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B.Pontecorvo

ON THE POSSIBLE EXISTENCE OF HADRON ISOMERS

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ON THE POSSIBLE EXISTENCE OF HADRON ISOMERS

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In this note we are concerned with the angular momenta of finite dimension micro objects excitable to many energy levels, such as molecules, atoms, atomic nuclei and the so-called elementary hadrons. In spite of the difference in their dimensions, there is some analogy in these objects. The angular momentum is the product of a momentum P times the radius R. Now, because of the uncertainty relation, $P \sim R^{-1}$, and as far as angular momenta are concerned, we are faced with a sort of similarity between quantum objects widely differing in their dimensions and in the separations of their energy levels. This similarity suggests that we may inquire into what happens in the case of objects of known structure, such as the atomic nuclei, to get a hint of what might happen in the case of objects of unknown structure, namely, the elementary hadrons.

The assumption that hadrons consist of partons may help to understand the analogy, but is not relevant at present; the main point is that hadrons have probably a very complex structure, and that in spite of this their energy levels are well separated (resonances).

As it is well known, in nuclear physics metastable nuclear levels are often observed, i.e. there exist certain states with lifetimes much larger than the lifetimes of "ordinary" states of comparable excitations. In general, this metastability is connected with the large angular momenta of states having relatively low excitations (nuclear isomerism). At the present time a large number of nuclear isomers is known, the maximum excitation energy of which reaches a few MeV. The measured lifetimes of stable nuclear excited states are in the interval of 10^{-17} - 10^{11} sec. Nuclear isomers are known which have total angular momenta greater than $J = 15$.

Why not consider very large spin values also in the case of hadrons? Then the question arises as to whether a metastability connected with large values of J is possible also in hadron physics. In other words, do hadron isomers exist? Here hadron isomers are defined as large spin states having relatively low excitation and decaying, say, by emission of pions (or photons if the excitation is very low) with lifetimes very long (because of the centrifugal barrier).

It turns out that it is difficult to exclude such a possibility on the basis of our knowledge of hadron physics. Two considerations are sufficient here. 1) The fact that at present no example was observed of hadron isomerism (connected with large J values) does not provide arguments against its existence. Probably, hadron isomers could not have been observed in experiments already performed, as it will be seen later, and only special investigations designed for the purpose can reveal them. 2) Naturally, the levels of quantum objects having large angular momenta, generally speaking, have high excitations. However, exceptions are possible. The appearence of isomerism just requires, as a rule, that sometimes there takes place a level "inversion", i.e. that some states of very high angular momentum have relative low excitations. It is well known that in the case of atomic nuclei such "inversion" is a quite frequent event: it is connected with the nuclear structure (orbits, magic numbers, form). It seems that in the case of hadrons nothing definite can be said from a theoretical point of view. There are very few empirical data on hadron resonances and it is impossible to make on their basis such a statistical analysis which would exclude the possibility of level "inversion". If such data do allow any conclusion to be drawn at all, they would rather suggest that "inversion" sometimes may take place: for example, there are known four boson pairs η and η' , ω and ϕ , η_{0+} (700) and η_{0+} (1070), f (1260) and f' (1514), the two components of each pair having, as far as we know, identical quantum numbers, while the masses of the components in each pair differ by a few hundred MeV. In the case of barions it looks as if the "inversion" were directly seen for N (1688) $J^P = 5/2^+$ and N (1780) $J^P = 1/2^+$, N' (1670) $J = 5/2^-$ and N'' (1700) $J^P = 1/2^-$, Δ (1236) $J^P = 3/2^+$ and Δ (1910) $J^P = 1/2^+$, Λ' (1520) $J^P = 3/2^-$ and Λ' (1670) $J^P = 1/2^-$. Of course, there may be a number of reasons explaning these data, for example, the existence of an additional quantum number (reminding of the atomic principal quantum number n); but in any case there are no data which would "a priori" indicate that the level inversion is impossible.

In connection with a possible experimental search for hadron isomers it is of interest to discuss their expected properties. As an example let us consider the two-particle decay of hadron isomers into particles of momentum K (the possibility that two-particle decays might often be less probable than many-particle decays is of no relevance here). If $KR \lesssim 1$, i.e. if the excitation is sufficiently low (say $<$ 1 GeV) and if the isomer angular moment is sufficiently large, the lifetime τ_I of the isomer can reach values several orders of magnitude larger than the lifetimes τ of ordinary resonances (say, $\tau_I \gg \tau \lesssim 10^{-21}$ sec).

Because of the very small width of hadron isomers, it is impossible to discover them by investigating elastic collisions of two particles in analogy with what is being done, for example, in the investigations of the barions N and Δ , The hadron isomers must be searched for by investigating their decay properties.

Naturally, the cross section for the inclusive processes in which an hadron isomer is generated, (i.e. the cross section for the production of the isomer together with any other hadrons) is extremely small at low energies and can become observable only at such high energies, that the contribution of waves with large orbital moments becomes considerable. Even at sufficiently high energies the cross section for the production of hadron isomers is expected to be considerably smaller than the cross section for the production of "narrow" hadrons (such as kaons and hyperons) with small spin values.

Thus, it is understandable why, even if hadron isomers were existing, no one would have noticed them until now: the decay length of the hadron isomers produced at existing accelerators is too short to be observed in a bubble chamber and the observation of hadron isomers, from an experimental point of view, is then equivalent to the discovery of ordinary resonances with small production cross sections σ (it is very difficult to find a new resonance if $\sigma \lesssim 10^{-30}$cm^2).

When the accelerator energy increases (Serpukhov, Batavia), the problem of observing hadron isomers stops being academical not only because of the contribution of high orbital waves but mainly because the decay length can be observed. With Lorentz factors of about 50 for hadron isomers, one could detect $\tau_I \geq 10^{-12}$ sec. in a bubble chamber and $\tau_I \gtrsim 10^{-15}$ sec in photoemulsions. Thus, in searching for hadron isomers by means of track detectors one should pay attention to "cascade decays" (or connected "stars"). These stars might have a very special appearence. For example, if the isomer happens to be a hyperon its "signature" might consist of three or more connected events (the isomer production, its decay with production of a hyperon, the hyperon decay).

Returning to the question as to whether hadron isomers could have been observed before, it may be stated that if charged hadron isomers with masses $\leq$ 2.2 GeV and lifetimes $> 10^{-9}$ sec existed, they would have been observed in the experiments already performed at Serpukhov /2/ provided the cross section for their production by 70 GeV protons were larger than 10^{-31} cm^2 .

Not long ago experiments were proposed and initiated [3], in which a search is made for long-lived particles. In such experiments a new type of "radioactivity" of the pseudo-nuclei, in which the particle might be detained, is looked for. At the time the metastability searched for was not assumed to be connected with large J values. In view of the ideas expressed above, it is natural to put the question: what will be the fate of an hadron isomer captured inside a nucleus? Probably an isomer captured inside a nucleus will decay by "internal conversion", a process similar to the decay of hypernuclei without pion emission. In such a process the energy transfer from the isomer directly to the nucleons predominates, and the mean life of the captured isomer is greatly shortened with respect to the mean life of the free isomer. This problem was discussed more than 15 years ago by Kobzarev and Okun [4] when the nature of the Λ particle metastability was not yet clear.

After the idea about the hadron isomerism had been already formulated, I was informed about a possible recent cosmic ray observation [5] of a particle having a mass of about 2 GeV and a mean life of about 10^{-14} sec. Because the mass is so large, it seems unlikely that such a particle would be the first example of hadron isomerism, in the sense of the word used in the present note (unless one would consider values $R \ll 1/m_\pi$).

The question about the existence of hadron isomers is quite fundamental, as the observation of such objects would prove the extreme complexity of hadrons. Consequently a search for hadron isomerism at accelerator laboratories and in cosmic ray investigations seems to be of great interest.

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