HE.1.1.09

Percolation Model for Nuclear Fragmentation of ^{28}Si (^{22}Ne) at 4.5(4.1)A GeV/c

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Abstract

The fragmentation of 4.5A GeV/c ^{28}Si and 4.1A GeV/c ^{22}Ne in emulsion has been investigated. A statistical percolation model, implying bond percolation mechanism, can describe qualitatively the distributions of fragments of charge greater than or equal to two. The model depends on two physical parameters: the bond breaking probability and the size of the fragment nucleus. The comparison between the model calculations and the experimental data has shown that the best value of the breaking probability is equal to 0.55.

1 Introduction:

In high energy nucleus-nucleus collisions, the fragments from the projectile and the target nuclei can be well separated. The process, where a part of the nucleus is suddenly liberated, is called fragmentation (Goldhaber ,1974) and if the second nucleus acts only as an energy injector, one denotes it limiting fragmentation (Heckman et al., 1972). Attempts have been made to study the critical phenomena in nuclear emulsions under the condition that the projectile fragmentation products can be isolated at 1A GeV (Waddington \ & Freier , 1985) with a sharp phase transition (Campi , 1988). In the last few years, a large amount of data has become available for the fragmentation process defined by the nuclear reaction $A_p + A_t \rightarrow A_f + X$, where A_p, A_t and A_f are the projectile, the target and the fragment mass numbers, respectively. These fragmentation reactions have been studied with many theoretical approaches, which are based on quite different physical assumptions. Different theoretical models based on the droplet description of the nucleus have been proposed (Gilkes et al., 1994 and Elliot , Singh \& Mukhopadhyay , 1986). Hufner and Mukhopadhyay (Hufner \& Mukhopadhyay ,1986) pointed out that the power law $Y(A_f) \alpha A_f^{-\lambda}$, where $Y(A_f)$ is the mass yield of the reaction , λ is the exponent and A_f is the fragment mass number. Aichelin (Aichelin, Hufner \& Barra , 1985) have therefore proposed a so-called minimum information model . Bauer and others have proposed the so-called statistical model which is based on the percolation theory (Bauer et al., 1986).

Bauer (Bauer et al., 1985) used a percolation model, for the nuclear fragmentation, in order to study the possibility of observing a phase transition of the nuclear matter in the high energy (> 10 GeV) protons collisions with the heavy targets. If the limiting fragmentation is fulfilled and the sources are well separated in the momentum space, then the study of the critical behavior by the percolation method becomes useful. An analysis has been done by Cole (Cole et al., 1995) in order to explain the similarities and differences which exist between the bond percolation process on a cubic lattice and the fragmentation of highly excited atomic nuclei. Elliot (Elliot et al., 1996) have studied the individual fragments formed in the projectile fragmentation of gold nuclei at 1A GeV incident on a carbon target as a function of the total charge multiplicity. Werner (Werner , 1994) introduced a percolation approach, which amounts to forming quark-matter droplets, when string fragments are close in space, the calculations are based on Gribov - Regge theory.In this paper, the percolation ideas are applied to describe the mass yield data of high energy 4.5A GeV/c ^{28}Si and 4.1A GeV/c ^{22}Ne with emulsion

Experimental Technique:

Stacks of Br-2 nuclear emulsion were exposed to a 4.1A GeV/c ^{22}Ne and 4.5A GeV/c ^{28}Si beams at Dubna synchrophasotran. The pellicles of emulsion have the dimensions of 20cm x 10cm x 600μm (undeveloped emulsion) . The intensity of the beam was about 10^4 particles/cm^2 and the beam diameter was

approximately 1cm. Along the track, double scanning has been carried out. All the charged secondary tracks emitted in the interactions have been classified into different groups (El-Naghy et al., 1998) : shower tracks (s), grey tracks (g) , black tracks (b)and n_h (= n_b + n_g). The g-particles emitted within $\theta \leq 3°$ and having L > 2cm are considered to be projectile fragments having Z =2. The b-particles of $\theta \leq 3°$ and L>1cm are due to projectile fragments having Z ≥3. The number of delta - electrons has been measured for each of these particles in order to determine the corresponding charge Z=3,,Z_b .

3 Percolation model :

Percolation models (Stuffer , 1985) are generally based on two ingredients 1) a description of the distribution of a set of points in a two dimensional space and 2) a criterion for deciding whether two given points are connected (clusters). The study of these clusters constitutes the percolation theory. Percolation theory is classified into three types: Site percolation theory, bond percolation theory and site bond percolation theory. In this study, we have used the bond percolation theory. The connection with the bond percolation theory is established according to the following procedure. The projectile nucleons are represented by points occupying a simple three-dimensional lattice in the coordinate space. The lattice spacings are related to the nuclear saturation density which equals 0.165 fm^{-3}. The number of points used equals the number of projectile nucleons and is conserved during the calculation as ($\sum_{i=1}^{m} A_F(i) = A_P$), where A_f (i) is the mass number of the ith fragment and m is the total multiplicity of all fragments, A_p is the projectile mass number. The nucleons are connected to their nearest six neighbors on the lattice via bonds representing the short ranged nuclear interactions. These bonds are then broken with a probability (P_B =E*/E_B), where E_B is the energy required to break one bond and E_B is the nuclear matter binding energy (16MeV) P_B will be used as an adjustable parameter to fit the experimental data , P_B has to be dependent on the impact parameter b. This approach is motivated by the Glauber approximation. For a given P_B(b) one generates a random number ξ_{ijk} between 0 and 1 for every bond B_{ijk} (where the indices correspond to the spatial location of the center of the bond of the lattice) and decide if the bond will be broken or not. If $\xi_{ijk} > P_B \Rightarrow B_{ijk}$ the bond is unbroken, and if $\xi_{ijk} \leq P_B \Rightarrow B_{ijk}$ the bond is broken. By using P_B as an input parameter, Monte Carlo algorithm decided for each bond individually whether it is broken or not. This procedure is followed by a counting algorithm which looks for the cluster and evaluates their sizes (Bauer , 1988). By summing over all the impact parameters and using

	< n_f >			
Charge	4.5 A GeV ^{28}Si + H	4.1 A GeV ^{22}Ne + H	14.6 A GeV ^{28}Si +H	200 A GeV ^{32}S + H
2	130.2 ± 6.7	100.2 ± 4.5	100.0 ± 9.0	78.0 ± 3.0
3	5.5 ± 1.4	4.0 ± 0.9	2.6 ± 1.0	2.8 ± 1.1
4	5.7 ± 1.3	3.2 ± 0.8	4.0 ± 1.4	2.8 ± 1.1
5	4.1 ± 1.2	6.9 ± 1.2	5.3 ± 1.5	2.5 ± 1.0
6	9.6 ± 1.8	12.9 ± 1.6	6.0 ± 1.5	3.5 ± 1.1
7	7.2 ± 1.6	11.1 ± 1.5	7.2 ± 1.7	4.6 ± 1.3
8	8.6 ± 1.7	15.4 ± 1.7	6.0 ± 1.5	5.3 ± 1.4
9	9.6 ± 1.8	10.7 ± 1.5	7.2 ± 1.7	7.8 ± 1.7
10	10.3 ± 1.9	12.5 ± 1.6	6.0 ± 1.5	5.3 ± 1.4
11	5.2 ± 1.3	-- --	7.2 ± 1.7	6.4 ± 1.6
12	8.9 ± 1.7	-- --	14.7 ± 2.5	5.8 ± 1.4
13	6.5 ± 1.5	-- --	9.8 ± 2.0	7.1 ± 1.6
14	3.8 ± 1.1	-- --	7.5 ± 1.7	14.5 ± 2.4
15	-- --	-- --	-- --	12.4 ± 2.2

a large number of Monte Carlo events, one is thus able to generate many inclusive mass yield distributions that can be compared with the experimental data

4 Results and Discussion :

Figure (1) displays the dependence of the multiplicity distribution on the breaking probability P_B for the reactions p+^{22}Ne at 4.1A GeV/c and p+^{28}Si at 4.5A GeV/c. The multiplicity distributions are calculated at different breaking probabilities at 0.35 (Fig. 1a), 0.55 (Fig. 1b) , 0.74 (Fig. 1c) and 0.85 (Fig. 1d) , one thousand runs are performed for each values of P_B. All projectile fragments with $Z \geq 3$ and most of the fragments with Z=1and Z=2 are emitted within the fragmentation cone defined by the critical angle Θ_c= 44 mrad at 4.5 A GeV/c. The event statistics for the two samples of ^{22}Ne and ^{28}Si are 2000 and 1000 , respectively.The projectile disintegration interactions are defined as those events where only projectile fragment with charge $Z \leq 2$ remains. In the Table the average multiplicities of fragments ,$<n_f>$, with charge Z is given for the quasi-nucleon events (n_h=0,1). Figure (2) shows the charge distribution of $Z \geq 2$ fragments. The solid squares represent the experimental data for the fragments of ^{22}Ne and ^{28}Si from their interactions with quasi-nucleons. The resulting distribution has a U shape which indicates to a mixture of the spallation and fission mechanisms. The curves are calculated at bond breaking percolation parametr P_B =0.55 for ^{22}Ne and ^{28}Si. The number of Monte Carlo events is one thousand for each projectile. Figure (3) shows the multiplicity distribution of $Z \geq 2$ fragments. The squares represent the experimental data of the multiplicity distribution of the fragments from ^{22}Ne and ^{28}Si interactions with quasi-nucleons. The curve is calculated according to the bond percolation model at P_B=0.55 for ^{22}Ne and P_B=0.60 for ^{28}Si . It is seen that the model calculations are in fair agreement with the experimental data for ^{22}Ne . A less agreement is shown for ^{28}Si data . The ^{4}He multiplicity distribution is presented in figure 4 (5 or 7 He fragments can of course only be found in ^{22}Ne and ^{28}Si break up).

5 Conclusion:

Percolation model implying the bond percolation mechanism has successfully reproduced the mass yield distribution for the fragments emitted from p+^{22}Ne and p+^{28}Se reaction. The charge and multiplicity of projectile fragments have been measured. The best fit was obtained, assuming cubic lattice with P_B=0.55 for the case of ^{22}Ne and P_B=0.6.

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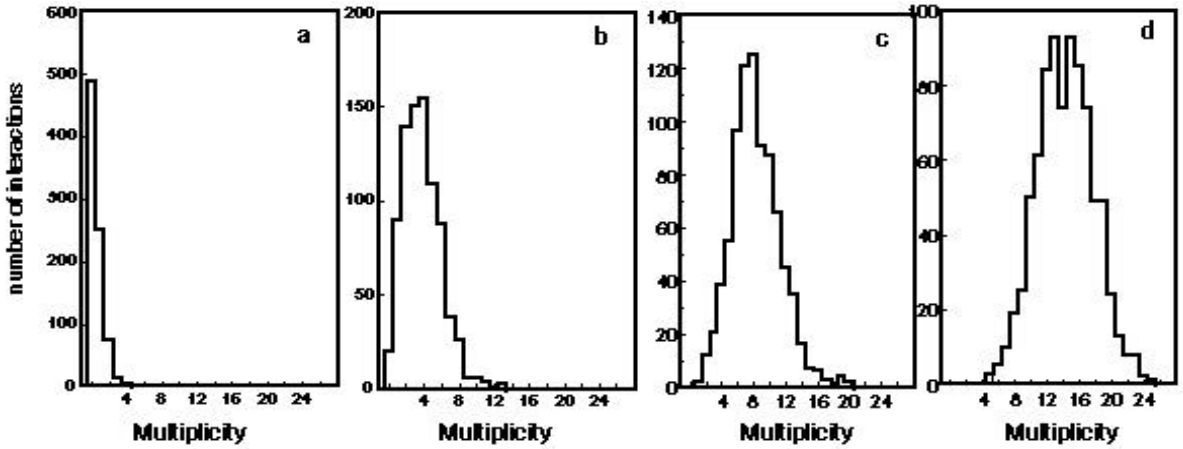

Figure 1:Multiplicity distribution for the reaction p**si interaction at different percolation parameters

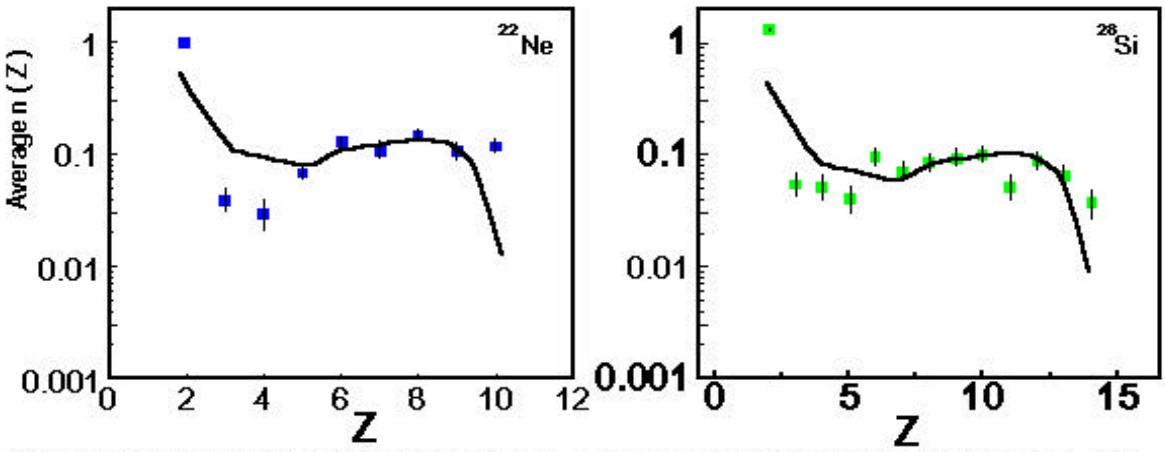

Figure 2: Charge distribution of the fragment of a quasi-nucleon type, the curv are calculated at PB =0.55

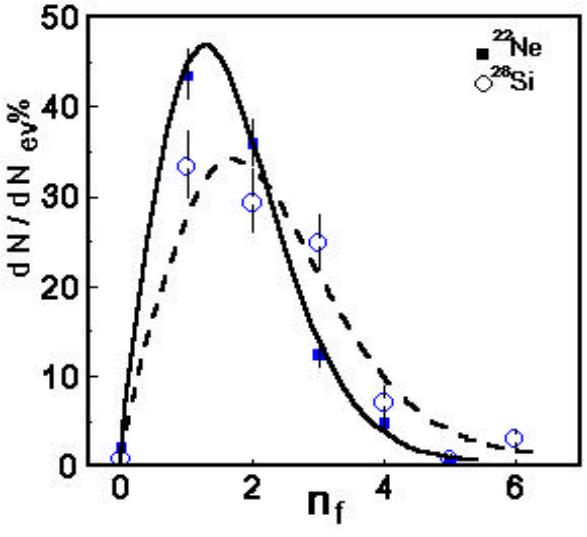

Figure 3: Multiplicity distribution of the fragment with charge >1 in interaction of quasi-nucleon type The curves are calculated by the percolation model

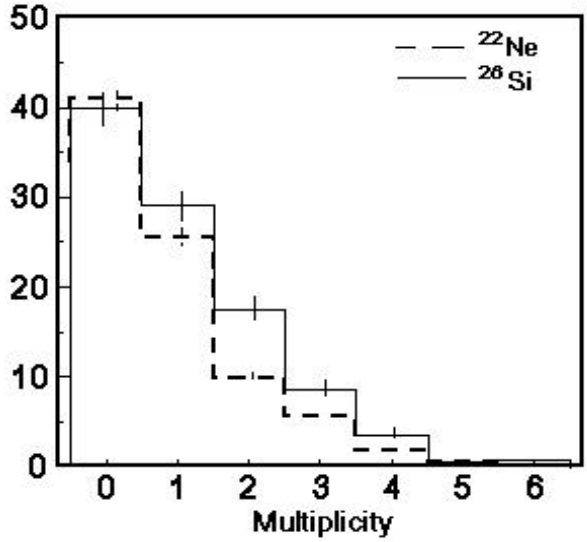

Figure 4: Multiplicity distribution of He fragment