Baryon repulsion as a consequence of quark models

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It is noted in the quark model of hadrons that the presence of identical quarks with parallel spins in the makeup of two colliding hadrons should manifest itself as an effective repulsion of the colliding hadrons.

The fact that a large number of "resonances" had been observed in experiments gave rise to two trends in the theory of elementary particles. In the first (heralded by Chew) it is proposed to regard all particles as equally elementary, and this approach is called "total democracy." In the second trend, new particles, quarks, are introduced and regarded as truly elementary, or at any rate more elementary than the baryons and mesons observed in experiments to date. This trend was originated by Fermi and Yang (mesons as bound baryon-antibaryon states), and the quark idea was formulated by Gell-Mann and Zweig, while modern quark models stem from the work of Bogolyubov and co-workers,[1] Hans and Nambu,[2] and Miyamoto[3] (for a detailed review see Okun's lectures[4]).

This raises the question whether the composite nonelementary nature of the hadrons can be revealed in experiments in which the energy is insufficient for the production of real quarks.

In this paper it is proposed to use the fact that quarks are fermions and are subject to the Pauli principle.

It is qualitatively obvious that this circumstance should make it difficult for particles containing identical quarks with parallel spins to approach one another. When scattering is described with the aid of the effective interaction potential of composite particles, this circumstance manifests itself as an additional repulsion at short distances.

We note that the Pauli principle itself does not represent repulsion: the Pauli principle means that the state of two electrons with parallel spins and symmetrical spatial wave function simply does not exist, and not that the energy in this state is higher than that of the state with antiparallel spin, nor that the scattering phase in the continuous spectrum for the ^3S wave (which simply does not exist) is shifted relative to that of the ^1S wave. Effective repulsion pertains to the interaction of composite particles in states that are allowed by the Pauli principle for these particles regarded each as an entity. Thus, for example, Δ^{++} is represented in the simplest scheme of colored quarks as (p_1, p_2, p_3), and Δ^+ by the superposition

$$1/\sqrt{3}[(p_1 p_2 n_3) + (p_1 n_2, p_3) + (n_1, p_2, p_3)].$$

Since Δ^{++} and Δ^+ are two different particles, the state of the pair $^7S_3$ *with parallel spins* $(s=3,\ 2s+1=7)$ *with symmetrical spatial* (*S*) *wave function is allowed.* When Δ^{++} and Δ^+ approach each other, however, the quark pairs p_1 or (and) p_2, p_3 with parallel spins from Δ^{++} and Δ^+ should be in the P state. A centrifugal potential appears in the interaction of the pairs of identical quarks. But the system Δ^{++}, Δ^+ is in the S state. The additional kinetic energy of the internal motion manifests itself effectively as a repulsion of Δ^{++} and Δ^+. The repulsion appears, albeit to a lesser degree, in the $^3S_1$ (i.e., deuteron) state of the $P+N$ system.

No such repulsion should occur in the interaction of $\Delta^{++}(p_1 p_2 p_3)$ and $\Delta^-(n_1 n_2 n_3)$ or Δ^{++} and $\Omega^-(\lambda_1\lambda_2\lambda_3)$.

Finally, there should be no short-range repulsion also in baryon-antibaryon interactions. The question is made complicated here, however, by annihilation, which results in an imaginary increment to the effective potential. Repulsion is predicted also in definite baryon-meson combinations, e.g., $\Omega^- + k^-$, where $\Omega^- = (\lambda_1\lambda_2\lambda_3)$ and $k^- = [(\lambda_1\bar{n}_1) + (\lambda_2\bar{n}_2) + (\lambda_3\bar{n}_3)]$. It is possible that it is precisely this repulsion that interferes with the formation of the so-called charmed resonances, which lie outside the octet and decuplet with respect to charge and strangeness. When atomic collisions are considered, the consideration of the Pauli principle for electrons is trivial.

When the alpha-particle model of the nucleus is considered, the Pauli principle for the protons and neutrons is taken into account by a special procedure in[5]. The effect was considered by Baz' earlier[7] in general form.

Let us turn to the elementary particles of interest to us. The main idea advanced above was stated long ago in a different form.[7] Using as an example the interaction between a proton P and a mesic atom $A(=\pi^-, p)$, we could trace the manner in which the $^3S_1$ state of the system $AP(=\pi^-, pp)$ at a short range comprises two protons in a state with $l=1$ and with a corresponding centrifugal potential, and a pion likewise in a state with $l=1$. In this mode, the effective repulsion could be calculated quantitatively.

It would be impossible to apply this idea to the Gell-Mann and Zweig quark models, inasmuch as the Pauli principle was not applied to quarks in these models, and reference was made to parastatistics (?) and similar distortions.

Modern quark models[1,2,3] operate with fermion quarks with spin 1/2. Now is therefore the time to raise, naturally and ligitimately, the question of how quark statistics becomes manifest in hadron interaction.

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