

CONCLUSION

In summary, these results suggest that the careful study of (N,Z) distributions may provide a basis for a qualitative discrimination among various assumptions about the physical nature of the nucleon transfer process. On the other hand, none of the assumptions studied can yet claim clear advantage. We believe that such a claim must wait upon a clearer understanding of the particle emission corrections, and of the systematic remnant discrepancies σ_A^2 and σ_Z^2 at high TKEL for the light targets, and in the slope of the cut widths $\sigma_{A/Z}^2$ and $\sigma_{Z/A}^2$ at low TKEL for the heavier targets. Both of these we believe may be ameliorated by the inclusion of angular momentum effects within the theoretical description.

ACKNOWLEDGEMENTS

Support of the U. S. Department of Energy, the University of Maryland Computer Science Center and Turkish Scientific and Technical Research Council for this research is gratefully acknowledged.

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