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TETRAHEDRAL PERCOLATION MODEL AND ENERGY SPECTRA OF NUCLEAR FRAGMENTATION

by

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ABSTRACT

A Monte Carlo simulation based on the so-called tetrahedral percolation model is shown to reproduce very satisfactorily the experimental data from high-energy proton-induced reactions. This suggests that the main features of nuclear fragmentation may be understood by geometric and probabilistic considerations only.

KEY-WORDS: nuclear reactions, fragmentation, percolation, Coulomb expansion, fragment energy spectra.

One of the most simple description of the nuclear fragmentation processes, observed in intermediate and high energy heavy–ion reactions, is given by the percolation theory. The pioneering works in this approach use either site percolation[1] or bond percolation[2] in a three–dimensional simple cubic lattice. More recently, a hybrid (site–bond) percolation has been also developed[3]. However, in spite of the relative success of the percolation models in reproducing the experimental fragment mass distribution, they offer no space to take into account the deexcitation of primordial fragments. This is so, because it is implicit in the percolation description of nuclear fragmentation a cold and explosive break–up of the compound system. In consequence, any attempt of calculating the fragment kinetic energy spectra by the standard percolation models seems very unrealistic[4], since in general the clusters are produced in very excited states and then decay to the final stable nuclei via particle evaporation or other secondary processes.

As the standard percolation produces in general very dilute and ramified primordial clusters, which can be hardly identified with final state nuclei, it has been realized by Chao and Chung[5] that the excited states would be associated with these kind of clusters, at least in a first approximation. Then, they have proposed a very simple prescription, based only upon geometric and probabilistic considerations, in order to take into account the deexcitation of these primordial exotic clusters.

As a matter of fact, instead of performing a standard percolation on a *sc* lattice, they have introduced the so–called tetrahedral percolation model on a *fcc* lattice, in which the criterion for the cluster buildup is given by the tetrahedron binding, *i.e.*, each particle in a cluster is linked by at least three neighbouring ones that form a triangle, such that the resulting geometric figure is a tetrahedron. In addition, clusters that share common particles can further be combined together, with the smallest cluster represented by the alpha particle, if symmetric nuclei are assumed. They claim that the tetrahedral percolation is a simple scheme for building up compact clusters without dangling ends and, in this respect, it is able to simulate the secondary effects, *e.g.*, particle evaporation and secondary fragmentation from the excited fragments. In this way, the more exotic (ramified) the primordial cluster, the more effective the tetrahedral percolation is in simulating the cluster decay.

It should be noted that other procedures within the standard percolation have been also proposed before, *e.g.*, by Campi and Desbois[6], who have introduced additional constraints on the initial conditions both in the configuration and in the momentum space, and by Santiago and Chung[7], who have supplemented the percolation calculation by a particle evaporation code.

In what follows, we report the results of a Monte Carlo simulation, by using tetrahedral percolation, such as given in Ref.5, altogether with a Coulomb expansion in which it is adopted a very simple ansatz for the initial fragment momenta, consistent with a purely geometric and probabilistic description of the nuclear fragmentation. However, as clusters with A = 2 and A = 3 obviously can not be generated by the

tetrahedral percolation, then in this work we superimpose a *sc* standard site percolation involving only the single particles left out by the tetrahedral percolation.

We consider a *fcc* lattice inside a sphere, containing 87 sites, which is appropriate to simulate the $p + Kr$ reactions, at 80–350 GeV, such as reported by the Purdue group[8]. Furthermore, we assume the probability parameter p to depend upon the impact parameter b in the same functional form than the number of primary collisions when the incident proton crosses the target nucleus, *i.e.*,

$$p(b) = 1 - p_0\sqrt{1 - (\frac{b}{R})^2} \tag{1}$$

where R is the radius of the nucleus target and p_0, the value of the probability parameter for central collision, which has to be chosen in a such a way that the average value of p equals the "critical" probability p_c to be introduced below. In the following, we use the Model II of the tetrahedral percolation, where clusters are combined only if they have at least two particles in common (see Ref.5 for more details), and we assume no isospin degrees of freedom. After the breakup, the Coulomb forces lead the excited clusters to repeal each other, until the asymptotic states are attained. The initial conditions for the Coulomb expansion[9] were taken as the following: the position $\vec{r_i}$ is assumed to be the center–of–mass of the cluster and the momentum $\vec{P_i}$ is obtained, assuming a Woods–Saxon distribution for the number density n, so that

$$\left|\vec{P_i}\right| = \hbar\left(\frac{3}{2}\pi^2 n\right)^{1/3}, \tag{2}$$

while the direction is randomly selected.

Experimentally, the kinetic energy spectra of fragments with a given size display a bell-shaped curve, while the mass distribution of light-to-medium size fragments seem to follow a power-law, *i.e.*, $Y(A_F) \propto A_F^{-\tau}$, where τ is the apparent exponent[8].

In Fig.1, the apparent exponent τ of the mass distribution and the average multiplicity $< M >$ of heavy fragments ($A_F \geq 4$) are displayed as a function of the probability p. It is seen that $< M >$ has a maximum of around 2.5 at $p \approx 0.62$. The value of p at this maximum can be regarded as the finite–size analogous of the critical probability p_c of infinite systems. So, our calculation gives $p_c \approx 0.62$, and at this "critical" probability, τ is around 2.4, which is very close to the Purdue's inclusive experimental results ($\tau = 2.6$, such as reported in Ref.8, but may be smaller if different treatment of the data is made and, in this case, $\tau = 2.3$, such as reported in Ref.10).

In Fig.2, the kinetic energy spectra of ^{12}C and ^{16}O (histograms) are compared with the Purdue's experimental data (solid lines), for lattice size parameter $d = 3.25 fm$, which yields the best fitting to the data. In this case, the estimated breakup density is 0.07 fm^{-3}, which is close to the value obtained by other calculations, *e.g.*, in Bondorf *et al.*[11] . Qualitatively, the histograms show a very good accordance

with the experimental data, althought, both for ^{12}C and ^{16}O, the peak is slightly shifted toward the low–energy part of the spectrum and the simulation overestimates the experimental data in this region.

Our results show a quite reasonable fitting with the experimental mass distributions and energy spectra. This means that the tetrahedral percolation, with some additional modifications, is able to reproduce the main features of the nuclear fragmentation processes at very high energies, as long as the inclusive data are concerned. Since only geometric and probabilistic considerations have been used, it is suggested that basically nuclear fragmentation is a stochastic process. It is believed that the small remaining discrepancies between the present results and the experimental data can be significantly reduced if an explicit treatment of the evaporation from non–exotic primordial clusters is incorporated.

FIGURE CAPTIONS

FIG:1

The average multiplicity $< M >$ of fragments with size $A_F \geq 4$ (a) and the apparent exponent τ of fragments (b) are plotted against the probability p. The number of runs is 2.500.

FIG:2

Fragment energy spectra for ^{12}C (a) and ^{16}O (b). The results (histograms) are compared with the experimental data of Hirsch *et al.* (dashed line). The number of runs is 2.500.

FIG. 1

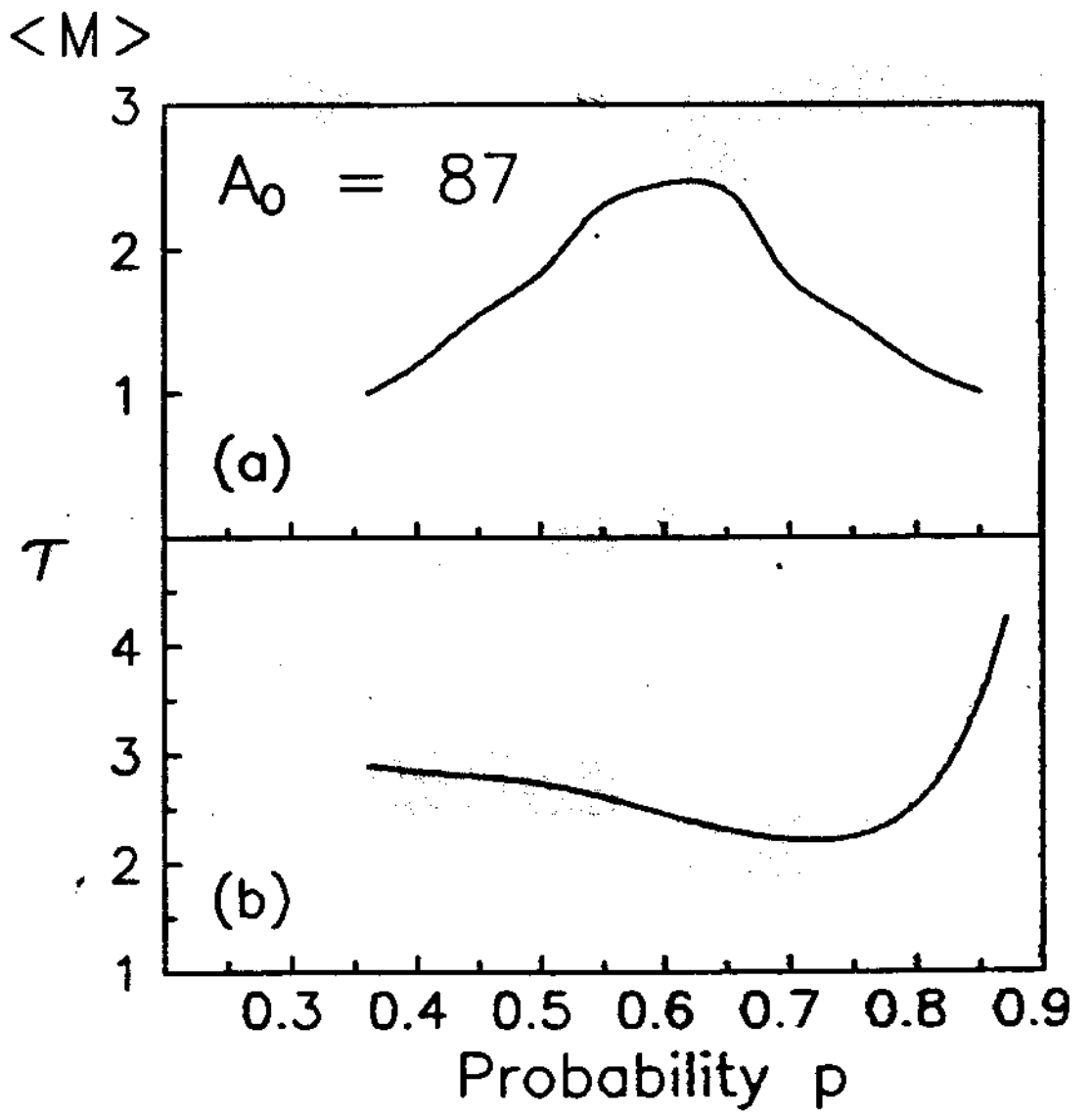
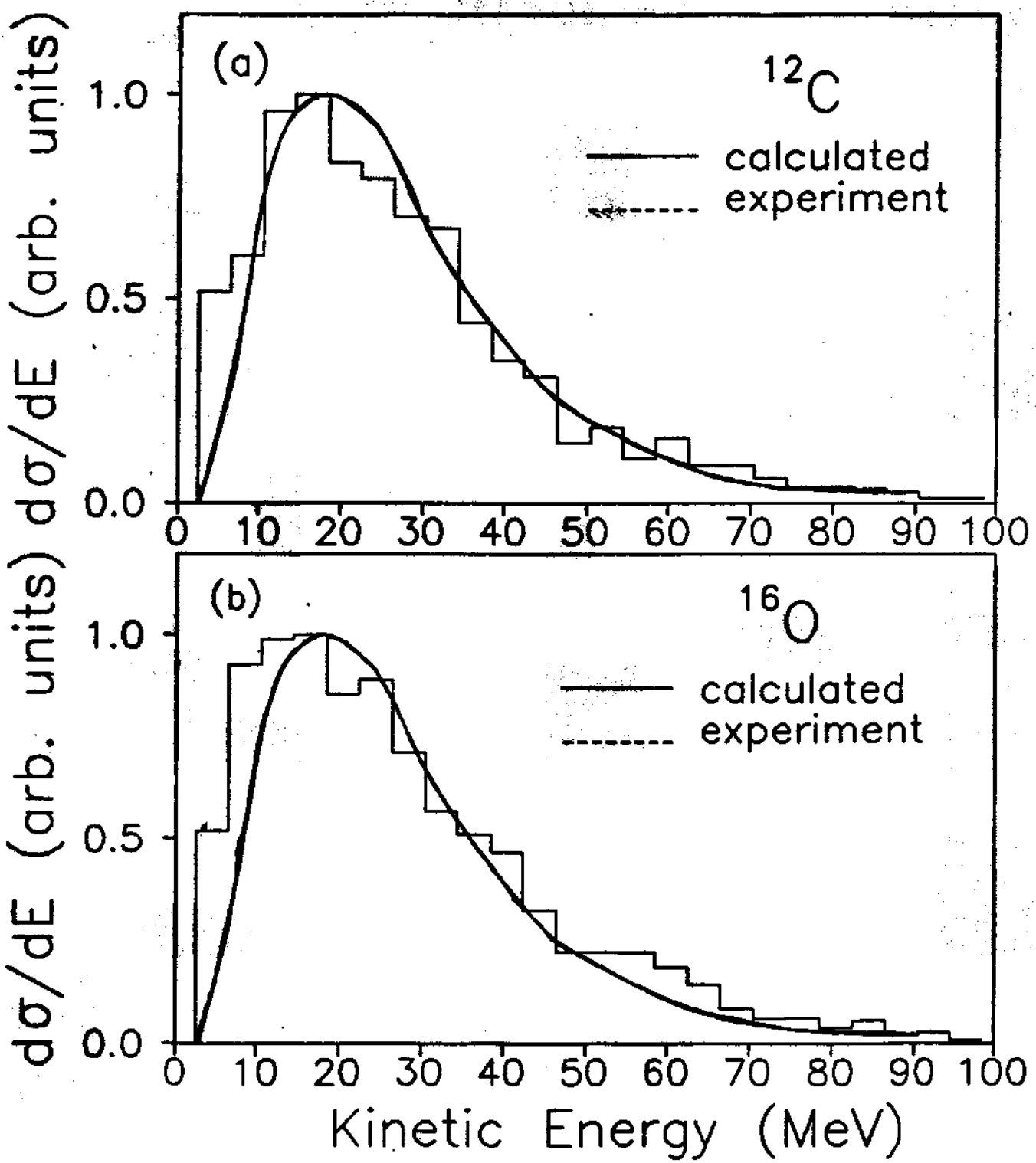


FIG. 2


(a)
^{12}C
calculated
experiment
(b)
^{16}O
calculated
experiment
dσ/dE (arb. units)
Kinetic Energy (MeV)
0.0
0.5
1.0
0
10
20
30
40
50
60
70
80
90
100

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