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THE MECHANISM OF TOTAL DISINTEGRATION OF HEAVY NUCLEI BY FAST HADRONS AND NUCLEI

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1. INTRODUCTION

The subject matter in this paper are studies of the mechanisms and characteristics of total disintegration of heavy nuclei caused by the impact of fast hadrons and nuclei. The intrinsic interest in understanding the processes involved, and importance of the expected results have a bearing on the interpretation of many phenomena met in particle physics, in new generation of nuclear energetics, and in ecology. The phenomena which may be revealed in investigating the disintegration mechanism are important for working out the methods of an application of a single massive target nucleus as subnuclear detector in high energy physics, as well.

It is desirable to discover a manifestation of some laws which may govern inside target nuclei within the extremely small volumes (10^{-15} m) acting during time intervals of the order of 10^{-24}—10^{-22} s.

2. THE DISINTEGRATION OF ATOMIC NUCLEI BY FAST HADRONS AND NUCLEI

The disintegration of complex nuclei, produced by the impact of fast hadrons and nuclei — of fast protons and other particles, e.g., was studied widely during many years [1—3]. The mechanism of this process is revealed experimentally [3—6]. The disintegration started in the collision appears as a complicated nuclear process developing in time and space in intranuclear matter consisting at least of three stages which last together about 10^{-24}—10^{-16} s after the impact. At the first stage, which lasts about 10^{-24}—10^{-22} s, the target-nucleus is locally damaged and fast nucleons with kinetic energies ≈ (20—500) MeV are densely emitted. At the second stage, lasting about 10^{-22}—10^{-16} s, the damaged and unstable residual target nucleus uses to evaporate light fragments — mainly nucleons, deuterons, tritons, α-particles. At the final stage — at about 10^{-17} s and probably more, when nucleons were emitted and light fragments were evaporated — the finally damaged target nucleus uses to decay into heavier nuclear fragments, some of them may be stable or they will decay into smaller parts.

In the light of the above presented mechanism of the disintegration process, the two stages should be clearly distinguished — the first one, as the «fast stage», lasting about 10^{-24}—10^{-22} s and the second or the «slow stage», including in fact the nuclear reaction in the damaged target nucleus — as the intranuclear process starting when the incoming hadronic or nuclear projectile and its successors are having left the damaged target nucleus — at about 10^{-22} s after the impact and lasting during about 10^{-22} up to 10^{-16} or more seconds.

Exactly, the destruction of the target nucleus by an energetic projectile lasts within the first stage only — during about 10^{-24}—10^{-22} s. In this nuclear reaction [4] initiated by hadronic or nuclear projectile, the struck nucleus is damaged locally — the cylindrical volume inside the target nucleus with the radius R_s around the projectile course is involved in the collision; $R_s \approx D_0$ is the strong interaction range which is approximately as large as the nucleon diameter D_0 is. After this time interval the projectile and/or its successors are passing through the target nucleus and all the nucleons involved in the collision (contained within the local volume) are emitted — as the so-called fast nucleons with energies of about 20 up to about 500 MeV [7,8].

2.1. *Physical Basis for the Experimentally Revealed Disintegration Mechanism*

The physical phenomena, revealed experimentally in our early works are basical for understanding the observed picture and characteristics of the disintegration of nuclei produced by the impact of the fast hadrons (protons and pions, e.g.) and nuclei. These phenomena are: 1) The observed passage of hadrons through layers of intranuclear matter — discovered in our experiments [8], studied in detail and described in our earlier works [9—14]; 2) The observed hadron generation in hadron-nucleon collisions goes through some intermediate objects which decay after no less than about 10^{-22} s; it is the case when the particle generation is in hadron-nucleus collisions, as well [15—17]; 3) The outcome from a collision of two massive nuclei is a composition of some number of statistically independent outcomes in nucleon-nucleus collisions at the same energy of the incident nucleon with the target nucleus, at all the possible impact parameters [1,18].

Let us sum up shortly our knowledge about the three above-mentioned phenomena.

The Hadron Passage through Layers of Intranuclear Matter. Very simple relation has been revealed experimentally [9—14]. The number n_N, or intensity n_N, of the nucleons emitted from a target nucleus, when a fast hadron collided with it, depends simply on the thickness λ of the intranuclear matter layer involved in the collision.

Quantitative relation is:

$$n_N = \lambda S \,(1 - e^{-(\lambda/\lambda_t)}), \qquad (1)$$

where λ in nucleons/S, $S = \pi D_0^2 \approx 10$ fm^2, $D_0 \approx R_S$ is the strong interaction range, D_0 is the diameter of the nucleon, $\lambda_t = 1/\sigma_t$ is the hadron mean free path in intranuclear matter in nucleons/S, σ_t is the hadron-nucleon total cross-section in S/nucleon. This formula is valid for the sample of the pure incident hadron passages through the target nucleus — when secondary mesons, which could be produced, do not appear; it is valid for the events with hadron production as well — as further investigations showed [15,20].

Formula (1) was tested experimentally to be valid for momenta of hadronic probes larger than about 2 GeV. The hadron passage through intranuclear matter is a nuclear analogue of the electromagnetic process — of the passage of electrically charged particle through layers of usual (atomic) matter. This phenomenon has been revealed in our experiments and studied in detail qualitatively and quantitatively as well [10,12,13].

In analysing this phenomenon, two methodical facts were of great importance: a) It is possible to estimate λ in [nucleons/S] [21] of any of nuclei practically at any distance from its center using data on the proton (and nucleons at all) distributions in them determined by R.Hofstadter [7,22,23]; in particular, the maximum thickness of any of the target nuclei may be determined well enough using the Hofstadter data; b) It is possible in the bubble chamber to determine the fast proton (nucleon) (20—500 MeV) intensity or multiplicity distribution in any sample of hadron-nucleus collisions. The high, nearly to 100 %, registration efficiency of neutral pions in the chamber allows one to select the events without secondary pions — additionally.

In confronting the data on the thicknesses of the intranuclear matter layers at any distance from the nuclei center of a nucleus with corresponding intensities of the emitted fast nucleons in a collision, one is in a position to conclude about the emission of the fast nucleons which the hadron passage through intranuclear matter is accompanied by. It is mostly obvious for the maximum and avarage thicknesses of the target nuclei.

The conclusions about the intensity of the nucleon emission described by formula (1), and about the localized region of the hadron-nucleus collisions are obtained this way, in particular.

The Particle Generation through Intermediate Objects or «Generons». The only tool available up to now to realize experiments in which the mechanism of the particle producing process would be revealed is to apply single massive target nucleus as a fine detector [15,16,24,25,26]. The particle producing process has been studied by means of the $^{131}Xe_{54}$ intranuclear detector, using the sample of events in which particles (hadrons) were produced and the sample in which the hadrons were not produced.

From such experimental investigations, we were in the position to conclude that:

1. *In hadron-nucleus interactions, hadrons are produced via some intermediate objects (we called them GENERONS) which decay after having left the parent nucleus (after more than about 10^{-22} s);*

2. *Indications were obtained that particle production in elementary hadron-nucleon collisions, in nucleon-nucleon collisions in particular, goes through such objects as well. The objects decay into commonly observed resonances and particles after liftime of about 10^{-22} s; in passing through layers of intranuclear matter, generons behave themselves as usual hadrons do it.*

3. *The intermediate objects can produce new objects in collisions with downstream nucleons in intranuclear matter in ones turn, and this way an intranuclear cascade of the intermediate objects may develop inside the parent nucleus. In most cases this cascade is colinear with the incident hadron course.*

The above-described mechanism of the particle production process allows one to derive formulas, for frequency distributions of various quantities describing yields from hadron-nucleus collisions in terms of frequency distributions of corresponding quantities describing yields from elementary hadron-nucleon collisions [16,17.27,28]. These formulas were tested experimentally [28].

The outcome from a collision of two massive nuclei is a composition from some number of statistically independent outcomes in nucleon-nucleus collisions at the same energy of the incident nucleon with the target nucleus, at all the possible impact parameters [1,18], with appropriate statistical weights.

The picture of the nucleus-nucleus collision process and the mechanism of the nucleus-nucleus collision processes were discussed in one of our former works [18]; it has been concluded that:

In head-on collision of two identical massive enough nuclei, at energy high enough — over a few GeV/nucleon in the center of their mass coordinate system, the nucleons in one of the nuclei pass through the second nucleus. The passage is the general phenomenon, but it occurs rarely in its pure form. On the background of it, the particle production occurs often in the nuclei collisions. The production goes through intermediate objects — the GENERONS — created first in $2 \rightarrow 2$ nucleon-nucleon endoergic collision reaction. In the coordinate system accepted here, many generons may become to be at rest, and use to decay into the usually observed «produced» hadrons, after the lifetime of about 10^{-22} s. In such configuration, simple picture appears: Two beams of the collimated monoenergetic nucleons with energies practically as large as the energies of the nucleons in the colliding nuclei, in GeV/nucleon, will escape from the collision region into opposite sides. From the center of the collision region many generated hadrons will be ejected through total 4π solid angle; many of the ejected hadrons will be organized into collimated spurts of hadrons — jets. The fragments of the colliding nuclei may not appear, both nuclei are totally disintegrated into nucleons. It happens due to the laws of fast nucleon emission induced by a hadron in its passage through layers of the intranuclear matter — any of nucleons involved in the interaction with the incident hadron is emitted from the target nucleus.

In the collisions of identical massive nuclei, the head on events can be simply distinguished — as the collisions without fragments of the colliding nuclei.

It is not excluded that collision events without the opposite beams of nucleons appear; the ejection of the generated particles from the center of the collision region will be observed only.

The total disintegration of the target nucleus by hadronic or nuclear projectiles should be treated, in the context of the results above written about, as some special case of the nuclei disintegration process — occuring with predictable probability.

2.2. *The Total Disintegrations of Nuclei by Fast Hadrons and Nuclei*

Let us start this section with the model-independent, experimentally suggested definition of the total disintegration of nuclei by fast hadrons and nuclei. Overview of various disintegration events observed long time ago in photographic emulsions [1] and may be in other track detectors and arrangements prompts such a definition.

The total disintegration of a fast nucleus, colliding with some other similar nucleus resting in the lab.system, is proposed to be defined, as such in which the incident nucleus is completely dispersed into its parent nucleons, and the struck nucleus is also shattered.

Such total disintegration of the incident magnesium nucleus produced in head-on collision with one of bromine nucleus is shown on «Plate 16—14» in the book of Powell, Fowler and Perkins [1], e.g..

The total disintegration of the colliding nuclei may happen only in some nucleus-nucleus head-on collisions; the hadron-nucleus collision does not produce the total disintegration of any of heavy nuclei, light nuclei may be disintegrated totally by a single fast hadron.

Independently of any of the reference systems, the total disintegration (or destruction) of a nucleus in collision with a hadron or a nucleus is proposed to be defined as such in which the nucleus in a hadron-nucleus collision or nuclei in a nucleus-nucleus collision are totally disrupted into the parent nucleons.

3. CONCLUSION AND REMARKS

And so, heavy nuclei may be totally disintegrated in central impact with other nucleus of similar mass number only, light nuclei, formed of a few nucleons, may be totally disintegrated in central impact with a single hadron (pion or nucleon, or other — e.g.). This conclusion is based on observations of appropriate collision events [1] and on the properties of the fundamental phenomenon — the hadron passage through layers of intranuclear matter [8—14]. It is worthwhile to take in mind that any hadron in passing through layers of intranuclear matter interacts locally with the nucleons at the distances no longer than the strong interaction range is and causes the emission of *all the nucleons involved* — as the so-called «fast» nucleons, with kinetic energies from about 20 up to 500 MeV [19]. As the consequences of such a scenario, one observes two collimated beams of nucleons from the colliding nuclei in their mass center systems. In the head-on collision the multiplicity of both of the observed opposite beams of nucleons is equal to corresponding mass numbers of the colliding nuclei. At any collision impact parameters (the distances between centers of the colliding nuclei) the multiplicities of nucleons in the opposite beams are correspondingly smaller. Usually, this pure picture may be covered by the accompaniment of the beams of produced hadrons, as well; this camuflage should be less effective at lower energies (at no more than about a few GeV/nucleon) of the colliding nuclei.

It is reasonable to expect, in the light of the above-mentioned phenomena that the colliding nuclei will interact mostly peripherally, as well — only peripheral groups of nucleons in them will be involved in the collision. The main parts of the nuclei will be not sufficiently disturbed to be disrupted, and these nuclear fragments emerging from the encounter will appear at the fast stage of the collison — lasting about 10^{-24}—10^{-22} s — with the velocity as such as of the incoming nuclei (in their center-of-mass system); the events of the total disintegration will occur consequently with large regularity, with observable frequency, determined by the nuclear sizes and collision impact parameters.

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