REMARKS ON SOME ANALOGY OF THE NUCLEAR AND NUCLEON FRAGMENTATION PROCESSES

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The results of several recent experiments suggest the existence of composite structure of the nucleon. Consequently some analogies in the properties of nucleons and nuclei are arising. For example, the diffraction pattern of elastic proton-proton collision, emerging at high energies, is similar to that of the proton-nucleus collision.

It is the aim of this note to draw attention to the analogy of behaviour of nuclei and nucleons in a different class of phenomena related to strongly inelastic collisions, namely in the "fragmentation" of a nucleon and that of a nucleus. The usefulness of adopting the concepts of elementary particle physics, namely the concepts of "factorization" and "limiting fragmentation", for classification of frequencies of emission of different nuclear fragments in a nucleus-nucleus collision has already been suggested by Heckmann *et al.* [2].

When presenting the analogy, the nuclear fragmentation will be described in a more detailed way than the fragmentation of the nucleon as the majority of high energy physicists is less familiar with the former field and it seems that this complicated process may be described at present in a simpler way than it has been usually done.

A strongly inelastic collision of two nucleons at high energy leads to the copious emission of secondary particles. Leaving open the problem of a satisfactory description of the central region of particle production, one can call the process the "fragmentation" of the nucleons [3].

A strongly inelastic collision of two heavy nuclei at relatively high energy (above 1 GeV) leads to the fragmentation of the nuclei *i.e.* to the copious emission of different nuclear fragments (hydrogen, helium, lithium *etc.*). None of the existing experiments is dealing with the fragments emitted both from the projectile and the target nucleus. The most rich source of information now available is the series of the Berkeley experiments [4] concerning

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the fragmentation of uranium and silver nuclei interacting with high energy protons.

In a highly inelastic collision of the proton with a heavy nucleus a considerable energy, comparable with the total binding energy of the nucleus, is imparted to the target nucleus.

There is a noteworthy success in the approximate description of many properties of the particle production process at high energy by the thermodynamical model of Hagedorn [5]. According to the model, particles are emerging from centers of hadronic matter, the characteristic temperature of the process being about $T = 150$ MeV, corresponding to the pion mass.

It is a remarkable feature of the energy spectra [6] of fragments emitted from the heavy nucleus that the overwhelming majority of them obeys the statistical Weisskopf shape of the spectrum [7]:

$$p(E)dE \cong \frac{E}{T^2} \exp\left(-\frac{E}{T}\right) dE.$$

If the energy of the incident particle is high enough and the energy imparted to the nucleus is near to the total binding energy of the nucleus, the temperature is approaching the universal value equal about $T \cong 15$ MeV for all heavy ($Z \geqslant 3$) fragments [4].

Looking for physical meaning of this characteristic value of temperature one can note that at lower energies the relation of temperature and excitation energy has the form

$$U = kAT^2,$$

where A is the mass number and k is a constant

$$k = 0.05 \div 0.1.$$

This relation suggests that the temperature $T \cong 15$ MeV may correspond to the maximal energy transfer. It seems appropriate to call the process at this energy transfer the "ebullition" of the nucleus. In favour of this conjecture one may add that the fragmentation of the heavy nucleus, if observed in nuclear emulsion, is strongly correlated with "large" stars, corresponding to a copious emission of "evaporated" particles. Moreover the energy spectrum of the fragments is shifted towards lower energies denoting a drastic lowering of the Coulomb barrier. This again suggests that the fragments are emitted in the "ebullition" of the nucleus, rapidly expanding and dissolving into many constituents [8].

The thermodynamical model is successful in describing the relative frequencies of different species of particles. The emission of heavier particles is favoured at higher energies [5].

The evaporation model describes well the relative frequencies of different nuclear fragments. The emission of heavier fragments is favoured at higher energies. The model is however valid only for low excitation energies and is to be elaborated for the case of the "ebullition" of nucleus. It seems that the following approximate formula may be valid for the probability of emission of the fragments:

$$p(m) = a \exp(-bm),$$

where a and b are constants and m denotes the mass of the most frequent isotope.

The existing models of the particle production in nucleon-nucleon collisions encounter difficulties in attempts to describe correctly the longitudinal momentum spectra of the secondary particles. In order to simplify the description, the existence of moving hadronic centers decaying isotropically in their rest frames has been often assumed.

The nuclear fragments are emitted with some preference of the forward direction in the laboratory. In order to reconcile this feature of the fragmentation with the thermodynamical model, it has been often assumed that the evaporation takes place from the excited nucleus moving with the velocity β of the order of 0.01 [4]. (It is not clear to what extent this notion corresponds to reality and to what extent it reflects merely the very old tradition of considering the sphere as the ideal, only acceptable shape.)

In both cases, in the nucleonic and the nuclear fragmentations, there exists some anomaly:

The overwhelming majority of emitted particles obeys the exponential law(s) of the (squared) transverse momentum distri-

The overwhelming majority of nuclear fragments obeys the exponential law(s) of the energy spectrum (with some uncerbution (with some uncertainty at the very low values), however recent experiments at the ISR at CERN show that there exists some anomalous component of the spectrum in the region of very high transverse momenta [11].

tainty at the very low values), there exists however some fraction (of the order of one percent) of strongly forward emitted particles with a different slope of the energy spectrum [9]. It is a remarkable physical phenomenon that sometimes very heavy (*e.g.* carbon or oxygen) stable nuclear fragments are emitted with the kinetic energy of the order of hundred MeV. The value of the energy characterizing the transition from the first kind of fragments (hereafter denoted as normal fragments) to the anomalous ones may be placed — with some uncertainty — at about 8 MeV per nucleon. (Trying to assert a physical meaning to this value one notes that it is equal to the separation energy of a nucleon.)

The existence of particles with anomalously big transverse momenta does not fit into the scheme of the conventional thermodynamical model (unless one assumes some "local heating" of the hadronic center to a higher temperature [5]).

It is difficult to explain the existence of the anomalous fragments from the point of view of the thermodynamical model (unless one assumes that there is some "local heating" of the nucleus to a higher temperature) [4].

The regions of anomalous fragmentations of nucleons and nuclei are at present very little known because of technical difficulty of the experiments studying the correlations of particles. One can perhaps only mention that:

Anomalous particles emitted in the proton-proton collisions are characterized by an excess of the positive charge [11].

Anomalous fragments emitted in the proton-nucleus collision exhibit an excess on the neutron-defficient side [4].

In both cases this may be a reflection of the excess of positive charge in the initial state. One can check this possibility experimentally by changing the sign of charge of one of the two colliding particles.

The above indicated analogies concern the confrontation of two "layers of reality" — the nucleonic one and the nuclear one. It is perhaps interesting to speculate about a possible link between the two "layers".

The production of particles in the nucleon-nucleus collision seems — at first sight — to be a very complicated nuclear process. However some concepts of the cosmic ray physicists using the notion of the excited hadronic center [10] may be helpful in recognizing that perhaps instead of the apparently complicated cascade a simpler state evolves in the nucleus with properties not essentially different from those in the nucleon-nucleon case — at least if one restricts attention to the part of the process which corresponds to the forward cone of the emitted mesons.

In contrast to the slow nuclear fragments emitted statistically (the nucleus being their source and their Galton board), the anomalous fragments, ejected strongly forwards with a big energy, seem to originate in some more direct interaction process.

Therefore it may exist some close correlation of the emission of anomalous nuclear fragments and the multiple meson production in nuclei.

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