# Instanton vacuum QCD effective action beyond chiral limit

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The features of light quarks placed into instanton vacuum are concentrated in the fermionic determinant $\det_N = \det(im\delta_{ij} + a_{ji})$, calculated by Lee and Bardeen [1]. In $\det_N$ we observe the competition between current mass $m$ and zero-modes overlapping matrix element $a \sim \rho^2 R^{-3}$. With typical instanton size $\rho \sim 1/3\,fm$ and inter-instanton distance $R \sim 1\,fm$, $a$ is of the order of the strange current quark mass, $m_s = 150\,MeV$. So in this case it is very important to take properly into account the current quark mass. The partition function of light quarks $Z_N$ is the fermionic determinant $\det_N$ averaged over instanton/anti-instanton positions, orientations and sizes. Then, the properties of the hadrons and their interactions are concentrated in the QCD Effective Action. We calculate this one via fermionic representation of $\det_N$ which provide easy way for the averaging over instanton collective coordinates – positions and orientations [2]. This approach leads to the Diakonov-Petrov(DP) Effective Action [3] with a specific choice of the degrees of freedom [4]. It was shown that DP Effective Action is a good tool in the chiral limit but failed beyond this limit, checked by the calculations of the axial-anomaly low energy theorems [4]. The solution of this puzzle was found in [5,6] where it was proposed so called Improved and Modified Improved Effective Action(IA, MIA) which are more properly taken into account current quark masses and satisfied axial-anomaly low energy theorems also beyond the chiral limit. The constituent quark mass $M$ become the function of the current mass $m$ and at small $m$ $M = M_0 + \gamma m$. At abovementioned values of the $\rho, R$ $M_0 = 358\ MeV$, $\gamma = -2$. Then, the total mass $M + m$ is almost constant at the region $m < 0.2\,GeV$ and the quark condensate has a rather strong $m$ dependence. As example, the strange quarks condensate $< s^\dagger s > \sim 0.5 < u^\dagger u >$ at $m_s \sim 0.15\,GeV$. These dependencies contrasted very much naive expectations and need detailed phenomenological analysis.
At the next step we are calculating the coefficients of the phenomenological effective chiral lagrangian given by Gasser and Leutwiller [7]. In the chiral limit appropriate phenomenological terms well reproduced by the instanton vacuum based Effective Action. Beyond chiral limit there are the terms of order$O(m)$ and $O(m^2)$ specified by the couplings $\bar{l}_3$ and $\bar{l}_4$ (see [7]). The calculations with MIA lead to $\bar{l}_3 = 1.39$, $\bar{l}_4 = 3.57$. These estimations are in a good correspondence with phenomenological values $\bar{l}_3 = 2.9 \pm 2.4$, $\bar{l}_4 = 4.3 \pm 0.9$ given in [7].

**References**

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