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Lattice caclulation of neutron and proton EDM in full QCD

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We report the recent study of neutron and proton electric dipole moment (EDM) from lattice QCD. We use the domain-wall fermion (DWF) in $N_f = 2+1$ in $24^3 \times 64$ lattice at $a^{-1} = 1.73$ GeV, which has been generated by RBC/UKQCD collaboration. DWF is suitable to control the chiral symmetry on the lattice especially near light mass. We also employ the AMA algorithm which is recently developed in order to reduce the statistical error, and as a result we obtain the finite value of neutron EDM in 300 Mev pion mass.

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Recently many plans of experiment of neutron, proton, charged particle and atoms electric dipole moment (EDM) has been proposed to more precisely search the CP-violation of QCD vacuum and higher five-dimensional operator in TeV scale physics (see Ref.[1] and references therein). Neutron EDM has been known to be sensitive to CP-violation of strong interaction between quark-gluon dynamics since strong interaction is dominated in the nucleon structure. In perturbative arguments [2, 3] the contribution from P and CP-violation of weak interaction via CKM matrix is very tiny, $|d_N^{\rm CKM}| \simeq 10^{-30}$–$10^{-32}$ e·cm whose magnitude is more than 4-digit below from current upper bound of neutron EDM 2.9×10^{-26} e·cm. Otherwise, since QCD Lagrangian has a θ-term proportional to P and CP-violating topological charge density of gluon field, neutron EDM suffering from θ-term has been expected. Highly suppression of neutron EDM from experimental measurement indicates that θ-magnitude is unexpectedly small (strong CP problem). According to quark model and many arguments of effective theories [4], the order of θ will be below 10^{-8}. The neutron EDM is also interesting object to search an indication of new physics, for instance supersymmetry (SUSY) model predicts many possible sources of CP-violating effect contributing toward neutron EDM and atom (mercury, etc) EDMs.

It is important to estimate the neutron EDM with more rigorous treatment of quark-gluon dynamics inside neutron in θ-term. Lattice QCD plays important role of this purpose since this enable theoretical calculation of hadronic contribution to EDM from the first principles. There have been several attempts of lattice calculation in quenched QCD [5, 7] and $N_f = 2$ QCD [6, 8] so far, however due to large statistical fluctuation associated with distribution of topological charge in gauge ensemble these values still have large uncertainties including some systematic errors. To reduce such uncertainties we attempt to employ chiral lattice fermion, domain-wall fermion (DWF), which approximately realizes the chiral symmetry on the lattice to being under a few % systematic ambiguity, and furthermore apply all-mode-averaging (AMA) [9], which is our developed algorithm to make use of sufficient way of machine resources. This strategy advances the accuracy of neutron EDM calculation toward 10% level with the present machine resource.

In this report we present the current status of nucleon EDM calculation using dynamical DWF gauge ensemble of $24^3 \times 64$ lattice at $a^{-1} = 1.73$ GeV^{-1} generated by RBC/UKQCD collaboration [10]. We carry out the calculation of nucleon EDM form factor which is extracted from three-point function of (nucleon)-(electromagnetic current)-(nucleon) including leading order of θ-term following the reference [5]. In AMA procedure we use $N_G = 32$ source locations to efficiently increase the statistics with sloppy CG solver relaxed stopping criteria under 0.003 normalized residual norm of CG involving deflation method. Low-mode which is used in the above is computed by Lanczos algorithm with Chebychev acceleration of 4D even-odd preconditioner of DWF kernel and we obtain 400 eigenmode for quark mass $m = 0.005$. Using near 400 configurations at two light quark masses (which correspond to 300 MeV–400 MeV pion mass) we obtain the result as shown in Table 1. We first obtain the finite value of neutron EDM over 1σ error at near 300 MeV pion in $N_f = 2+1$ QCD.

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Table 1: Lattice results of neutron and proton EDM form factor at each squared transfer momenta. Using the linear fit function we obtain EDM which is value of extrapolated form factor into zero momentum.

	$m = 0.005$		$m = 0.01$	
$-q^2$ GeV^2	neutron (e·fm)	proton (e·fm)	neutron (e·fm)	proton (e·fm)
0	−0.048(25)	0.020(39)	0.0024(21)	0.021(33)
0.198	−0.051(21)	0.018(31)	0.0003(19)	0.017(28)
0.382	−0.048(16)	0.032(23)	−0.011(13)	0.011(21)
0.555	−0.052(20)	0.020(29)	−0.018(15)	−0.0020(24)
0.721	−0.052(26)	0.031(34)	−0.014(21)	0.0075(30)

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