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THEORETICAL ASPECTS OF THE ANTIPROTON-NUCLEUS ANNIHILATIONS

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(presented by J. Cugnon)

ABSTRACT : The following two aspects are briefly examined : (1) the occurrence of $\bar{p}$ annihilation by two nucleons is made plausible and shown to enhance strangeness production ; (2) current ideas concerning the break-up of the residual nucleus are presented ; they involve the concepts of phase transition and percolation.

1. INTRODUCTION

Annihilations of slow $\bar{p}$'s on nuclei raise questions which make them an interesting field of study for hadronic and nuclear interactions. The recent experimental results[1-3] seem, at the present level of analysis, consistent with the simplest scenario : the incident $\bar{p}$ annihilates on a single nucleon, creating a few pions which induce a cascade of two-body collisions inside the nucleus, ejecting some fast nucleons and leaving the residual nucleus in an excited state. We shall mention here two refinements of this picture. The first point concerns the possible occurence of $\bar{p}$ annihilation with two nucleons, originally advocated by Kahana[4]. The second deals with the breaking of the residual nucleus, a topic currently discussed in other contexts of nuclear physics[5].

2. ANNIHILATION WITH TWO NUCLEONS

A close look suggests that this process is quite likely to occur. Indeed the collision of the incident $\bar{p}$ with one nucleon creates a $(\bar{N}N, b=0)$ fireball which, in vacuum, is doomed to annihilate rapidly but has nevertheless a finite lifetime τ . It thus travels for some distance before decaying and can interact in the meantime with another nucleon to form a $(\bar{N}NN, b=1)$ fireball. A rough estimate of the frequency of this process can be made by using rate equations, assuming longitudinal motions. The $\bar{p}$, $(\bar{N}N)$ and $(\bar{N}NN)$ abundances are given by

$$\frac{dN_{\bar{p}}}{dz} = -\frac{N_{\bar{p}}}{\lambda_a}, \quad \frac{dN_0}{dz} = \frac{N_{\bar{p}}}{\lambda_a} - N_0\left(\frac{1}{\lambda_{aa}} + \frac{1}{\lambda_d}\right), \quad \frac{dN_1}{dz} = \frac{N_0}{\lambda_{aa}} \qquad (1)$$

where λ_a is the $\bar{p}$ absorption length, λ_d the decay length of the $(\bar{N}N)$ fireball and λ_{aa} the reaction length for $(\bar{N}N)+N \rightarrow (\bar{N}NN)$. System (1) is integrated with suitable initial conditions and gives the fraction R of $(b > 0)$ annihilations. Results can be found in reference 6, where it is shown that R is of the order of 10 to 20 % in heavy nuclei.

The decay properties of a $(\bar{N}NN)$ fireball can be explored by a phase space model. For a given total energy, the branching ratios depend upon a single parameter (roughly, the volume per initial baryon of the fireball), which, in reference 6 has been fixed by fitting the average pion multiplicity from $\bar{p}p$. The remarkable (but not really surprising) prediction of the model is the strong enhancement of strangeness yield for $b=1$ compared to the usual $(b=0)$ annihilation : the energy

cost for the production of a ΛK pair is lower than for a $K\bar{K}$ pair.

Table I gives a summary of the predictions of strangeness production by different models. It is seen that the strangeness yield may not be a clean signature for the formation of quark-gluon plasma, if the latter is not saturated in strangeness, as advocated in reference 7.

	% pionic	$\langle n_\pi \rangle$	% $K\bar{K}$	% YK	% K^+	$\langle K^+\rangle/\langle\pi\rangle \times 10^3$	S/A
$\bar{p}p$, experiment	95	4.8	5	-	2.5	5	
$\bar{p}p$, microcan.[6]	95.1	4.8	4.9	-	2.45	5	
$\bar{N}NN$, microcan.[6]	87.0	4.3	2.9	10.1	6.45	15	0.13
$\bar{N}(3N)$, microcan.[6]	89.5	4.0	2.1	8.0	5.05	13	
$\bar{N}NN$, canon.[8] T = 160 MeV							~ 0.2
Quark-gluon plasma, T = 200 MeV[9]						250 25,if F=0.1	0.4

Table I : Strangeness yield in various channels, as predicted by different models. In the last column, A is the total baryon number. On the last line, F is the strangeness saturation degree of the plasma, in the $\bar{p}p$ system, according to reference 7.

3. NUCLEAR FRAGMENTATION

The pions from annihilation are expected to transfer to the nucleons an average energy of a few hundred MeV[10,11]. This is sufficient to break the target into pieces. The precise mechanism has not been elucidated yet and is under intensive study in other nuclear systems. Annihilation creates an interesting situation where an appreciable amount of energy is deposited without compressing the nucleus[10]. Two limiting scenarios have been advanced.

3.1. Liquid-gas phase transition

If the deposited energy is uniformly spread over the whole nucleus, thermodynamical concepts are useful. The equation of state for nuclear matter is sketched in fig. 1, which shows isotherms typical of a van der Waals fluid ; nuclear matter has this behaviour because the internucleon force is attractive at long distance and strongly repulsive at short distance. A nucleus like ^{208}Pb receiving 600 MeV from the pions is excited to a temperature of ~ 5 MeV, below the critical temperature, and keeps roughly its original density. This results in building up pressure in the system, which starts to expand. It will reach the coexistence region and eventually end in the gaseous phase. The signature of such a

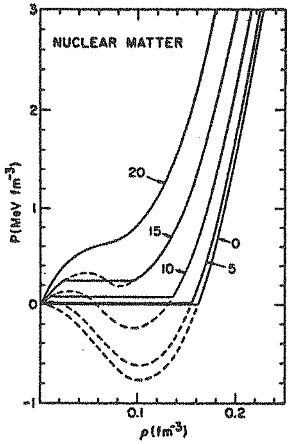

Fig. 1 : Typical isotherms with the Maxwell construction (equal chemical potential) for symmetric nuclear matter (ref. 15). The region enclosing the dotted lines is the coexistence region. The numbers give the temperature in MeV.

transition is believed to be contained in the mass yield which, according to Fisher$^{12)}$, shows a typical power law :

$$p(A) \propto A^{-\tau} \qquad (2)$$

where the critical exponent τ is between 2 and 3, when the temperature is close to the critical temperature.

3.2. Nuclear percolation

In the other extreme picture, the pions eject a number of nucleons by hard collisions and the spatial structure of the damage inflicted to the nucleons, i.e. the voids left over by the hit nucleons, is assumed to be crucial for the breaking of the nucleus. Many models are based on this idea but the relation has been made only recently to percolation models. In reference 13 it is assumed that a fraction (1-p) of the nucleons are ejected in the hard process. The arrangement in fragments is determined by a criterion of close proximity for neighbours in the Ap remaining nucleons. Furthermore, in order to avoid unrealistic nuclear shapes, like a spaghetto, these are split up into more compact shapes by a given prescription. This simple nuclear percolation model turns out to be close to a 2-dimensional lattice percolation model (see fig. 2). In particular, no large cluster exists below the percolation threshold $p_c = 0.6$. In the usual terminology : for $p > p_c$, a few small clusters break loose from a large one, a process akin to <u>evaporation</u> ; for $p < p_c$, the system breaks up into many pieces, of small or intermediate size : a situation often referred to as <u>multifragmentation</u>. A remarkable, but somewhat disturbing, property of this nuclear percolation model is the prediction of a mass yield of type (2), but now for p close to the percolation threshold. Therefore, it seems that the mass yield is not the indicator for a particular phase transition but points only to the existence in general of a phase transition, associated to large fluctuations. Other experimental informations like the multiplicity distribution or fragment-fragment correlations may be more helpful in this respect.

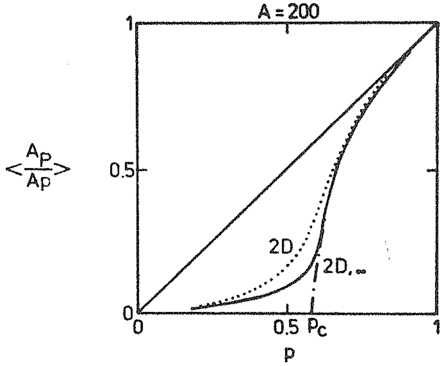

Fig. 2 : Ratio of the largest cluster size to the remaining system size Ap after ejection of A(1-p) nucleons for different percolation models : full line, reference 13, dotted line, 2D lattice percolation model for A=200, dot and dashed line, the same for an infinite lattice.

The intranuclear cascade (INC) calculations$^{10,14)}$ favour the second limiting picture for the interaction between the pion and the nucleon systems. The pions eject almost at random a few energetic nucleons. Figs. 3 et 4 show the results of an INC calculation for the distribution of the number M_ν of last particles (including pions). The number M_ν is tentatively transformed in terms of the parameter p on the bottom scale. It turns

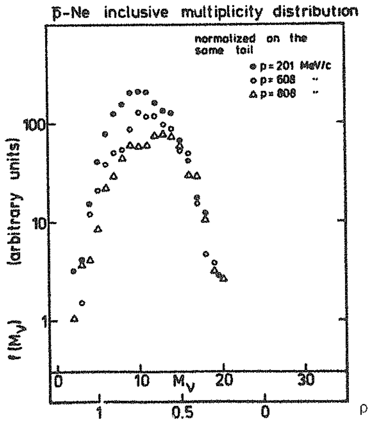

Fig. 3 : Calculated multiplicity M_ν distribution$^{14)}$, M_ν is the number of final pions added to the numbers of struck nucleons.

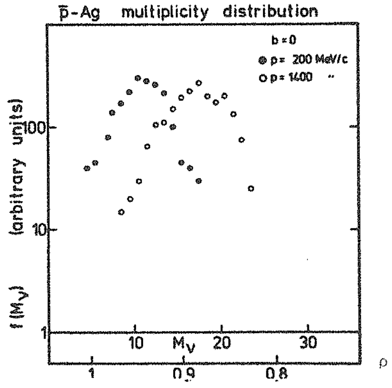

Fig. 4 : Same as fig. 3 for Ag target.

out that medium heavy targets provide the opportunity of studying the percolation transition $p \approx p_c$.

4. CONCLUSION

We have pointed out the possibility of a primary stage consisting of $\bar{p}$ annihilation on two nucleons, leading in particular to enhanced strangeness production, even in the hadron phase.

We also have shown that the study of the outcome of the annihilation can very much help in understanding the nuclear fragmentation resulting from the deposition of energy by the primary products of annihilation. Measurements of mass yield and multiplicity distribution are waited for. In the percolation picture,varying target mass and $\bar{p}$ energy allows to cover the different percolation regimes.

1. N. Di Giacomo, this workshop.
2. W. Kanert, this workshop.
3. N. Piragino, this workshop.
4. S. Kahana, Proceedings of the Workshop on Physics at LEAR, Erice 1982 (U. Gastaldi & R. Klapisch, eds., Plenum 1984), p. 485.
5. For a review, see J. Hüfner, MPI Preprint 1984-V34.
6. J. Cugnon & J. Vandermeulen, Phys.Lett. 146B(1984)16.
7. S.C. Phatak & N. Sarma, Bhabha Institute preprint 1984.
8. C. Derreth, W. Greiner, H-Th. Elze & J. Rafelski, preprint UCT-TP9/84.
9. J. Rafelski, Phys.Rep. 88(1982)331.
10. M. Cahay, J. Cugnon & J. Vandermeulen, Nucl.Phys. A393(1983)237.
11. M. Clover, R. De Vries, N. Di Giacomo & Y. Yariv, Phys.Rev. C26 (1982)2128.
12. M.E. Fisher, Physics 3(1967)225.
13. X. Campi & J. Desbois, preprint Orsay 1985-5.
14. J. Cugnon & J. Vandermeulen,to be published.
15. B. Friedman & V.R. Pandharipande, Nucl.Phys. A361(1981)502.