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The lowest-lying of all nuclear levels is the pion so, whether or not it is thought to occupy a fundamental niche in the hadron hierarchy, it is inevitable that this particle should receive intense experimental investigation. Physicists by now possess far-reaching quantities of pion data, and theoretical attention has correspondingly become enormously detailed. A deep question has arisen from all this attention: Does the relative smallness of the pion mass (140 MeV) directly reflect some fundamental aspect of strong interactions, or is it a "dynamical accident" that the spacing between this lowest nuclear level and the remainder of the spectrum is several times larger than the displacement of the pion level from zero? Some current theoretical trends associate a special pion status with its low mass--in conflict with the idea of "nuclear democracy." This note proposes to review that part of the evidence arising from strong-interaction experimental data.

To begin, it is unquestionable that the small pion mass makes this particle quantitatively more prominent than its colleagues as a "carrier" of the nuclear force and leads to important practical consequences. The inverse Yukawa relation between force "range" and carrier mass means that when selection rules allow a pion to be exchanged between two hadrons it generates a longer range force than do any other possible exchanges. The existence of classical nuclear physics as a discipline separated from high energy nuclear physics depends upon the fact that the range of the force between two nucleons is the pion Compton wavelength and correspondingly large compared to a nucleon Compton wavelength. A nonrelativistic local nucleon wave function thereby acquires meaning and the typical nuclear level spacing becomes smaller than or of the order of $m_\pi^2/2M_N = 10$ MeV. Without the small pion mass, the model describing nuclei as combinations of individual nucleons would be a poor approximation. Nuclear levels would still be classifiable according to atomic mass number, B, but the mean level spacing for $B \geq 2$ would be similar to that for $B = 0,1$; i.e. of the order of 500 MeV.

The pion, however, is by no means the only carrier of the nuclear force. In fact, for a meson-baryon combination, selection rules forbid pion exchange and the force range is determined by the mass of much heavier particles, like the ρ or the nucleon. There consequently is no significance possible for a nonrelativistic local wave function and the level spacing is large. Nevertheless the same general principles have been shown to prevail in meson-baryon dynamics as in the nucleon-nucleon combination.[1] A similar conclusion obtains for combinations of two mesons. The dominant and especially simple role of the pion in generating the Yukawa force between baryons appears fortuitous.

Even for the two-nucleon system, moreover, pion exchange is not the whole story in force generation. Careful analysis has shown that ρ and ω exchange contribute according to the same principles that govern π exchange, the differences being due to the mass differences between these mesons. There is thus no basis anywhere in the nuclear force picture for attributing a qualitatively special status to the pion. From the point of view of force generation the pion seems nothing more than the least massive hadron.

What about high-energy reaction rates? Is there anything anomalous about the pion cross section, say for collisions with nucleons? The general empirical rule is that the total cross section for a nucleon in collision with a target of baryon number B increases gradually with B. This rule includes the pion, whose high energy cross section appears entirely normal. Again, no basis for special status. The same can be said for intermediate energies, where resonance phenomena are the general rule, the pion participating in a nonexceptional fashion. (Low energies are a different story, as we shall see.)

What does the SU_3 classification of hadrons into multiplets of "similar particles" tell us?[2] The pion has been successfully placed into an octet which otherwise includes the K, of mass 495 MeV, and the η , of mass 550 MeV. The similarity of properties within the octet makes it unlikely that a special status could be assigned to one member and not to all, but the "average mass" of the octet (370 MeV) cannot be described as a strikingly small number. Thus the success of SU_3 diminishes the plausibility of a direct connection between the small pion mass and some fundamental aspect of strong interactions.

The above evidence all suggests a plebian status for the pion; wherein lies contrary evidence? The most important support for special pion status arises from the success of the PCAC hypothesis, particularly as employed by Weinberg[3] (and described by Treiman in an earlier issue of this journal[4]), which makes successful predictions about reactions involving low-energy pions by assuming an off-mass-shell extrapolation with simple behavior as the four-momentum of the pion approaches zero. Because of the small pion mass it is argued that this simplicity should still be present in observable on-shell amplitudes when the pion three-momentum is small. A number of different experimental observations support the predicted simplicity of low-energy pion amplitudes, so an explanation is required. The usual motivation for PCAC is field-theoretical,[5,6] identifying the pion as a Goldstone boson (supposed ideally to have zero mass) associated with the breakdown of γ_5 invariance; proportionality between the pion field and the divergence of the axial vector (weak) current then legitimizes the desired smooth extrapolation. Such reasoning marks the pion as distinguished, especially if the axial current is one of a few "fundamental" currents satisfying simple commutation relations.[7] In particular one would not then expect the pion to share equal status with particles of higher spin (2^-, 4^-, etc.) on a Regge trajectory, since there are not supposed to be fundamental weak currents with corresponding high-spin transformation properties.

Evidently a vital question is whether the pion does or does not lie on a trajectory. Superficial indications from high-energy photopion production experiments suggest that it does not,[8] but the issue is far from resolved. On the other hand, the same experiments are nearly unequivocal about a point discussed in the March, 1967, issue of this journal[9]: if the pion does lie on a trajectory, the Lorentz quantum number M at zero momentum-transfer is now almost certainly M = 1 and not M = 0. In other words there is parity-doubling--sometimes called "conspiracy." Lorentz-group properties for M = 1, if the pion had zero mass, would require a vanishing of all pion amplitudes at zero pion four-momentum. Such vanishing was one of the key consequences of PCAC, but now, as emphasized by Mandelstam,[10] we no longer need any special association between the pion and the axial current to understand the general tendency of low-energy pion amplitudes to be small. Once the mass is small and M is equal to one, Lorentz invariance does the rest.

A further low-energy prediction "derived" from PCAC was an approximate "universal" formula for all pion threshold scattering lengths. Sakurai,[11] however, has pointed out that a dominant role for the ρ pole in the crossed $\pi\pi$ amplitude suffices to explain such universality if the ρ itself has an approximately universal coupling. The latter condition is required if the ρ is to dominate the low momentum transfer region of electromagnetic form factors (as it seems to do) since these form factors at zero momentum transfer are just particle electric charges, quantities well known to have universal values. The consistency constraints operating here would allow a prediction about the threshold scattering lengths of <u>any</u> low-mass particle carrying non-zero isotopic spin. Again, a connection with the axial current is unnecessary.

We have reviewed the chief evidence arising from strong-interaction data. The case for a special pion status is seen to be unconvincing, although photoproduction experiments will of course drastically alter the picture if they can demonstrate that the pion does not lie on a Regge trajectory. In the face of the many contrary indications surveyed above, such a momentous development has to be counted at present as unlikely.

FOOTNOTES AND REFERENCES

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