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Shifman M A, Vainshtein A I & Zakharov V I. QCD and resonance physics. Theoretical foundations. *Nucl. Phys. B* 147:385-447, 1974; QCD and resonance physics. Applications. *Nucl. Phys. B* 147:448-518, 1974; and, QCD and resonance physics. The ρ-ω mixing. *Nucl. Phys. B* 147:519-34, 1974.
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Basic parameters of low-lying hadronic states are shown to be determined by the quark interaction with strong gluon fields existing in the QCD vacuum. The vacuum structure is parametrized by quark and gluon condensates. A systematic approach is developed for calculating the properties of particles built from quarks. [The *SCI*® indicates that these papers have been cited in more than 1,105, 780, and 385 publications, respectively.]

Deriving Properties of Matter from the Vacuum Structure

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After the discovery of the J/Ψ particle in 1974[1,2]—the so-called November revolution—it became obvious that all particles observed in nature are built from quarks. Free quarks do not exist—they are permanently bound by a very peculiar force whose origin is due to the quark interaction with gluons, the cementing component of hadronic matter.[3]

In the mid-1970s, I was a young postdoctoral student in the ITEP, Moscow. The theory group there was excellent—one of the best. The only drawback was that we were isolated from the world scientific community. Every publication, even a letter to a colleague abroad, had to be censored—an enormous waste of time.

For our work, the idea was to start from short distances, where the quark-gluon dynamic was under theoretical control, and then extrapolate to larger distances trying to extract maximal information on hadronic properties. Surprisingly, we started getting interesting results for heavy charmed quarks almost immediately.[4] (By "we," I mean my teachers, A. Vainshtein and V. Zakharov, and myself.) The real success came, however, after V. Novikov, L. Okun, and M. Voloshin joined us. It turned out that a whole variety of the charmonium parameters are predictable, and, for about a year, we played the game of getting particle widths and masses from simple numbers. In 1977, we submitted a review report.[5] At about that time, it became clear that our success was limited; our method could not be generalized on classical states without a new understanding and new ideas.

It was a hot summer, just before vacation, and our big collaboration ceased to exist. We—Vainshtein, Zakharov, and myself—were leisurely discussing something when the first hints appeared. The conjecture was that the vacuum is actually something like a gluon medium, and all particle properties are due to the quark interaction with this medium which can be conveniently parametrized by certain quark and gluon condensates. We worked out the first implications of the gluon condensate in fall 1977. At first, we were discouraged by a wrong sign for one of the most important particles (rho meson). Then we suddenly understood that this sign could be compensated by the four-quark condensate—a real breakthrough. The accuracy of our predictions turned out to be much higher than anyone could expect *a priori*. Inspired, we worked at a feverish pace for the whole academic year. When the final paper was ready, it contained more than 300 typewritten pages. We could not make a preprint out of it because, according to Soviet bureaucratic rules, preprints could have no more than 40 pages (or 50, I do not remember exactly). So, we divided it artificially into seven or eight parts, trying to do it in such a way that it would not be immediately obvious to the censor. It appeared as three papers occupying the whole issue of *Nuclear Physics*.

We worked on this method (it is called "QCD sum rules") until 1982. Now, all important hadronic states have been successfully described within this approach,[6] and the limits of its applicability are well established.

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