ONE POSSIBILITY OF CONSTRUCTING A SYSTEM OF THE "ELEMENTARY" PARTICLES

I. V. CHUVILO

Joint Institute for Nuclear Research

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A possibility is discussed for setting up a system of the baryons and mesons based on the postulate that there is a single "elementary" baryon and a single "elementary" meson, with a strong interaction between them. The "elementary" particles chosen are an isotopic singlet baryon Ω^- with strangeness -3 and an isotopic doublet of mesons K^+, K^0 with strangeness $+1$. Conclusions are obtained that agree qualitatively with the known experimental data on processes that involve "strange particles." Some qualitative results on form factors are obtained.

As the result of the great achievements of experimental high-energy physics, during the last decade a number of new unstable particles have been discovered — the hyperons and K mesons. The foundations of the systematics of these particles have been laid in the well known papers of Gell-Mann and Nishijima (the G-N scheme).[1] But such a large number of "elementary" particles is in some respects surprising. Therefore doubts as to their elementary nature arise from time to time. This gives rise to attempts to represent the known particles as some sort of composite structures, so as to diminish the number of "elementary" particles, and also to restrict the set of the interactions.

We present here one more possibility, which we believe has not been discussed so far; retaining all the baryons and mesons that are known and predicted by the G-N scheme, we can nevertheless decidedly diminish the number of "elementary" particles.

It would be extremely attractive to leave in the systematics only one "elementary" baryon and only one "elementary" light particle. Remaining within the framework of the G-N scheme, we can limit our choice to the isotopic singlets Ω^-, Λ^0, and Z^+, with the respective strangenesses -3, -1, and $+1$. The most interesting possibilities are obtained with Ω^- and Z^+, with which we can associate as the "elementary" light particles the isotopic doublets (K^+K^0) and $(K^-\overline{K}^0)$, respectively. The sets Ω^-, K^+, K^0 and Z^+, K^-, $\overline{K}^0$ are symmetric with each other. An explanation of the various effects can be given with either one or the other type of theory. In what follows we shall use the type with Ω^-, K^+, K^0, since it seems to us that it corresponds more to the known experimental data.

Thus we shall assume that there exist only electrically neutral and singly charged baryons and K mesons.

We shall suppose that the "elementary" baryon is the hypothetical negatively charged Ω^- hyperon of the G-N scheme, an isotopic singlet $(I = 0)$ with strangeness $S = -3$ and usual baryon spin (s = half-integral number).

We assume that the "elementary" light particle is the isotopic doublet (K^+, K^0), $I = 1/2$, which is a boson in ordinary space (s = integer) and has strangeness $S = +1$. The antiparticles of our chosen particles will be $\overline{\Omega}^+$ and $(K^-\overline{K}^0)$, respectively.

We define a strong ΩK interaction and begin the construction of the series of baryons with the isotopic doublet of the Ξ hyperons; we define their structure by combining Ω^- with each of the two K mesons we have postulated, i.e., in the form*

$$\Xi^0 = (\Omega^- K^+), \quad \Xi^- = (\Omega^- K^0).$$

We then define the structure of the sequence of Σ hyperons, an isotopic triplet, by combining two K mesons with the Ω^- in the three possible ways, namely

$$\Sigma^+ = (\Omega^- K^+ K^+), \quad \Sigma^0 = (\Omega^- K^+ K^0), \quad \Sigma^- = (\Omega^- K^0 K^0).$$

It is known that the Σ^0 hyperon cannot exist long and goes over into a Λ^0 hyperon by a fast electromagnetic transition. This could be explained by assuming that it is not possible for the K^+K^0 pair to exist together near the Ω^-, and that through a strong K^+K^0 interaction (in an isotopic singlet state) it forms a bound state $\omega^+ = (K^+K^0)$, which could be understood as a meson with the strange-

*In the type of theory with Z^+, K^-, $\overline{K}^0$ the construction begins with the isotopic doublet of the nucleons, according to the scheme $p = (Z^+\overline{K}^0)$, $n = (Z^+K^-)$.

ness S = +2, isotopic singlet, predicted by the G-N scheme.

Thus the structure of the isotopic singlet Λ^0 hyperon can be written in the form $\Lambda^0 = (\Omega^-\omega^+)$. Continuing with the addition of K^+ and K^0 mesons, we get the structure of the isotopic doublet of the nucleons in the form

$$p = (\Omega^-\omega^+K^+), \qquad n = (\Omega^-\omega^+K^0).$$

Now, in virtue of our original assumptions, there remains only one possible structure $Z^+ = (\Omega^-\omega^+\omega^+)$, which corresponds to a hyperon that is an isotopic singlet with strangeness S = +1, which is also contained in the G-N scheme.

From the pairs of particles (K^+K^0) and antiparticles $(K^\circ K^-)$; in combination with a $\overline{\Omega}\Omega^+$ pair we can construct four isobosons with schemes of the type $(K\overline{K}\Omega\overline{\Omega})$.

We can identify the charged systems with the π^+ and π^- mesons, and from the neutral systems we can construct the third component of the isotopic triplet (π^+, π^0, π^-) and a neutral isotopic singlet, which is contained in the G-N scheme as the ρ^0 meson.

Thus, by postulating only two elementary particles we have been able to construct all the particles of the G-N scheme. The attraction of the scheme under discussion is that we can get along with only two particles both in ordinary and in isotopic space, and also with only two types of interaction. Furthermore we can identify the π mesons with the quanta of the field that gives the (ΩK) coupling.

Using the proposed scheme, we can get from the measured masses of the known hyperons estimates of masses for the predicted hyperons. The differences $m_{\Sigma^-} > m_{\Sigma^0} > m_{\Sigma^+}$ and $m_n > m_p$ are very probably a consequence of the fact that $m_{K^0} > m_{K^+}$ (cf. reference 2). Then we may suppose that the Ξ^0 particle must be lighter than the Ξ^- by an amount of the order of $5 m_e$ (cf. reference 3).

For the absolute magnitude of the energy of coupling of the K mesons with the Ω^- one gets a value of the order of $1200 - 1300\, m_e$. It follows from this that the Ω^- hyperon is $250 - 350\, m_e$ heavier than the Ξ particle. This means that obviously the Ω^- hyperon should decay by the schemes (if we accept the rule $|\Delta S| = 1$)

$$\overline{\Omega} \to \Xi^0 + \beta^- \quad \text{or} \quad \Omega^- \to \begin{matrix} \Xi^0 + \pi^- \\ \Xi^- + \pi^0. \end{matrix}$$

An interesting situation occurs in the estimate of the mass of the Z^+ hyperon. If we begin with: 1) the masses of the proton and the K meson and their binding energy, or 2) with the mass of the Λ^0 particle and the mass and binding energy of the ω^+, both routes lead to the conclusion that the mass of Z^+ must be of the order of $1500\, m_e$. With such a mass, however, the Z^+ hyperon cannot be observed, since we know of no ways in which it can be converted into a stable baryon or nucleon, since it is lighter than the latter. The question of the existence of the Z^+ hyperon, the value of its mass, and the manner of its decay is extremely interesting.

The scheme developed here provides possibilities for explaining a large number of known experimental facts about the production and interactions of hyperons and K mesons. We shall examine only some of them.

It seems most natural to explain a reaction of the type

$$\pi + N \to Y + K,$$

by a process of dissociation of the π meson in the field of the Ω^- particle into a pair of mesons $(K, \overline{K})$, followed by annihilation of the $\overline{K}$ meson so formed with one of the K mesons around the Ω^- (with annihilation of a pair K^+K^- or $K^0\overline{K}^0$). In this scheme the Λ^0 particles produced in reactions

$$\pi + N \to \Lambda^0 + K,$$

will be produced predominantly "backward" in the center-of-mass system, since in this case the K meson leaves the composite system practically without interaction, moving in the "forward" direction, and the $\overline{K}$ meson interacts only with the K meson, without touching the ω^+ system.

The charged hyperons from the reactions

$$\pi^- + p \to \Sigma^- + K^+, \qquad \pi^+ + n \to \Sigma^+ + K^0$$

will have a sharp "forward" directionality in the center-of-mass system, since now both the K^- and the $\overline{K}$ meson interact with the $K\omega^+$ system in the nucleon.*

On the other hand, in the reactions

$$\pi^- + p \to \Sigma^0 + K^0, \qquad \pi^- + n \to \Sigma^- + K^0,$$
$$\pi^+ + n \to \Sigma^0 + K^+, \qquad \pi^+ + p \to \Sigma^+ + K^+$$

both of the channels that have been mentioned can take part. Therefore it seems that the angular distributions of these reactions should be more nearly isotropic in the center-of-mass system, possibly with some preference for emergence of the Σ particles in the "backward" direction. It would be interesting to check these arguments for the reaction

*For experimental data on this point see reference 4.

$$\pi^+ + p \rightarrow \Sigma^+ + K^+,$$

for which the experimental data known so far[4] contradict the consequences of our scheme.

With increase of the energy of the incident π meson a $K\bar{K}$ pair that is produced may leave the compound system; this leads to the production of K^+K^- and $K^0\bar{K}^0$ meson pairs. With the same total cross section for production of strange particles this can lead to a decrease of the cross section for production of YK pairs as compared with its value up to the threshold for production of $K\bar{K}$ pairs (at π-meson kinetic energy 1.34 Bev).* An analysis shows that reactions of the type

$$\pi^- + N \rightarrow N + K^- + K^0, \quad \pi^+ + N \rightarrow N + \bar{K}^0 + K^+,$$

that go in one step are preferred over the reactions

$$\pi^- + p \rightarrow n + K^+ + K^-, \quad \pi^+ + n \rightarrow p + K^0 + \bar{K}^0,$$

which require a further step of charge transfer $K^+ \rightleftarrows K^0$.

Let us now consider the question of the interaction of $\bar{K}$ mesons with nucleons. We first note the smallness of the charge-transfer effect in the reaction $K^- + p \rightarrow \bar{K}^0 + n$, which is due to the necessity for this process to go through a link $K^-K^+ \rightarrow K^0\bar{K}^0$.†

Of all the reactions of the type‡ $K^- + N \rightarrow Y + \pi$, the most probable is the reaction $K^- + n \rightarrow \Lambda^0 + \pi^-$, since it goes through the process $K^-K^0 \rightarrow \pi^-$ without the participation of the $\Omega^-\omega^+$ system.

Another curious point that we note is that in interactions of $\Sigma^\pm$ hyperons with nucleons, reactions of the type

$$\Sigma^\pm + \overset{0}{N^+} \rightarrow \Sigma^0 + \overset{+}{N^0},$$

are more probable than reactions of the type

$$\Sigma + N \rightarrow \Lambda^0 + N,$$

since the former go only through the charge-transfer process $K^+ \rightleftarrows K^0$.

Is the observation of the ω^+ particle possible? If it can actually exist, then the most convenient way to produce it is by the reactions $K + N \rightarrow \Lambda^0 + \omega^+$. If $m_\omega < 2m_K$, the threshold for these reactions must be at a K-meson kinetic energy less than 1.23 Bev. Decay of this particle is possible through the schemes $\omega^+ \rightarrow K + \pi$ or $\omega^+ \rightarrow \pi^+ + \pi^0$. So far there are no definite experimental indications of reactions and decays of these types. The observation of the ω^+ particle is one of the basic problems of the scheme we are discussing.*

We now go on to the problem of the production of the cascade particles $\Xi^{-,0}$ and Ω^-. It is obvious that the simplest way of producing the Ξ^- hyperon will be by reactions with neutrons, since they go only through the $\bar{K}\omega^+$ interaction:

$$\bar{K} + n \rightarrow \Xi^- + K, \quad \pi + n \rightarrow \Xi^- + K + K.$$

On the other hand reactions of the types

$$K^- + p \rightarrow \Xi^- + K^+, \quad \pi^- + p \rightarrow \Xi^- + K^+ + K^0$$

are less probable, since for them an additional redistribution of energy between the K^+ and ω^+ mesons is required. The production of the Ξ^0 hyperon is possible only in reactions with protons,

$$\bar{K} + p \rightarrow \Xi^0 + K, \quad \pi + p \rightarrow \Xi^0 + K + K.$$

Reactions of the type $\bar{K} + n \rightarrow \Xi^0 + K$ are less probable. Thus the observation of Ξ^0 is possible in liquid-hydrogen bubble chambers, and the production of Ξ^- is difficult.

As is well known, the Alvarez group[3] has observed the Ξ^0 hyperon in a liquid-hydrogen bubble chamber and has not observed the Ξ^- hyperon. Thus the facts are in agreement with the consequences of our scheme. For the reasons indicated the reaction $\pi^- + p \rightarrow \Xi^- + \omega^+$ is also unsuitable for the observation of the ω^+ meson.

The process of production of the Ω^- hyperon is still more difficult to observe. In this case all the possible reactions of the type

$$\bar{K} + N \rightarrow \Omega^- + K + K, \quad \pi + N \rightarrow \Omega^- + K + K + K$$

involve more than one stage, and their yields must be very limited.

We must also note the interesting possibility of explaining the decay properties of hyperons by the mechanism of production of a virtual $K\bar{K}$ pair followed by decay of the $\bar{K}$ meson. This gives results in qualitative agreement with existing experimental data.

Finally, we can try to draw some qualitative conclusions about the electric form-factors of nucleons. In our scheme they have the structures

$$p = (\Omega^-\omega^+) K^+, \quad n = (\Omega^-\omega^+) K^0.$$

From this it can be seen that since the system $(\Omega^-\omega^+)$ is very tightly packed the core of the nucleon must be electrically neutral.† Because the

*Such a behavior of the cross-sections for the YK and $K\bar{K}$ reactions has been suggested by Wang Kang-Ch'ang on other considerations.

†In the Z^+, K^-, $\bar{K}^0$ scheme this reaction is allowed, which is clearly in contradiction with experiment.

‡In the Z^+, K^-, $\bar{K}^0$ scheme the treatment has to be in terms of a virtual $K\bar{K}$ pair around the Z^+.

*The same is true of the reaction $K^- + p \rightarrow Z^+ + \omega^-$ for the Z^+, K^-, $\bar{K}^0$ scheme.

†A similar picture was suggested by V. I. Veksler on the basis of an analysis of the angular distributions of hyperons from $\pi + p$ reactions.

outer "shells" of the proton and neutron have respectively a K^+ and a K^0 meson, we can suppose that these particles mainly determine the natures of the electric form-factors of the respective nucleons. It seems to us that this picture corresponds to the known experimental facts.[5]

A question that could be discussed is that of the mean radius of the electric charge distribution in the proton. It may perhaps be somewhat smaller (by a factor of about $m_K/m_\pi \sim 3$) than is believed. A possibility that seems more attractive, however, is obtained by introducing the $K\Omega$ coupling by means of π mesons. Then the electric radius of the proton will be that corresponding to the π meson, and the magnetic moments of nucleons will be given by the sum of the Dirac moment of the Ω particle and the additional moment of the π-meson "coat," with a mean radius of the order of that of the π-meson cloud.

We have here dealt only with effects associated with the existence of the "strange" particles. We believe that within the framework of our model there are interesting possibilities for explaining many questions of the structure of nucleons (isobars, etc.), and a number of effects associated with them (photomesonic processes, etc.).

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