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QCD theta-vacua from the chiral limit to the quenched limit

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We study the quark mass dependence of the QCD θ -vacua in the framework using the Veneziano – Di-Vecchia Lagrangian, which reproduces topological properties of QCD on the two boundaries related to the quark mass, i.e. the chiral limit and the quenched limit. Then we find that for any quark mass, there are the continuous structures of the vacua, including the first order phase transitions at $\theta = \pi$. We also investigate general mechanisms of the QCD θ -vacua dependent on the quark mass; how the vacuum is determined in QCD and what role then the quark mass plays for the determination. To do this we reveal the quark mass dependence of the chiral condensate. Additionally we discuss what is the difference of the phase transition at $\theta = \pi$ in the chiral and quenched limit from the point of view of the θ -vacuum structure dependent on the quark mass.

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