

Hadronic electric dipole moments in R -parity violating supersymmetryAmand Faessler,¹ Thomas Gutsche,¹ Sergey Kovalenko,² and Valery E. Lyubovitskij^{1,*}¹*Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany*²*Departamento de Física, Universidad Técnica Federico Santa María, Casilla 110-V, Valparaíso, Chile*

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We calculate the electric dipole moments (EDM) of the neutral ^{199}Hg atom, neutron and deuteron within a generic R -parity violating SUSY model (\mathcal{R}_p SUSY) on the basis of a one-pion-exchange model with CP -odd pion-nucleon interactions. We consider two types of the \mathcal{R}_p SUSY contributions to the above hadronic EDMs: via the quark chromoelectric dipole moments (CEDM) and CP -violating 4-quark interactions. We demonstrate that the former contributes to all the three studied EDMs while the latter appears only in the nuclear EDMs via the CP -odd nuclear forces. We find that the \mathcal{R}_p SUSY induced 4-quark interactions arise at tree level through the sneutrino exchange and involve only s and b quarks. Therefore, their effect in hadronic EDMs is determined by the strange and bottom-quark sea of the nucleon. From the null experimental results on the hadronic EDMs we derive the limits on the imaginary parts of certain products $\text{Im}(\lambda'\lambda'^*)$ of the trilinear \mathcal{R}_p -couplings and show that the currently best limits come from the ^{199}Hg EDM experiments. We demonstrate that some of these limits are better than those existing in the literature. We argue that future storage ring experiments on the deuteron EDM are able to improve these limits by several orders of magnitude.

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I. INTRODUCTION

Over the years CP -violation (CPV) remains one of the central themes of particle physics and cosmology. By now the manifestations of CPV have been observed experimentally in the systems of K and B mesons. In the Standard Model (SM) there are two sources of CP -violation: the CKM phases and the QCD θ -term. The former explains the observed CP -asymmetries in flavor changing K and B decays (for a recent review see, e.g. [1]) while the θ -term, being flavor blind, is irrelevant for them but contributes to flavor neutral CP -odd observables such as electric dipole moments (EDM) of nucleons and nuclei (for review see, e.g. [1–3]). Physics beyond the SM is introducing new complex parameters and, therefore, new sources of CP -violation in both flavor changing and neutral sectors. In supersymmetric (SUSY) models, these parameters come from the soft SUSY breaking sector and the superpotential μ -term.

In order to reveal the physics behind CP -violation one needs complementary information on various CP -odd observables. Among them the EDMs of leptons, nucleons and nuclei are attracting rising experimental and theoretical efforts as a sensitive probe of physics beyond the SM. During the last few years a significant progress has been achieved in experimental studies of various EDMs [4–7]. Presently there exist stringent upper bounds on the neutron EDM, d_n , [5] and the EDM, d_{Hg} , of the neutral ^{199}Hg atom [6]:

$$|d_n| \leq 3.0 \times 10^{-26} e \cdot \text{cm}, \quad (1)$$

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$$|d_{\text{Hg}}| \leq 2.1 \times 10^{-28} e \cdot \text{cm}. \quad (2)$$

Recently it was also proposed to measure the deuteron EDM, d_D , in storage ring experiments [7] with deuteron ions instead of neutral atoms. The advantage of these experiments is the absence of Schiff screening, which introduces significant uncertainties in the case of neutral atoms. This allows a direct probe of the d_D . In the near future it is hoped to obtain the experimental upper bound of

$$|d_D| \leq (1 - 3) \times 10^{-27} e \cdot \text{cm}. \quad (3)$$

The upper limits for the EDMs, derived from the above null experimental results, stringently constrain or even reject various models of CPV [2]. For the case of the SUSY models with the superpartner masses around the electroweak scale $\sim 100 \text{ GeV} - 1 \text{ TeV}$, these limits imply the CPV SUSY phases to be very small. Various aspects of the calculation of the EDMs within the popular versions of SUSY models with [8,9] and without [10–13] R -parity conservation have been studied in the literature.

In the present paper we are studying the EDMs of the ^{199}Hg atom and the deuteron as well as of the nucleon in the framework of a generic SUSY model without R -parity conservation (\mathcal{R}_p SUSY) on the basis of chiral perturbation theory (ChPT). We consider CP -violation in the hadronic sector originating from the quark chromoelectric dipole moments (CEDMs) and 4-quark effective interactions which are induced by the complex phases of the trilinear \mathcal{R}_p -couplings λ' . From the experimental bounds of Eqs. (1) and (2) we derive upper limits on the imaginary parts of the products $|\text{Im}(\lambda'_{i33}\lambda'_{i11})|$ and $|\text{Im}(\lambda'_{i22}\lambda'_{i11})|$ of the trilinear \mathcal{R}_p -couplings and compare these limits to the existing ones. We also discuss the prospects of the deuteron EDM

experiments from the view point of their ability to improve these limits.

II. HADRONIC EDMs: BASIC FORMALISM

Here we briefly outline basic formulas for the calculation of the EDMs of the neutral ^{199}Hg atom, the deuteron and nucleons. The ^{199}Hg is a diamagnetic atom with a closed electron shell. Its EDM is dominated by the nuclear CP -violating effects characterized by the Schiff moment S_{Hg} , generating a T -odd electrostatic potential for atomic electrons. The ^{199}Hg atomic EDM is given by [14]

$$d_{\text{Hg}} = -2.8 \times 10^{-4} S_{\text{Hg}} \cdot \text{fm}^{-2}. \quad (4)$$

The deuteron EDM is a theoretically rather clean problem [15] since the deuteron represents the simplest nucleus with a well understood dynamics. The corresponding EDM can be written as the sum of the three terms

$$d_D = d_p + d_n + d_D^{NN}, \quad (5)$$

where d_n , d_p are the neutron and proton EDMs, respectively, and d_D^{NN} is due to the CP -violating nuclear forces.

The EDMs of nucleons, d_n , d_p , the proton-neutron CP -odd interaction term, d_D^{NN} and the Schiff moment S_{Hg} can be evaluated on the basis of a one-pion-exchange model with CP -odd pion-nucleon interactions [3,15,16].

The CP -odd pion-nucleon interactions are conventionally classified according to their isospin (T) properties [17]:

$$|\Delta T| = 0 \text{ transition: } \mathcal{L}^{(0)} = \bar{g}^{(0)} \bar{N} \vec{\pi} \vec{\tau} N, \quad (6)$$

$$|\Delta T| = 1 \text{ transition: } \mathcal{L}^{(1)} = \bar{g}^{(1)} \bar{N} N \pi^0, \quad (7)$$

$$|\Delta T| = 2 \text{ transition: } \mathcal{L}^{(2)} = \bar{g}^{(2)} (\bar{N} \vec{\pi} \vec{\tau} N - 3 \bar{N} \tau^3 N \pi^0), \quad (8)$$

where the fields N and $\vec{\pi}$ correspond to the doublet of nucleons and triplet of pions, respectively.

For the calculation of the hadronic EDMs this Lagrangian is combined with the standard Lagrangian of the strong πNN interaction

$$\mathcal{L}_{\pi N} = g_{\pi N} \bar{N} i \gamma_5 \vec{\pi} \vec{\tau} N. \quad (9)$$

Here $g_{\pi N}$ is the CP -even πNN coupling, which in the chiral limit satisfies the Goldberger-Treiman relation:

$$g_{\pi N} = g_A \frac{m_N}{F_\pi} = 12.9, \quad (10)$$

where $g_A = 1.267$ is the nucleon axial charge, $m_N = m_p = 938.27$ MeV is the nucleon mass and $F_\pi = 92.4$ MeV is the pion decay constant. In the adopted approach the nucleon EDMs are induced by the standard one-loop diagram with the charged π -meson which involves one CP -even and one CP -odd vertex corresponding to the

terms in Eqs. (6)–(9), respectively. In the leading order of the chiral expansion one finds [18]:

$$d_n = -d_p = \frac{e g_{\pi N} (\bar{g}^{(0)} + \bar{g}^{(2)})}{4\pi^2 m_N} \ln \frac{m_N}{M_\pi}, \quad (11)$$

where $M_\pi = M_{\pi^+} = 139.57$ MeV is the π -meson mass. Thus, from Eqs. (5) and (11) it follows that the nucleon contributions to the deuteron EDM cancel out in the leading order of the chiral expansion. This cancellation is a specific result of the SU(2) version of ChPT [19] which does not hold in the SU(3) extension [9]. In the present paper we do not consider the issues of the latter case.

The pion exchange between two nucleons with one CP -even and one CP -odd vertex, corresponding to the terms in Eq. (6)–(9), respectively, generates a P - and T -odd potential of proton-neutron forces. With this potential one can calculate the d_D^{NN} term in Eq. (5) as the expectation value of $e\mathbf{r}/2$, where \mathbf{r} is the relative proton-neutron coordinate. In this way one obtains the following result [3,15]:

$$d_D^{NN} = -\frac{e g_{\pi N} \bar{g}^{(1)}}{12\pi M_\pi} \frac{1 + \xi}{(1 + 2\xi)^2}, \quad (12)$$

where $\xi = \sqrt{m_N E_B}/M_\pi$ and $E_B = 2.23$ MeV is the deuteron binding energy. Numerically, one gets

$$d_D^{NN} = -2.3 \times 10^{-14} \bar{g}^{(1)} e \cdot \text{cm}. \quad (13)$$

Recently the Schiff moment S_{Hg} [16] has been calculated within a reliable nuclear structure model which takes full account of core polarization on the basis of the P - and T -odd one-pion-exchange potential generated by the interactions in Eqs. (6)–(9). The result for a finite range interaction is

$$S_{\text{Hg}} = -0.055 g_{\pi N} (0.73 \times 10^{-2} \bar{g}^{(0)} + \bar{g}^{(1)} - 0.16 \bar{g}^{(2)}) e \cdot \text{fm}^3. \quad (14)$$

Using the above equations one can derive from the experimental upper bounds in Eqs. (1)–(3) the following constraints on the πN CPV couplings:

$$\begin{aligned} \text{present } d_{\text{Hg}}: & |0.73 \times 10^{-2} \bar{g}^{(0)} + \bar{g}^{(1)} - 0.16 \bar{g}^{(2)}| \\ & \leq 10.6 \times 10^{-12}, \end{aligned} \quad (15)$$

$$\text{present } d_n: |\bar{g}^{(0)} + \bar{g}^{(2)}| \leq 2.3 \times 10^{-12}, \quad (16)$$

$$\text{future } d_D: |\bar{g}^{(1)}| \leq (0.43\text{--}1.3) \times 10^{-13}. \quad (17)$$

As evident, the future storage ring experiments with deuterons [7] are going to improve the limit on the CPV $\Delta T = 1$ πN coupling $\bar{g}^{(1)}$ by about 2 orders of magnitude.

In what follows, we calculate the \mathcal{R}_p SUSY contributions to the quantities S_{Hg} , d_n , d_p and d_D^{NN} via the CP -odd

πNN interactions (6)–(8) and derive upper limits on the \mathcal{R}_p -couplings involved in these observables.

III. CP -VIOLATING INTERACTIONS IN \mathcal{R}_p SUSY

The effective CP -odd Lagrangian in terms of quark, gluon and photon fields up to operators of dimension six, normalized at the hadronic scale ~ 1 GeV, has the following standard form:

$$\begin{aligned} \mathcal{L}^{\text{CPV}} = & \frac{\bar{\theta}}{16\pi^2} \text{tr}(\tilde{G}_{\mu\nu} G^{\mu\nu}) - \frac{i}{2} \sum_{i=u,d,s} d_i \bar{q}_i \sigma^{\mu\nu} \gamma_5 F_{\mu\nu} q_i \\ & - \frac{i}{2} \sum_{i=u,d,s} \tilde{d}_i \bar{q}_i \sigma^{\mu\nu} \gamma_5 G_{\mu\nu}^a T^a q_i \\ & - \frac{1}{6} C_W f^{abc} G_{\mu\alpha}^a G_{\nu\beta}^b G_{\rho\sigma}^c \varepsilon^{\mu\nu\rho\sigma}, \end{aligned} \quad (18)$$

where $G_{\mu\nu}^a$ is the gluon stress tensor, $\tilde{G}_{\mu\nu} = \frac{1}{2} \varepsilon_{\mu\nu\sigma\rho} G^{\sigma\rho}$ is its dual tensor, and T^a and f^{abc} are the SU(3) generators and structure constants, respectively. In this equation the first term represents the SM QCD θ -term, while the last three terms are the nonrenormalizable effective operators induced by physics beyond the SM. The second and third terms are the dimension-five electric and chromoelectric dipole quark operators, respectively, and the last term is the dimension-six Weinberg operator. The light quark EDMs and CEDMs are denoted by d_i and \tilde{d}_i , respectively. In what follows we adopt the Peccei-Quinn mechanism, eliminating the $\bar{\theta}$ -term as an independent source of CPV.

We also consider the 4-quark CPV interactions of the form [20,21]

$$\begin{aligned} \mathcal{L}_{4q}^{\text{CPV}} = & \sum_{i,j} \{ C_{ij}^P (\bar{q}_i q_i) (\bar{q}_j i \gamma_5 q_j) + C_{ij}^T (\bar{q}_i \sigma_{\mu\nu} q_i) \\ & \times (\bar{q}_j i \sigma^{\mu\nu} \gamma_5 q_j) \}, \end{aligned} \quad (19)$$

where the sum runs over all the quark flavors $i, j = u, d, s, c, b, t$. The operators of the above Lagrangians in Eqs. (18) and (19) can be induced by physics beyond the SM at loop or tree level after integrating out the heavy degrees of freedom.

We are studying the CPV effects in the hadronic sector induced by the trilinear interactions of the \mathcal{R}_p SUSY models. The corresponding part of the R_p -violating superpotential reads:

$$W_{\mathcal{R}_p} = \lambda'_{ijk} L_i Q_j D_k^c, \quad (20)$$

where the summation over the generation indices i, j, k is understood, L, Q and D^c are the superfields of lepton-sleptons, quarks-squarks and CP -conjugated quarks-squarks, respectively, and λ'_{ijk} are the complex coupling constants violating lepton number conservation. Equation (20) results in the interactions

$$\begin{aligned} \mathcal{L}_{\lambda'} = & -\lambda'_{ijk} (\tilde{\nu}_{iL} \bar{d}_k P_L d_j + \tilde{d}_{jL} \bar{d}_k P_L \nu_i + \tilde{d}_{kR} \bar{d}_j P_R \nu_i^c \\ & - \tilde{l}_{iL} \bar{d}_k P_L u_j - \tilde{u}_{jL} \bar{d}_k P_L l_i - \tilde{d}_{kR} \bar{u}_j P_R l_i^c) + \text{H.c.} \end{aligned} \quad (21)$$

with $P_{L,R} = (1 \mp \gamma_5)/2$.

The interactions of the Lagrangian (21) generate the terms in the effective CPV Lagrangians (18) and (19) at certain orders in the λ' -couplings. It is straightforward to derive the corresponding contribution to the 4-quark contact terms (19). It arises from a tree level contribution induced by the sneutrino, $\tilde{\nu}$, exchange given by

$$\mathcal{L}_{4q}^{\text{CPV}} = [C_{sd}^P(\bar{s}s) + C_{bd}^P(\bar{b}b)](\bar{d}i\gamma_5 d) \quad (22)$$

with

$$C_{sd}^P = \sum_i \frac{\text{Im}(\lambda'_{i22} \lambda_{i11}^*)}{2m_{\tilde{\nu}(i)}^2}, \quad C_{bd}^P = \sum_i \frac{\text{Im}(\lambda'_{i33} \lambda_{i11}^*)}{2m_{\tilde{\nu}(i)}^2}, \quad (23)$$

where $m_{\tilde{\nu}}$ is the sneutrino mass. Note, that the four-quark term involving only d -quarks is absent in (22) due to $\text{Im}(\lambda'_{i11} \lambda_{i11}^*) \equiv 0$.

The interactions of the Lagrangian (21) generate the quark EDMs, d_q , and CEDMs, \tilde{d}_q , starting from 2-loops [11,12] and the dominant \mathcal{R}_p -contributions are of second order in the λ' -couplings. It was shown in Ref. [12] that the up-quark EDM and CEDM are suppressed by the light quark mass and mixing angles, which, therefore can be neglected. The quark EDMs are irrelevant for our study based on the pion-exchange model with the interaction the Lagrangian (6)–(8). We also do not consider the Weinberg term, which does not appear at the order of $O(\lambda'^2)$ unlike the quark CEDMs and 4-quark contact terms. In our analysis we use for the d -quark CEDMs the result of Ref. [12]

$$\tilde{d}_d = Z^g \frac{\alpha_s}{32\pi^3} \sum_i \frac{m_b}{m_{\tilde{\nu}(i)}^2} F\left(\frac{m_b^2}{m_{\tilde{\nu}(i)}^2}\right) \text{Im}(\lambda'_{i33} \lambda_{i11}^*), \quad (24)$$

with the loop function

$$\begin{aligned} F(x) = & \int_0^1 dy \frac{1-y(1-y)}{y(1-y)-x} \ln \frac{y(1-y)}{x} \\ & \rightarrow \frac{\pi^2}{3} + 2 + \ln x + \ln^2 x \end{aligned} \quad (25)$$

for $x \rightarrow 0$.

The expression (24) corresponds to the d -quark CEDM at the hadronic scale ~ 1 GeV. The renormalization group factor is evaluated to be $Z^g = 0.84$ [12].

IV. \mathcal{R}_p SUSY INDUCED HADRONIC EDMS

We are studying the EDMs generated by pion-exchange with the CP -odd pion-nucleon interactions given by Eqs. (6)–(8). We assume that these interactions originate from the quark level effective Lagrangian (18) and (19).

The corresponding relationships between the CPV πN -couplings, $\bar{g}^{(k)}$ of (6)–(8) and the parameters \tilde{d}_q , C_{ij}^P of (18) and (19) can be conventionally extracted from the matching condition

$$\langle \pi^0 N | \mathcal{L}^{\text{CPV}} + \mathcal{L}_{4q}^{\text{CPV}} | N \rangle = \langle \pi^0 N | \mathcal{L}^{(0)} + \mathcal{L}^{(1)} + \mathcal{L}^{(2)} | N \rangle. \quad (26)$$

In Ref. [9] the contributions of the quark CEDMs to the couplings $\bar{g}^{(k)}$ were determined on the basis of the chiral Lagrangian and of the phenomenological evaluation of the nucleon matrix elements in the l.h.s. of Eq. (26). There appear nonzero contributions only to the $\bar{g}_{\text{CEDM}}^{(0,1)}$ couplings

$$\begin{aligned} \bar{g}_{\text{CEDM}}^{(0)} &= -1.02 \times \left(\frac{\tilde{d}_d}{\text{GeV}^{-1}} \right) \\ &= -6.3 \times 10^{-7} \sum_i \text{Im}(\lambda'_{i33} \lambda_{i11}^{*}), \end{aligned} \quad (27)$$

$$\bar{g}_{\text{CEDM}}^{(1)} = 9.2 \times \left(\frac{\tilde{d}_d}{\text{GeV}^{-1}} \right) = 5.7 \times 10^{-6} \sum_i \text{Im}(\lambda'_{i33} \lambda_{i11}^{*}). \quad (28)$$

Here we disregarded the contribution of \tilde{d}_u as it is strongly suppressed in \mathcal{R}_p SUSY [12].

Because of its isospin structure, the effective 4-quark interaction in Eq. (22) contributes only to the $|\Delta T| = 1$ coupling $\bar{g}^{(1)}$ in Eq. (7). We derive the corresponding contribution using Eq. (26). In order to evaluate the matrix element in the l.h.s. of (26) we apply the relation of partial conservation of the axial current (PCAC)

$$\langle \pi^0 | \bar{d} i \gamma_5 d | 0 \rangle = -F_\pi \frac{M_\pi^2}{2m_d}, \quad (29)$$

where $m_d = 9$ MeV is the d -quark current mass. We also need to know the nucleon matrix elements of the scalar currents

$$\langle N | \bar{s} s | N \rangle = G_S^{(s)}, \quad \langle N | \bar{b} b | N \rangle = G_S^{(b)}. \quad (30)$$

The values of $G_S^{(s)}$, $G_S^{(b)}$ are subject to significant uncer-

tainties. In our analysis we use the estimates from Refs. [22,23]

$$G_S^{(s)} = (0.64\text{--}3.9), \quad G_S^{(b)} = 9 \times 10^{-3}. \quad (31)$$

For the value of $G_S^{(s)}$ we indicate the interval of possible values according to Ref. [22]. For $G_S^{(b)}$ we only need an order of magnitude estimate which will be sufficient to conclude that it is associated with the subdominant term not essential for our analysis.

From the matching condition (26) and using Eqs. (19), (23), and (29)–(31) we find for the contribution of the 4-quark interactions

$$\begin{aligned} \bar{g}_{4q}^{(1)} &= -F_\pi \frac{m_\pi^2}{2m_d} (C_{sd}^P G_S^{(s)} + C_{bd}^P G_S^{(b)}) \\ &= -(3.6\text{--}21.7) \times 10^{-9} \sum_i \text{Im}(\lambda'_{i22} \lambda_{i11}^{*}) - 5 \\ &\quad \times 10^{-11} \sum_i \text{Im}(\lambda'_{i33} \lambda_{i11}^{*}). \end{aligned} \quad (32)$$

Equations (27), (28), and (32) show that the CPV πN couplings $\bar{g}^{(0)} = \bar{g}_{\text{CEDM}}^{(0)}$ and $\bar{g}^{(1)} = \bar{g}_{\text{CEDM}}^{(1)} + \bar{g}_{4q}^{(1)}$ receive the contribution from $\text{Im}(\lambda'_{i33} \lambda_{i11}^{*})$ dominated by the d -quark CEDM while the contribution from $\text{Im}(\lambda'_{i22} \lambda_{i11}^{*})$ appears solely via the 4-quark CPV interactions (22).

Now we are ready to derive the constraints on the trilinear \mathcal{R}_p -couplings from the experimental bounds of Eqs. (15)–(17). Using the expressions (27), (28), and (32) we obtain from the above experimental bounds the upper limits on $|\text{Im}(\lambda'_{i33} \lambda_{i11}^{*})|$ and $|\text{Im}(\lambda'_{i22} \lambda_{i11}^{*})|$. These limits, extracted from the EDMs of the ^{199}Hg atom, neutron and deuteron, are given in Table I together with the existing limits on $|\lambda'_{i33} \lambda_{i11}^{*}|$ and $|\lambda'_{i22} \lambda_{i11}^{*}|$ [24]. The limits from the EDMs of ^{199}Hg and the deuteron are shown for the uncertainty interval of the scalar nucleon form factor introduced in Eq. (31). It is seen that the presently most stringent limits on $|\text{Im}(\lambda'_{ikk} \lambda_{i11}^{*})|$ come from the ^{199}Hg atom EDM (2). The forthcoming experiments on the deuteron EDM (3) are going to improve these limits by about one to 3 orders of magnitude. Note, that we obtained about

TABLE I. Upper limits on the imaginary parts of the products of the trilinear \mathcal{R}_p -couplings derived from the experimental bounds on the EDMs of neutron [5], ^{199}Hg neutral atom [6] and deuteron [7]. The existing constraints from other experiments on the absolute values of the corresponding products of \mathcal{R}_p -coupling are taken from Ref. [24]. The limits are evaluated with all the superpartner masses equal to 300 GeV.

Experiment	d_n [5]	d_{Hg} [6]	d_D [7]	Existing limits [24]
$\sum_i \text{Im}(\lambda'_{i33} \lambda_{i11}^{*}) $	3.6×10^{-6}	1.9×10^{-6}	$(0.8\text{--}3.2) \times 10^{-8}$	$ \lambda'_{133} \lambda_{111}^{*} \leq 4.5 \times 10^{-5}$ $ \lambda'_{233} \lambda_{211}^{*} \leq 5.4 \times 10^{-3}$ $ \lambda'_{333} \lambda_{311}^{*} \leq 1.3 \times 10^{-3}$
$\sum_i \text{Im}(\lambda'_{i22} \lambda_{i11}^{*}) $	-	$(0.3\text{--}1.9) \times 10^{-3}$	$(2\text{--}36.1) \times 10^{-6}$	$ \lambda'_{122} \lambda_{111}^{*} \leq 4.5 \times 10^{-5}$ $ \lambda'_{222} \lambda_{211}^{*} \leq 1.3 \times 10^{-3}$ $ \lambda'_{322} \lambda_{311}^{*} \leq 1.3 \times 10^{-3}$

1-order of magnitude improvement for the limit $|\text{Im}(\lambda'_{133}\lambda'^*_{i11})| \leq 1.2 \times 10^{-5}$ previously derived in Ref. [12] from the neutron EDM constraint (1) on the basis of the SU(6) quark model. The existing limits on the absolute values of the corresponding products of the λ' -couplings depreciate the present EDM limits on $|\text{Im}(\lambda'_{122}\lambda'^*_{i11})|$, being more stringent, while they do not exclude the values of $|\text{Im}(\lambda'_{133}\lambda'^*_{i11})|$ within the limits derived from EDMs. We also observe that the future deuteron EDM experiments are expected to decrease the upper limits on $|\text{Im}(\lambda'_{122}\lambda'^*_{i11})|$ below the values excluded by the existing limits on the absolute values of these products.

V. SUMMARY AND CONCLUSIONS

We have studied the contributions of the trilinear \mathcal{R}_p -couplings to the ^{199}Hg atom, neutron and deuteron EDMs within ChPT, applying the pion-exchange model of CPV nuclear forces. We have analyzed the \mathcal{R}_p -contributions via the d -quark CEDM and CPV 4-quark interactions. We have shown that the \mathcal{R}_p SUSY induced 4-quark interactions contributes only to the nuclear EDMs such as ^{199}Hg and deuteron EDMs via the CPV nuclear forces and do not contribute to the neutron EDM. We have

also found that these two type of mechanisms give rise to a dependence of the hadronic EDMs proportional to different λ' -couplings. Therefore, taking into account both mechanism allows one to obtain a complimentary information on the imaginary parts of the products of the λ' -couplings. The corresponding upper limits from the null experimental results on measurements of the above mentioned hadronic EDMs are given in Table I. We have demonstrated that the present limits from the ^{199}Hg EDM experiments are by a factor ~ 6 more stringent than those from the experiments on the neutron EDM and that the planned storage ring experiments with the deuterium ions would be able to significantly improve these limits.

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