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ON THE PROBLEM OF PROVING THE EXISTENCE OF "CHARMED" PARTICLES

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A.A.Tyapkin

ON THE PROBLEM OF PROVING THE EXISTENCE OF "CHARMED" PARTICLES

Submitted to ЯФ

Тяпкин А.А. **E1 - 8657**

К вопросу о доказательстве существования "очарованных" частиц

Отмечается, что существование "очарованных" частиц должно проявиться в наблюдениях фотоэмульсионным методом нового типа гиперфрагментов.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований
Дубна 1975

Tyapkin A.A. **E1 - 8657**

On the Problem of Proving the Existence of "Charmed" Particles

реф

In order to search for "charmed" particles a possibility of performing an experiment is discussed in which one could observe a new particle and prove a necessity of introducing for this particle a new quantum number conserved in strong interactions.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Preprint of the Joint Institute for Nuclear Research
Dubna 1975

There are reasons to expect that in the near future the theoretical predictions of the existence of a whole family of new hadrons - a peculiar "demographic" explosion in the elementary particle world - will be proved experimentally. The quark model of elementary particles suggested by Gell-Mann[1] and Zweig[2] has given a physical interpretation of the theory of unitary symmetry of strong interactions based on the SU(3) unitary group. The experimental proof of the Ω^--hyperon existence has become a triumph of the theory of SU(3) unitary symmetry.

It is interesting that in 1964 some authors[3-8] began discussing a possibility of expanding the symmetry of strong interactions up to the SU(4) unitary group due to the introduction of a new quantum number suggested to be called a "charm"[4]. A possibility of elaborating the original representations of four fields (quarks) with the whole charge number was considered attractive. It is this perspective of retreating from quarks having fraction charges that appeared the basic reason for increasing the rank of the symmetry group[*]. To be true, there was no single opinion concerning the subatantiation of this argument even at that time.

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[*] Considerations on the lepton-hadron symmmetry in the 4-quark model were also essential.

The requirement for the existence of a whole family of hadrons not observed experimentally earlier was regarded to be the weak point of the new composite hadron model. To avoid the seeming unjustified great increase of the number of particles some attempts were made to introduce within the SU(4) symmetry the degeneracy of strong interactions in one of the quantum numbers[9].

The problem of substantiation of the fourth quark radically changed after the discovery[10] of neutral currents in weak interactions which extremely intensified the problem of the absence of strange particle decay according to decay schemes due to neutral currents. After the introduction of the lepton doublet containing the new quark and the Cabbibo superposition of a neutron and a strange quarks there appeared a possibility of removing the contribution of neutral currents to strange particle decays*). This circumstance was considered as the basic argument evidencing for the addition to the isotopic doublet of the normal quarks (p, n) and to the singlet of the strange quark (λ) of the fourth quark (p') of isosinglet with zero strangeness and the electric charge +2/3 but differing from the proton quark by a nonzero value of the supercharge or the "charm" quantum number.

The solution of the above problem of weak interactions due to

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*) This possibility had been discussed before the discovery of neutral currents in 1973, but then it was not distinguished among other explanations of the absence of the $K_L \to 2\mu$ decay.
It is worth noting that, e.g. , in the review paper[11] of 1972 various reasons for the absence of this decay were discussed but only in view of the paradox resulting from the failure to observe the $K_L \to 2\mu$ decay.

the expansion of strong interaction symmetry, has, undoubtedly, the features of elegance selected normally by Nature itself. The requirement of this conception to have a whole family of unknown hadrons was considered since then to be the greatest theoretical prediction in physics. The short lifetime (10^{-11} - 10^{-13} sec) and larger masses (2-5 GeV) of the predicted particles could be a reason of their nondiscovery in earlier experiments.

The enviable confidence of the supporters of the four-quark model in the existence of the new quantum number and the detailed discussion of the properties of predicted hadrons (see, e.g.,ref.[12]) produced a direct effect on experimentalists aiming them at special experiments for searching for new particles. The first result of this search was the discovery of a new particle with a 3.1 GeV mass and the lifetime 10^{-20} sec at three laboratories[13-15]. In the SU(4) symmetry scheme this particle is interpreted as a vector meson ($p'\bar{p}'$) similar to the vector meson φ (1020) consisting of a strange quark and an anti-quark (λ , λ). Despite the likelihood of the interpretation of the new particle the final confirmation of the correctness of the way chosen to generalize the unitarity symmetry of strong interactions can be given only by experiments proving the existence of the new quantum number C conserved in strong interactions. It is worth noting that the future discovery of new particles with masses and lifetimes in the expected ranges cannot be considered a decisive experiment proving finally the existence of a whole family of new hadrons including the fourth quark. Even the observation of the events of the pair production of new particles cannot be considered a decisive experiment. An additional experimental evidence is necessary that a new particle should not be produced without pair productions of "charmed" particles, e.g., in the pair with a strange particle. In this case it will be evidently shown that no expansion of the family of strange particles can explain the existence of discovered particles without introducing a new quantum number. It is clear that for the final solution of the problem rich statistics of events on new particle production is required. Therefore, under such conditions the decisive experiment can be performed much later than the discovery of the representatives of the family of "charmed" particles since experimental difficulties for observing these particles impede greatly detailed investigation of their production.

In this connection in our paper we draw attention to a possibility of performing an experiment, in which the discovery itself of new particle existence would contain evidences for its belonging to the family having a new quantum number. In spite of the comprehensive discussion in the literature of the search for "charmed" particles which became especially hot after discovering the ψ-meson, no attention has been paid yet to the existence of the new type of barions.

Consider barion systems including a new quark p'. When interacting with nuclear matter such barion systems for the time peculiar for strong interactions should transfer to the lowest mass state with the same "charm" quantum number and the same strangeness. This means that besides the Λ^{o}-hyperon ($S \neq 0$, $C = 0$) there should be two more quantum states (the superon with $C \neq 0$, $S = 0$ and the superhyperon with $C \neq 0$, $S \neq 0$) stable for strong interaction in nuclear matter*). If one proceeds from the analogy with hyperons, the antisymmetric state (p, n, p') of the isosinglet with the quantum numbers $Q = +1$, $I = 0$, $S = 0$, $C = +1$ should be expected to be the lightest one among superons. As for superhyperons, one of the antisymmetric states (n, Λ, p') or (p, Λ, p') of the isodoublet with the quantum numbers $Q = 0$ or $+1$, $I = 1/2$, $S = -1$, $C = +1$ should possess stability properties in nuclear matter.

Proceeding from the analogy with hyperons, one may expect that similar to the case with Λ^0-hyperons, the forces of interaction with nucleons would cause the production of bound systems consisting of nucleons and superons or superhyperons. This assumption is quite natural since for the whole family of barions one might expect the closeness of exchange forces and the appropriate interaction potential corresponding to them. For the (p, n, p') superon interaction with nucleons similar to $N\Lambda^0$- interaction, one might expect the reduction of forces due to the isotopic spin prohibition of the one-meson exchange. The isodoublet state of the superhyperon should be free of this limitation.

The production of superfragments in high energy particle interaction with nuclei shows quite directly when observing stars in photoemulsion. If the lifetime of new barions is 10^{-13} sec or longer, the observation of stars from the decay of new barions bound in nucler fragments in photoemulsion is one of the reliable methods not only for discovering such particles but a simultaneous evidence

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*) If the difference of superon and superboson masses does not exceed the nucleon mass, of course.

for their principal difference from the world of strange particles due to the conservation of the new quantum number in strong interactions.

The basic feature of new superfragments according to which they can be safely identified is an anomalously large energy sum of particles produced in supernuclear decay. In normal hypernuclei containing the Λ-particle fragment energy is 176 MeV for non-meson decay and 37 MeV for pion production decay. If the superhyperon mass is about 2 GeV, not smaller than 1 GeV is released in its decay.*)

It is worth mentioning that with such a considerable energy release the direct mass-spectroscopy of superons at charged particle energy should be complicated by the neutral boson and barion generation. Therefore, for the safe determination of the superon mass it is necessary to detect some events of supernuclear decay with the detailed analysis of different assumptions on the neutral component of the particles stopped in a star. The presence of fast particles in the second star due to supernuclear decay and the summary energy of its prongs exceeding considerably the mass difference of the Λ-hyperon and the nucleon allow one to discover and safely distinguish between these decays from the normal hypernuclear disintegration. The search for such events provided that they are not smaller than 10^{-2} from the number of secondary stars in the normal hypernuclear decay is quite possible. Besides, the superon short lifetime, if it is only not much smaller than 10^{-13} sec, should simplify additionally the search for new supernuclear decays, since the

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*) In this case annihilation stars may cause some difficulties for the observation of these superfragment decays.

effective region of the secondary particle appearance is limited by the distance of the order of $100\,\mu$ from the first star in which the production of "charmed" particles occurs. For instance, the alpha-particle for the time of 10^{-12} sec covers 10 and 30 μ at the initial energies of 5 and 25 MeV, respectively.

Thus, the discovery of superfragments should be possible even if the cross section of "charmed" particles is 5×10^{-3} smaller than that of strange particle generation, i.e., at the level of $20\,\mu$b in proton-nucleon or pion-nucleon collisions.

The photoemulsion method for detecting the decays of nuclear fragments allows the expectation of obtaining additional information considerably exceeding the unambiguity of interpreting the events as the superfragment decay. The decays of "charmed" particles should result mainly in the appearance of strange particles. Therefore, the safe discovery in the second star of the strange particle would have the decisive importance for confirming the correctness of event interpretation. In the case of the (p, n, p') superon decay one should expect either Λ^0-hyperon or K^0-meson production, since the K^--particle decay requires the emission of two positively charged leptons or hadrons. Either a Λ^c-hyperon or $\bar{K}^0$-or K^--meson should be produced simultaneously in the neutral superon decay (n, Λ, p'). The production of a Λ^c-hyperon when it remains in one of the fragment debris should result in the third star.

Thus, the observation of the cascade of two secondary stars (the first is accompanied by the abnormally large energy release or the observations of a single secondary star accompanied by the K-meson decay, can be considered as the most convincing evidence for "charmed" particle production. The photoemulsion method makes it possible to obtain a maximally complete autograph of the new particle in the case of the combined detection of the anomalous hyperstar and the decay of the "charmed" boson in the forefront cone of the primary star. Small lifetimes of these particles make possible this complete detection of the pair of "charmed" particle generation also.

The expectations for the efficiency of the photoemulsion method application for detecting new short-lived particles and "anomalous" hyperstars described above could be illustrated by the examples of evidences for the existence of such particles obtained earlier by this method.

Now when discussing the problem of discovering "charmed" particles/16/ again attention was drawn to the event detected by Japanese physicists in 1971 when exposing a photoemulsion stack to cosmic rays/17/. They have detected a unique event of short-lived heavy particle decay into a neutral pion and a charged particle. Under the assumption that the charged particle is a pion or a proton the authors have determined the mass of the decayed particle equal to 1.8 and 2.9 GeV. The lifetime of the particle detected by the authors was estimated to be some units product 10^{-14} sec.

Now when interpreting this event as the decay of "charmed" boson we must ascribe the track of the charged particle to the K^+ - meson. Then the mass of the discovered particle is 2.3 GeV. This value agrees completely with theoretical evaluations using this mass value of 3.1 GeV of the psi-mesom for estimating the mass of the "charmed" quark.

The authors of ref.[18] have performed the analysis of possible imitation of events similar to those detected by the Japanese physicists. The probability of imitating such a particle decay due to nuclear interaction of charged particles with photoemulsion nuclei has been evaluated as 4×10^{-5}. Other possible reasons (the decay of charged K-mesons and the "fridents" process) give much smaller probabilities of false appearance of the discussed event. The obtained evaluation of background probability means that the safe discovery of such decays with Dalitz-pair generation from the neutral pion is possible only if the production cross section of new particles is larger than 100 μb.

Besides, the fact itself of the discovery of the short-lived heavy particle, as has been mentioned above, does not prove the belonging of the new particle to the family of particles having the new quantum number conserved in strong interactions. Thus, the search for hyperfragments with a large energy release in their decay is decisive. The discovery of separate events of hyperfragments produced by cosmic rays needed the search for tens thousands of primary nuclear stars. Among them is a unique event detected in 1955 by Fry et al.[19]. The discovered particle has decayed into three charged particles covering only 9 μ from the centre of the 30-prong star. Consequently, a short range of the nuclear fragment to the decay allows its interpretation as a superfragment with an about 10^{-12} sec lifetime.

The average range in the discovered secondary star belonged to a proton. The shortest range of about 2 μ of the recoil nucleus was ascribed to the hydrogen isotope. The abnormality of the discovered star and the uniqueness of the event itself were concentrated in the third track 12200 μ long. The measurements of ionization density and scattering allowed one to determine the mass of this particle to be 585 ± 100 MeV. Defining this particle as the K-meson, the authors have found that the full energy released in the stars was 550 MeV which corresponds to a hyperon with a mass of about 1400 MeV.

This event remained unexplained till 1964 when the Ω^--hyperon had been discovered. At present this event is interpreted as nuclear disintegration caused by Ω^--hyperon stop and decay. Indeed, if one suggests the emission of a not detected Λ^0-particle, the hyperon mass of 1665 MeV agrees well with the later measurements*).

Now, when considering the unique event as a superhyperon (n, Λ, p') decay we must add a π^0-meson to the detected K-meson but not only the Λ^0-hyperon which was not captured by fragment debris and remained not detected in the experiment as a neutral particle. Consequently, the mass of the suggested superhyperon according to the data of this event must be not smaller than 1.8 GeV.

Thus, the properties of the second star discovered in 1955 as an anomaloulsy large released energy, the observation of the K-meson in the decay products and, at last, a short range of the unstable

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*) The present day Rosenfeld Tables give /19/ as the first one for the Ω^--hyperon mass.

nuclear fragment make up a complete set of evidences for the explanation of this event as a superfragment decay. In any case, there are reasons, along with the accepted interpretation of Fry's event as the first observation of the Ω -hyperon giving a nuclear star, to discuss in detail the interpretation of this unique event presented in this paper.

Of course, only a purposeful search for anomalous hypernuclei in photoemulsion exposed at maximum accelerator energies, with the sufficient statistical material of some hundred normal hyperfragments will allow to clarify completely the origin of appearing such events.

The "charmed" particle physics will undoubtedly need the very labour-consuming photoemulsion technique. To be true, even at present one may expect the modification of this method. For instance, the combination of this method with spark chambers may be quite promising for an approximate determination of the region where the required events could be search for. This combined method may appear quite effective when studying "charmed" particles in neutrino beams where long-term exposure of tens kilograms of photoemulsion are necessary to obtain such rare events.

The system of automatic recognition consisting of microscope combined with TV cameras may prove quite promising for detecting events in photoemulsion.

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