ON 'MINI-CLUSTER' OBSERVED BY CHACALTAYA EMULSION CHAMBER EXPERIMENT

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It is mentioned that the phenomena of 'Mini-Cluster' observed by Chacaltaya emulsion chamber experiment support the model of hadronic matter based on the theory of finite degree of freedom.

1. Introduction

The world of elementary particles has been more and more enlarged and diversified and, at the same time, unifying relations in it have gradually been established basing on the quantum field theory. In this case, the quantum field theory itself has been unchanged in its foundation, though basic fields and their interactions have been effectively selected. The quantum field theory gives divergent results showing that the theory is not completely defined. The difficulty is avoided for practical problems by choosing the renormalizable type of theories. Even in the renormalizable case, the theory contains an undefined part left to future theories. The renormalization theory evades the divergence difficulty by replacing arbitrarily the undefined divergent part by an appropriate finite constant and considers only things independent of details of the undefined part. We want to consider, however, the difficulty or inconsistency in the fundamental theory as a moment for deeper recognition of the existence of elementary particles.

The divergence difficulty is due to the infinite degree of freedom of the quantum field given by the set of all possible values of momentum or equivalently of position of the particle associated to the field. The quantum field with a finite degree of freedom is contradictory to the space-time description so that the theory of finite degree of freedom requires the reformation of the concept of space-time based on the non-space-time description [3]. The theory of finite degree of freedom suppresses the high momentum part of the degree of freedom referring to a universal timelike vector[1] and gives consequences for the part left undefined in the renormalization theory [3].

The ultrahigh energy nuclear interactions have long been investigated by the emulsion chamber experiments of Brasil-Japan collaboration and Soviet group. They found various kinds of fireballs as intermediate states of multi-hadron productions [4,5]. It is considered that the approach using phenomenological models is effective for the interpretation of fireball phenomena. In this case, when the models reflect a basic idea, its validity can be tested by experimental facts. The model of hadronic matter [2] of which hadrons are made based on the theory of finite degree of freedom seems to give a picture which explains qualitatively the characteristic properties of hadrons and hitherto found fireballs [9,3].

The hadronic matter is made mainly of a great number of virtual urbaryon pairs (quark pairs) generated by vacuum polarization. Due to the finite degree of freedom of urbaryon, it is an extended matter with a fairly uniform density and a volume generally proportional to its mass apart from individualities. Recently the Brasil-Japan collaboration observed bundles of electromagnetic showers with very small transverse momenta (some 10 MeV) accompanied by decay products of Chiron-type fireballs (Chiron and Geminion)[6]. The bundle of electromagnetic showers is called 'Mini-Cluster'. It is mentioned in this paper that the phenomena of 'Mini-Cluster' support the picture of fireballs made of the hadronic matter based on the theory of finite degree of freedom.

2. A Picture of Hadrons and Fireballs made of the Hadronic Matter

The basic particle (urbaryon) of the hadronic matter is a bare quark q having color and flavor and obeying the theory of finite degree of freedom. 'bare' is to distinguish q from the physical quark Q[8] mentioned below but we call q simply quark in the following. The hadronic matter consists of a certain number of quarks carrying quantum numbers of the system and a large number of virtual quark pairs generated by vacuum polarization. The position degree of freedom of the field of basic particle distributes with a density (1/v) in the hyperplane perpendicular to a universal timelike vector N_μ, that is, the space in the Lorentz system (we call N-system) in which $N_\mu = (1,0,0,0)$. The relative velocity between the N-system and our laboratory system on the earth is considered some $10^{-3}c$ (c is the light velocity) on cosmological grounds so that our laboratory system is considered approximately the N-system for high energy phenomena[3]. The volume v is given by

$$(4\pi/3)K_1^3 v \approx (2\pi\hbar)^3,$$

when the effective cutoff of the momentum degree of freedom is K_1. (The cutoff function should have a sufficiently long tail.)

Due to the Fermi statistics, only a finite number of quarks can occupy the volume v. This acts to extend the volume of the system and to make its density uniform. Hadronic matter is assumed to be a superposition of states confined with the maximum compactness so that the mass is, apart from individualities, e.g. vibrational excitations, in general given by

$$M \approx \rho V \approx \rho(n/f)v,$$

where ρ is the density being a constant, f is the number of quarks in v and, V and n are expectation values of the volume and the number of quarks of the system, respectively. The quantum field theory implies that the hadronic matter has its proper V and n for each quantum state. In a broad view, it is assumed that all colorless ground states (hadrons) have nearly the same V and n given by

$$V \approx V_N \approx (4\pi/3)(1/M_N)^3 \;, \quad n \approx n_N \approx f(V_N/v),$$

where M_N is the nucleon mass. Hadron resonances are considered excited states of hadrons by surface vibrations.

We consider that there exists a free physical quark Q clothed in a cloud of virtual quark pairs like a physical electron in QED clothed in a cloud of virtual electron pairs. In our picture, when Q and anti Q combine to form a meson $(Q'\bar{Q}')$ (Q' represents a deformed physical quark in the hadron), hadronic matter of the volume $2V_Q - V_N$ should disappear. This corresponds to the binding energy

$$B \approx \rho(2V_Q - V_N) \approx 2M_Q - M_N,$$

where M_Q is the physical quark mass. Conversely, in order to decompose $(Q'\bar{Q}')$ into Q and $\bar{Q}$, we should produce hadronic matter of the volume $2V_Q - V_N$. The produced giant hadronic matter is, however, a colorless fireball which decays into hadrons. This is a limited color confinement in our picture. For definiteness and simplicity, we assume that all colored ground states have nearly the same V and n given by

$$V \approx V_Q \approx 10\ V_N, \quad n \approx n_Q \approx 10\ n_N,$$

so that $M_Q \approx 10\ M_N$.

The effective cutoff momentum K of hadronic matter of size n is given by

$$K \approx nK_1,$$

where K_1 is the effective cutoff momentum of the basic particle (quark). The production probability of hadronic matter is suppressed when the momentum surpasses its effective cutoff K, although it can be accelerated when it is stable, e.g. by an electromagnetic field, far beyond K due to a long tail of the cutoff function. The effective cutoff for the Lorentz factor is given by, in the N-system,

$$\Gamma \approx K/M \approx (nK_1)/(\rho nv) \approx (K_1/\rho v),$$

which is insensitive to the size of hadronic matter. Cosmic ray experiments seem to suggest that there exists an effective cutoff around 10^4– 10^5 for Lorentz factors of fireballs insensitive to their sizes. When we take $K_1 \approx 10\ M_N$ (in this case, $n_N \approx 10^4$), we have $\Gamma \approx 10^5$.

Hitherto found fireballs are three kinds of ordinary fireballs H, SH and UH quanta having masses about 3 GeV, 30 GeV and 300 GeV, respectively, which decay mainly into pions and four kinds of exotic fireballs Mini-Centauro, Centauro, Geminion and Chiron, the decay products of which contain almost no pions. The masses of Mini-Centauro and Geminion are about 30 GeV and the masses of Centauro and Chiron are considered as being around 300 GeV.

We assume that the fireballs decay in accordance with the schema mentioned below and, in each step of decays, the sum of masses of decay products is about equal on an average to half of the mass of the decaying fireball. This scheme gives the right order of magnitude of multiplicity and transverse momenta of decay products characterizing each fireball.

H quantum decays into several pions. SH quantum decays into several H quanta. UH quantum decays into several SH quanta. Mini-Centauro decays into several nucleon pairs $(N\bar{N})$'s. Centauro decays into several Mini-Centauros. Geminion decays into a physical quark pair $Q\bar{Q}$[8]. Chiron decays into several Geminions.

In view of the model of hadronic matter, H, SH and UH quanta are the hadronic matter of the volume around V_N, 10 V_N and 100 V_N, respectively. (H quantum is considered an excited state hadronic matter of $V \approx V_N$ by volume vibration. In this case, H quantum is not a superposition of hadron resonances.) Centauro and Mini-Centauro are interpreted as UH quantum and SH quantum, respectively, in which the production of the participating H quanta in their decays is suppressed due to that the momenta of the H quanta surpass their effective cutoff and, instead of each H quantum, a nucleon pair $N\bar{N}$ is produced for which the effective cutoff momentum is larger than that of H quantum[7]. Chiron is interpreted as UH quantum in which the production of the participating SH quanta in the decay is suppressed due to that the momenta of the SH quanta surpass their effective cutoff and, instead of each SH quantum, a physical quark pair $Q\bar{Q}$ is produced for which the effective cutoff momentum is larger than that of SH quantum. The physical quark pair thus produced instead of a SH quantum is, regardless of whether the SH quantum belongs to decay products of a larger fireball or not, considered to be a Geminion.

3. 'Mini-Cluster'

The decay products of exotic fireballs have definite nuclear collision mean free paths so that they are considered to be indestructible. In our picture, the decay products of Centauro type and Chiron type fireballs are nucleons and physical quarks, respectively. In this case, in order to produce physical quarks in the p-$\tilde{p}$ collider interaction, the colliding particles should have at least $\Gamma M_{SH} \approx 10^6$ GeV which is far beyond the present collider energies[10]. The observed collision mean free path of the decay product of Chiron type fireballs is considerably short compared with that of the nucleon. This fact is in accord with our model, since the physical quark is an indestructible hadronic matter of the volume much larger than that of the nucleon.

Owing to that the nuclear matter is a fairly homogeneous many body system, the liquid drop model is applied to heavy nuclei and the excitations being considered due to surface vibrations are observed. The hadronic matter in our picture is also a fairly homogeneous many body system so that the excitations due to surface vibrations should be observed. We consider that the hadron resonances are due to surface vibrations. The surface vibration of the physical quark should also have observable effects.

The frequencies of stationary surface waves of liquid drop is[11]

$$\omega_\ell = [(4\pi\epsilon/3M_d)\ell(\ell-1)(\ell+2)]^{1/2}, \quad \ell = 2, 3, \ldots ,$$

where ϵ is the surface energy per unit area and M_d the mass of the drop. When ϵ is assumed to be the same for all hadronic matter and M_Q is taken to be 10 GeV, the ratio $\hbar\omega_2(Q)/\hbar\omega_2(N)$ of the quantum $\hbar\omega_2$ for the physical quark to that for the nucleon is about 1/3. In our picture, $\hbar\omega_2(N)$ is the spacing of hadron resonances for $\Delta J = 2$ and is about 500 MeV. Then $\hbar\omega_2(Q)$ turns out to be about the pion mass. In view of the oversimplification of our model, it is possible that $\hbar\omega_2(Q)$ is considerably smaller than the pion mass, e.g. some 10 MeV. In this case, the n quantum excited state of surface vibration of the physical quark, $E_n = n\hbar\omega_2(Q)$, decays emitting n photons of energy $\hbar\omega_2(Q)$. The transition probability per unit time for the γ emission of the liquid drop is given by[11]

$$(\Gamma_\gamma/\hbar) = (1/4)[\omega_2(Q)/c]^5[QM]^2/\hbar ,$$

where $[QM]$ is the quadrupole moment of the emitting system. The quark is considered to move fairly freely in its massive neutral clothes of virtual pairs. (For the hadronic matter, just as heavy nuclei, the liquid drop model and the degenerate Fermi gas model are considered valid for collective motions and individual particle motions, respectively.) Then the life time of the γ emission of the physical quark is estimated to be around 10^{-12} sec. (Γ_γ is the γ ray width.)

Thus we consider that the recently observed 'Mini-Cluster' accompanied by a decay product of the Chiron type fireballs is due to the surface vibration of the physical quark and accordingly supports the model of hadronic matter based on the theory of finite degree of freedom.

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