Constituent, current or simply quarks ?

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Abstract

The study of the saturation of $SU(3) \times SU(3)$ chiral algebra encouraged by the success of the Adler-Weissberger sum rule for the square of the ratio $\frac{G_A}{G_V}$ has been performed with an algebraic approach, which lead to a unitary transformation between the classification group and the weak charges, which was established on heuristic grounds. By considering quarks as physical objects, as the Orsay group assumed, one was able to reproduce the form of the transformation for the motion of the quark in the containing hadron. This interpretation has been an important stone for the construction of the standard model, for which the quarks are together with the leptons the fundamental fields.

The 50's, the Golden Decade of Weak Interactions

In that decade a great progress has been achieved for weak interactions :

1) The oscillation of neutral caons proposed by Gell-Mann and Pais and studied experimentally by Piccioni inspired Bruno Pontecorvo the idea of neutrino oscillations, which will be found after various decade and is a milestone for the extension of the standard model.

2) To solve the $\theta\tau$ enigma Lee and Yang made the hypothesis of parity violation confirmed by the group lead by madame Wu in the decay of polarized cobalt.

3) Marshak and Sudarshan, and Feynman and Gell-Mann formulated the V - A theory of weak interactions.

SU(3) and Cabibbo Theory for the Weak Current oh the Hadrons

Sakata proposes that pseudoscalar mesons are built by a pair consisting of the nucleons, the hyperon Λ and their antiparticles and Gell-Mann and Neemann improve his model by classifying the eight baryons in the adjoint representation of SU(3). At conclusion of a research begun in collaboration with Gatto, Cabibbo proposes that the hadron weak current is a combination of the two charged currents of SU(3). Ademollo and Gatto show that SU(3) breaking modifies the predictions of the symmetry only at second order. Later Glashow, Iliopoulos and Maiani predict the existence, the weak couplings and the order of magnitude of the charmed quark inspired by the low values of the mass differences of the neutral caons and of the branching ratio of K^L into a pair of muons.

SU(6) and the Quark Model

In the framework of SU(3) Gell-Mann and Zweig already have introduced quarks to build the mesons. By assigning to them a spin $\frac{1}{2}$ Sakita has been able to classify in the adjoint representation of SU(6) the nonet of the vector mesons together with the octet of the pseudo calar mesons, but the demand of antisymmetry lead him to classify the spin $\frac{1}{2}$ octet of the baryons together with a SU(3) singlet with spin $\frac{3}{2}$ in the totally antisymmetric 20 representation, while the experimental evidence was for a decuplet with that spin. This circumstance lead Gursey and Radicati to propose the totally antisymmetric 56 representation, which has been shown by Beg, Pais and Singh to imply the value$-\frac{2}{3}$ for the ratio of the magnetic moments of the nucleons in good agreement with their experimental values. Greenberg and Messiah, to get the right statistics, assumed the presence of an additional SU(3) quantum number with a complete antisymmetry of the quarks: The development of that idea will bring later to the discovery of the quantum field theory of strong interactions, QCD.

The non Relativistic Quark Model

Morpurgo and his collaborators developed a non relativistic model for hadrons built with physycal quarks and tried with a Millikan like experiment to find fractional charges. They were very clever to realize that events, which might suggest fractional charges, were a consequence of experimental byers. Since other attemts to isolate quarks were unsuccessful, the attitude was to consider them mathematical objects useful to make predictions and not physical objects.

The Adler-Weissberger and the Saturation of the Chiral Algebra

By considering the proton diagonal matrix element of the commutator of two strangeness conserving axial charges in the infinite momentum frame proposed by Fubini and Furlan, Adler and Weissberger were able to write a sum rule, which allowed them to get the square of the ratio $\frac{G_A}{G_V}$ in terms of the total cross-section of the scattering of the charged pions on proton.

This result encouraged the search for solutions of the sum rules obtained by restricting the physical states to the baryons of the 56 of SU(6) by Amati and Bergia and to a larger set of states by Gatto, Maiani and Preparata. They found that by adding two representations of $SU(6) \times SO(3)$, namely the 20 with l = 1 and the 70 with L = 2, one would get the successful prediction

$$D - F = \frac{1}{3}$$

for the two reduced matrix elements of the matrix elements of the axial charge between the states of the baryon octet introduced by Cabibbo.

The Transformation Between Constituent to Current Quarks

The study of the saturation of the $SU(3) \times SU(3)$ chiral algebra was continued with my participation in Rome, Florence and Geneva at CERN with Hagen Kleinert and Carlos Alberto Savoy and gave rise to the proposal of the generator for the transformation between what will be called later constituent and current quarks :

$Z = (\boldsymbol{W} \times \boldsymbol{M})_z$

where $\boldsymbol{W}$ transforms as the spin 1 SU(3) singlet of the adjoint, 35, SU(6) representation and $\boldsymbol{M}$ as a vector of SO(3), in good agreement with experiment.

This research continued with Savoy, in collaboration with Enrico Celeghini, by demanding to satisfy the algebraic conditions established by Weinberg for the spectrum, and lead to predict linear Regge trajectories for the mesons and that the components of M commute.

What was missing was the physical interpretation of the transformation.

The Interpretation of Z by the Orsay Group

Despite the absence of evidence for particles with fractional charge the Orsay group, Alain Le Yaouanc, Luis Oliver, Olivier Pene and Jean-Claude Raynal had the happy intuition of considering quarks as physical particles and discovered as motivation for Z the relativistic motion of the quarks in the containing hadron, which will be confirmed by the form of the Melosh-Wigner transformation for the quark polarization between the directions of its momentum and the momentum of the hadron :

$\boldsymbol{\sigma} \times \frac{\boldsymbol{p}}{p_o+p_z+m}$

the form proposed for Z and the components of p commute, as we found algebraically for the components of M. The most relevant achievement of the long study on the consequences of the SU(3) chiral algebra has been that the quarks should be considered as physical particles.

The Right Polemical Paper by Celeghini and Sorace

After the paper by the Orsay group, which in a preliminary version quoted our paper as a contribution of some Italians and were obliged by the referee to change this definition for the double reason that science is international and also because the authors were not all Italian (indeed Carlos spoke a perfect Italian with a northern accent as a consequence of his previous stay in Padua and Hagen learned it as a consequence of been fond of Italian opera and we discussed physics in my mother language), Celeghini and Emanuele Sorace wrote the paper: "Neither Constituent nor Current Quarks: Simply Quarks."

They were right, since the transformation, as the Orsay group had shown, was a consequence of the motion of quarks in the hadron, but the polemical title had as a consequence the non publication in a period where a lot of people worked on the phenomenological consequences of the transformation, before realizing that all the right predictions had been found by our group some years before.

Paul Sorba to express his appreciation for the proposal of Carlos to deduce the Melosh-Wigner transformation from the Poincare' group said : "Neither Celeghini, nor Sorace : Simply Savoy".

Sakata versus Gell-Mann and the Revenge of Morpurgo

In his epistemological-philosophical paper Sakata, advocating a materialistic interpretation of the reality, criticizes what he calls the neo-positivistic attitude of Gell-Mann, which lead him to consider quarks as a useful mathematical tool without assuming their physical existence, which has been the same of Planck, when he introduced the constant, which took his name, as a mathematical trick not to be explained, or of Lorentz, who found the invariant transformation for the Maxwell equations, interpreted by Einstein with the revolutionary assumption that time is relative.

The discovery of charm and the use-fullness of the non-relativistic approximation for the mesons with hidden charm were good news for the approach of Morpurgo and his collaborators, previously considered with skepticism.

The Flavordynamics Activity of the Orsay Group

The victory of their point of view helped the "quark" group of Orsay, which was not favorably considered by the academician for the double reason of their phenomenological approach, in conflict with the traditional rigorous mathematical formation in France, and their participation to the 1968 activity, in particular against the hierarchical organization of the research activity.

It has been natural for the group the field of research opened by the experimental discovery of the charm and beauty quarks. I had the pleasure to collaborate with them in both fields on proposal of Luis, which I met at Berkeley and Paris. In particular their clever remark that the rates and the isospin sum rule for the Cabibbo allowed decays of the D^s into $\bar{K}\pi$ implied an important final state interaction has been the input to account for the large SU(3) symmetry violations in exclusive two body decays.

Between their important contributions I want to stress the determination of the Isgur Wise function, which demanded the great mathematical ingenuity of Jean-Claude.

Conclusion

The sadness for the absence of Jean-Claude may be *assouplie* by thinking that his brilliant scientific career has been a consequence not only of his exceptional mathematical talent, which allowed him to solve every complicate problem, he faced, but also of being a member of a team, where a deep friendship forbade competitive attitude, which often transforms the collaboration in hostile attitude. The example of the "quark group", which contributed to form high level scientists, by limiting to the "other half of heaven" I think to Belem Gavela and Asmaa Abada, is a very good one for how research should be efficiently organized.