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ANTIPROTON ANNIHILATION ON NUCLEI

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ABSTRACT

A dynamical model is described for the $\bar{p}$ annihilation on nuclei. The energy transfer from the multipion system to the baryonic system is studied, as well as the response of the latter. Annihilation on two nucleons are studied and evidence for these events is searched for in experimental data.

INTRODUCTION

The bulk of the experimental results on $\bar{p}$-annihilation on nuclei obtained so far, especially at LEAR, is consistent[1,2,3] with the following dynamical picture :

(1) the $\bar{p}$ annihilates on a single nucleon at the surface of the nucleus, creating a few pions, with the same properties as those observed in the free space $\bar{p}p$ or $\bar{p}n$ annihilations ;

(2) some of the pions cascade through the nucleus, interacting with the nucleons, ejecting some of them, in a process by which they can also be absorbed ;

(3) after a fast ejection process, the nucleus possibly dissipates its remaining excitation energy in much slower processes, like evaporation and/or fission.

Several questions are however still open. What is the amount of energy transferred to the nucleus ? How is this energy transformed ? Is the annihilation process (point (1)) so simple ? We examine some of them below.

TRANSFER OF ENERGY. NUCLEUS RESPONSE

The 2 GeV or so carried by the primordial pions (those issued from the annihilation) is not entirely used to excite the nuclear system. Some of the pions can escape from the nucleus right away, because of the peripheral nature of annihilation. Furthermore, only a fraction of the pions are eventually absorbed. These effects reduce fairly well the energy transfer to the baryonic system (the nucleus) from the available 2 GeV. For annihilation at rest, the energy pumped from the pion system lies around 500 MeV for annihilation at rest and 800 MeV for annihilation in flight in the LEAR regime. The amount of energy transferred to the baryonic system is given in Fig. 1, as a function of time, for typical systems. Roughly speaking, the energy acquired to the nucleus is dissipated on two time scales. First, energy is removed by the ejection of rapid nucleons. Afterwards, energy is dissipated on a moderate time scale, in a way which is very close to ordinary evaporation (see Fig. 2). For a system like Mo, the amount of energy after the fast

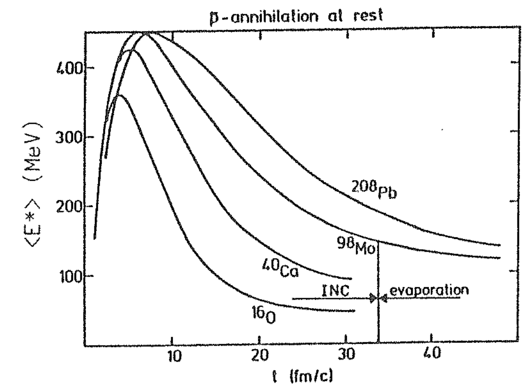

Fig. 1. Time evolution of the target excitation energy after $\bar{p}$-annihilation at rest.

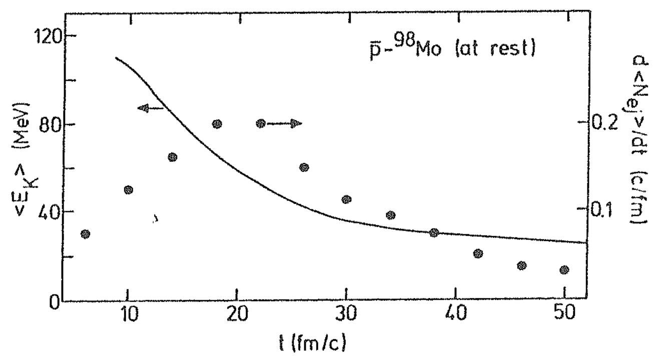

Fig. 2. Time evolution of the mean kinetic energy of the ejected nucleons (full curve, left scale) and of the number of ejected nucleons (dots, right scale) after $\bar{p}$-annihilation at rest on ^{98}Mo.

emission process reaches about 150 MeV (up to about 250 MeV in annihilation in flight), i.e. about 1.5 MeV per baryon. According to current ideas, this energy is removed by evaporation of, mainly, neutrons. A rather elaborate calculation based on the intranuclear cascade for the first step and on evaporation models for the second one reproduces rather nicely the observed residual mass spectrum[3,4] for several nuclei. On the average, a nucleus like ^{98}Mo looses about 15 nucleons, but fluctuations are large and it can loose up to 30 nucleons.

A strongly debated question is to know whether a nucleus can fragment in many pieces of intermediate size (the so-called multifragmentation). Related questions are : what is the minimal excitation energy per baryon E_c^* for the onset of this process ? Is the transition from evaporation to multifragmentation rapid ? What is the effect of "pre-equilibrium" emission ? Those problems are studied with heavy ion beams and are starting to receive partial answers. For instance, it seems that $E_c^* \approx 3$ MeV per particle. Antiproton beams present several advantages : (i) it is a way to deposit energy without large momentum ; (ii) the dynamics is better understood ; (iii) there is no strong impact parameter dependence. Of course, beams of larger energy than at LEAR will be required. The best energy range corresponds to 1-5 GeV incident energy.

UNUSUAL ANNIHILATIONS

A possible deviation from the scenario sketched in section 1 is that the annihilation is not a point-like event in space-time. In other words, one may consider that the annihilating system lasts for some time and has particular properties before the appearance of "asymptotic" pions. On these simple grounds one may wonder whether the annihilation involves two nucleons, both of which participating to the annihilating system. This idea has been exploited in Ref. [5]. Therein, it is assumed that the decay properties of ($\bar{N}NN$), as well as of $\bar{N}N$ are governed by phase space. The approach is a one parameter free model (roughly, the volume of the annihilating system). The parameter is fixed on the $\bar{N}N$ properties, which are well reproduced. The model is then used to make predictions on the $\bar{N}NN$ system. The most striking one is the enhancement of the strange particle yield.

The existence of annihilation on two nucleons is directly demonstrated by the observation of the $\bar{p}d \to p\pi^-$ process[6]. These ideas have also been used to try to extract from experimental data, the probability of having an annihilation on two nucleons. In all generality, one can write the yield per annihilation for the production of a strange species S as :

$$Y(S) = P_1 Q(1,S) + P_2 Q(2,S) + P_3 Q(3,S) + \dots \qquad (1)$$

where P_1, P_2, P_3 are the probability of having an annihilation on one, two,... nucleons, respectively and where $Q(i,S)$ is the probability of producing the species S after an annihilation on i nucleons. The knowledge of these quantities is rather fragmentary, since they deal with complicated rescattering process following annihilation. What has been done up to now is to compare the observed yield with $Q(1,S)$, which is usually known with good confidence, in some cases at least. We just list a few results in Table I. As can be seen the annihilation on one nucleon cannot explain the experimental yields. The comparison clearly points out the necessity to call for two nucleon annihilations. The case of K_0^S in the last reaction is nevertheless very puzzling since there the production yield seems to be inhibited. This case certainly desserves further investigation. This is also true for the measurements of Ref. [7]. They refer to 4 GeV/c antiproton reactions, for which the evolution of the strange particle abundances is more complicated than in the LEAR regime.

Table I. Comparison of observed strange particle yields and quantity Q(1,S)

Systems	Observable	Experimental yield	Q(1,S)
$\bar{p}$ + C (ref. 8)	K^+/π^-	0.030	0.015
$\bar{p}$+C,Ta,Pb (ref. 9)	Λ	$(1.9\pm0.4)\times10^{-2}$	< 0.01
$\bar{p}$+Bi	hypernucleus (fission)	3×10^{-4}	$\}\lesssim 10^{-4}$
U (ref. 10)	hypernucleus (fission)	9×10^{-4}	
$\bar{p}$ + ^{20}Ne (ref. 11)	Λ	$(1.95\pm0.43)\times10^{-2}$	$< 10^{-2}$
	K_0^S	$(0.85\pm0.17)\times10^{-2}$	$\{< 2.5\times10^{-2}$, $> 1.2\times10^{-2}$

CONCLUSION

We have underlined the interest of $\bar{p}$-annihilation in nuclei, in two respects : (i) it is a useful way to study the multifragmentation of the nucleus ; (ii) it is the seat for unusual annihilations. We have here shown a simple example, but one may imagine more complex processes. More generally, $\bar{p}$-annihilation in nuclei is a tool to study hadronic systems in special environments.

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