Electric Dipole Moments in Gauge Mediated Models
and a Solution to the SUSY CP Problem

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Abstract

The SUSY CP problem in the framework of gauge mediated SUSY breaking model is considered. We first discuss the electric dipole moments of the electron and neutron, which are likely to be larger than the experimental upper bound if all the phases in the Lagrangian are $O(1)$. We derive a constraint on the phases in the so-called $\mu$- and $B_\mu$-parameters and gaugino masses. Then, we discuss a model in which the CP violating phase can be adequately suppressed. If the $\mu$- and $B_\mu$-parameters originate from the same superpotential interaction as the SUSY breaking field, the CP violating phase vanishes. However, in this class of models, the ratio $B_\mu/\mu$ becomes too large, and we discuss a possible scenario to fix this problem.
1 Introduction

Supersymmetry (SUSY) is an attractive solution to one of the most serious fine-tunings in nature, i.e., it ensures the stability of the electroweak scale against radiative corrections. However, the SUSY standard model (SSM) may introduce other (less severe) fine-tunings, since some of the parameters in the SSM and/or their phases must be very small to avoid unwanted FCNC and CP violating processes. (These are called SUSY FCNC problem and SUSY CP problem.)

In gauge mediated SUSY breaking model [1], the SUSY FCNC problem can be beautifully solved. In this scheme, the mechanism to mediate SUSY breaking to the SSM sector does not distinguish between flavors, and the universality of the scalar mass matrices is automatically guaranteed.

However, the SUSY CP problem still remains. In particular, in gauge mediated model, the electric dipole moments (EDMs) of the electron and neutron are likely to be larger than the current experimental constraint if the possible phases in the Lagrangian are all $O(1)$. Therefore, it is better to come up with some idea to suppress the CP violating phase in the gauge mediated model.

In the first half of this letter, we discuss the electron and neutron EDMs in the framework of the gauge mediated model, and derive a constraint on the CP violating phase. As a result, we will see that the EDMs are likely to be larger than the current experimental constraint if the CP violating phase is $O(1)$. Then, in the second half, we consider a mechanism to suppress this CP violating phase so that the EDMs are within the experimental constraints.

2 SUSY CP Problem in Gauge Mediated Model

First, we discuss constraints on the phases in the gauge mediated model. In the gauge mediated model, all the off-diagonal elements in the sfermion mass matrices vanish. Furthermore, so-called $A$-parameters are not generated at the one loop level. Therefore, CP violating phases in these parameters are suppressed enough to be consistent with experimental constraints.
However, (some combinations of) the phases in the gaugino masses, $\mu$-parameter, and $B_\mu$-parameter are physical, and in general, they can be large enough to conflict with experimental constraints. In particular, since the mechanism to generate $\mu$- and $B_\mu$-parameters are unknown, there is no guarantee of cancellation between their phases.

Let us discuss this issue in more detail. The relevant part of the Lagrangian of the SSM can be written as

$$\mathcal{L} = -\int d^2\theta \mu H_1 H_2 - B_\mu H_1 H_2 - \frac{1}{2} \left( m_{G1} \tilde{B} \tilde{B} + m_{G2} \tilde{W} \tilde{W} + m_{G3} \tilde{G} \tilde{G} \right) + \text{h.c.} \quad (1)$$

Here, $H_1$ and $H_2$ are the Higgs fields coupled to the down-type and up-type quarks, and $\tilde{B}$, $\tilde{W}$, and $\tilde{G}$ are the gauginos for $U(1)_Y$, $SU(2)_L$, and $SU(3)_C$ gauge groups, respectively. In the above Lagrangian, all the parameters $\mu$, $B_\mu$, and $m_{Gi}$ can be complex. However, by using phase rotations of Higgs bosons, Higgsinos, and gauginos, we can make some of them real. To be more specific, denoting

$$\mu = e^{i\theta_\mu} |\mu|, \quad B_\mu = e^{i\theta_B} |B_\mu|, \quad m_{Gi} = e^{i\theta_G} |m_{Gi}|,$$  

physical quantities depend only on the combination

$$\theta_{\text{phys}} \equiv \text{Arg}(\mu B_\mu^* m_G) = \theta_\mu - \theta_B + \theta_G. \quad (3)$$

In the gauge mediated model, flavor symmetries are well preserved in the squark and slepton mass matrices, and SUSY contributions to the CP violation in FCNC processes are negligible. However, as discussed in many works \cite{2}, the EDMs of the electron and neutron are important check points. Indeed, non-vanishing $\theta_{\text{phys}}$ may induce sizable EDMs.

In order to discuss the constraint on $\theta_{\text{phys}}$, we calculate the electron EDM $d_e$ in the framework of the gauge mediated model for several values of the messenger scale $M_{\text{mess}}$. In the calculation, we take $\sin \theta_{\text{phys}} = 1$ and $N_5 = 1$, where $N_5$ is the number of the vector-like messenger multiplet in units of $\bar{5} + 5$ representation of $SU(5)_G$. The result is shown in Fig. 1. One should note that $d_e$ is proportional to $\sin \theta_{\text{phys}}$, and hence we can estimate $d_e$ for other values of $\sin \theta_{\text{phys}}$ by rescaling the result given in Fig. 1. Furthermore, the EDM of the electron is enhanced for larger values of $\tan \beta \equiv \langle H_2 \rangle / \langle H_1 \rangle$. The mechanism #1In gauge mediated model, phases of the gaugino masses are universal, and we denote them as $\theta_G$.\footnote{In gauge mediated model, phases of the gaugino masses are universal, and we denote them as $\theta_G$.}
of this enhancement is the same as those for other leptonic penguin diagrams such as for the muon magnetic dipole moment [3, 4] and for lepton-flavor violating processes [5]. In particular, the electron EDM comes from diagrams which are very similar to those for the muon $g-2$, and those quantities are closely related in the gauge mediated model:

$$d_e \simeq \frac{m_e}{2m_{\mu}} \tan \theta_{\text{phys}} \times a_{\mu}^{\text{SSM}},$$

where $a_{\mu}^{\text{SSM}} = \frac{1}{2}(g_{\mu} - 2)^{\text{SSM}}$ is the SSM contribution to the muon magnetic dipole moment.

The experimental constraint on the electron EDM is remarkably good. By using $d_e = (0.18 \pm 0.12 \pm 0.10) \times 10^{-26} e \text{ cm}[6]$, we obtain a constraint on the electron EDM:

$$|d_e| \leq 0.44 \times 10^{-26} e \text{ cm},$$

where the right-hand side is the upper bound on $d_e$ at 90 % C.L.

With the above constraint, we can derive a bound on $\theta_{\text{phys}}$. Since $d_e$ is proportional to $\sin \theta_{\text{phys}}$, the upper bound on $|\sin \theta_{\text{phys}}|$ is given by $10^{-1}$ to $10^{-3}$, depending on the
mass scale of the superparticles and $\tan \beta$. If we adopt relatively large value of the wino mass ($m_{\text{G}_2} \gtrsim 400 \, \text{GeV} - 1 \, \text{TeV}$, depending on $\tan \beta$), $\theta_{\text{phys}}$ can be as large as 0.1, and it may not be a serious fine tuning. However, in this case, squarks and gluino become relatively heavy, and we may lose the motivation for low energy SUSY as a solution to the naturalness problem. On the other hand, if we consider lighter wino, $\theta_{\text{phys}}$ is constrained to be less than $O(10^{-2})$, which requires more fine tuning of this phase. In the following, we consider a solution to this problem.\(^{\#2}\)

Before discussing the model to suppress $\theta_{\text{phys}}$, we briefly comment on the constraint from the neutron EDM $d_n$. We can also obtain a constraint on $\theta_{\text{phys}}$ from the neutron EDM. However, the constraint is less severe because the experimental constraint on $d_n$ is not as stringent as that on $d_e$, and also because the heavier squark masses suppress the theoretical value of $d_n$. With the same underlying parameters, the constraint on $\theta_{\text{phys}}$ is about a few times weaker from $d_n$ than from $d_e$.

## 3 Toy Model and Basic Idea

Let us consider a toy model in which $\theta_{\text{phys}}$ vanishes automatically.

We denote $X$ as the SUSY breaking field whose scalar and $F$-components acquire non-vanishing vacuum expectation values (VEVs). Furthermore, $q$ and $\bar{q}$ are the vector-like messenger fields, and SUSY breaking parameters in the SSM sector are generated by integrating them out. In this section, we do not specify the mechanism that generates an $F$-component for $X$, and we just adopt the following form of the superpotential:

$$W = X F_X^* + y_q X \bar{q} q + \frac{y_H}{M_*^{n-1}} X^n H_1 H_2,$$

where $F_X$ is the VEV of the $F$-component for $X$, $y_q$ and $y_H$ are complex parameters, $n$ is a fixed integer, and $M_* \simeq 2.4 \times 10^{18}$ GeV is the reduced Planck scale.

With the above superpotential, $\mu$, $B_\mu$, and $m_{G_i}$ are given by

$$\mu = \frac{y_H}{M_*^{n-1}} \langle X^n \rangle,$$

\(^{\#2}\)In the gauge mediated model, the SUSY CP problem can be solved if $B_\mu$ vanishes at the messenger scale. For this approach, see Refs. 7, 16.
\[
B_\mu = \frac{n_{H\nu}}{M_{\nu}^{n-1}} \langle X^{n-1} \rangle F_X, \tag{8}
\]

\[
m_{Gi} = \frac{g_i^2}{16\pi^2} c_i N_5 \frac{F_X}{\langle X \rangle}, \tag{9}
\]

where \( g_i \) is the relevant gauge coupling constant for the standard model gauge group and \( c_i \) is the group theoretical factor. From these expressions, we can easily see \( \theta_{\text{phys}} \) vanishes.

In other words, all the phases in the Lagrangian can be eliminated with phase rotations of the scalars, chiral fermions, and gauginos. Therefore, in this case, there is no CP violation in the SSM (except for the phase in the KM matrix).

However, this scenario is not phenomenologically viable, since the relative size of the \( \mu^- \) and \( B_\mu^- \) parameters is not in the required range. The ratio of \( B_\mu \) to \( \mu \) is given by

\[
\frac{B_\mu}{\mu} = \frac{nF_X}{\langle X \rangle}. \tag{10}
\]

On the other hand, if \( N_5 \sim O(1) \), mass scale of the superparticles in the SSM sector is estimated as

\[
m_{\text{SSM}} \sim \frac{g_{\text{SM}}^2}{16\pi^2} \left| \frac{F_X}{\langle X \rangle} \right|, \tag{11}
\]

where \( g_{\text{SM}} \) is the relevant gauge coupling constant of the standard model gauge groups.

Then, the ratio \( F_X / \langle X \rangle \) has to be of the order of \( 10^{−100} \) TeV, where the lower bound is from the experimental constraint on the masses of the superparticles while the upper bound is from the naturalness point of view. As a result, the ratio given in Eq. (10) is about 2 − 3 orders of magnitude larger than the phenomenologically acceptable value \( \frac{B_\mu}{\mu} \).

Therefore, this toy model does not work although it has the attractive feature of vanishing CP violating phase \( \theta_{\text{phys}} \).

### 4 Improved Model

Now, we propose an improved model in which the ratio \( B_\mu / \mu \) can be in the required range. One possibility to suppress the ratio \( B_\mu / \mu \) is to introduce another field which also

\#3If the messenger multiplets have large multiplicity of \( N_5 \sim 100 \), \( F_X / \langle X \rangle \) can be smaller (see Eq. (10)) and \( B_\mu / \mu \) may be in the required range. Even if \( N_5 \sim 100 \), perturbative picture can be valid up to the Planck scale if the messenger scale is as high as \( O(10^{16} \text{ GeV}) \). In this case, the SUSY breaking scalar masses are significantly suppressed at the messenger scale, but can be generated by the running effect.
acquires a VEV. If this new field couples to the Higgs fields, and also if it can generate a large enough \( \mu \)-parameter, the ratio \( B_\mu/\mu \) may be in the required range. Of course, if the VEV of this new field has an arbitrary phase, the SUSY CP problem cannot be solved. Therefore, the new field has to be somehow related to the original SUSY breaking field \( X \).

In our model, we duplicate the SUSY breaking sector, and couple both of them to the Higgs fields. Then, if the SUSY breaking field in one sector has a larger VEV than the other, the \( \mu \)-parameter is enhanced and the ratio \( B_\mu/\mu \) can have a required value. Furthermore, in order not to introduce a new phase which may spoil the cancellation in \( \theta_{\text{phys}} \), we impose symmetry which interchanges these two sectors. If this symmetry is exact, however, the hierarchy between the VEVs of the two SUSY breaking fields cannot be generated. Therefore, we introduce a (small) breaking parameter of this symmetry.

There are two conflicting requirements on the breaking parameter. First, this breaking parameter has to be large enough so that the VEV of one SUSY breaking field is about 2 – 3 orders of magnitude enhanced relative to the other. On the contrary, if this breaking parameter is too large, its CP violating phase may spoil the cancellation in \( \theta_{\text{phys}} \).

It is non-trivial to generate a large enough hierarchy with such a small breaking parameter. If the VEV of the SUSY breaking field is determined by the inverted hierarchy mechanism \[8\], however, small modifications of the parameters may significantly change the VEV of the SUSY breaking field. In particular, in this class of models \[9, 10\], the potential of the SUSY breaking field is lifted only logarithmically, and a small perturbation at the Planck scale can result in a significant change of the minimum of the potential. In this section, we use a simple model as an example, and see how the scenario mentioned above can work.

In our discussion, we use a model based on \([\text{SU}(2)]^3 \times [\text{SU}(2)]^3 \times \text{SU}(5)_G\) symmetry as an example, where the standard model gauge group \( \text{SU}(3)_C \times \text{SU}(2)_L \times \text{U}(1)_Y \) is embedded in \( \text{SU}(5)_G \) in the usual manner. (For the original SUSY breaking model based on the inverted hierarchy mechanism with \([\text{SU}(2)]^3 \times \text{SU}(5)_G\), see Ref. \[10\].) We show the particle content of this model in Table 1. Here, \( \text{SU}(2)_S \) and \( \text{SU}(2)'_S \) are strong gauge interactions which break supersymmetry, while \( \text{SU}(2)_B \)'s are introduced to stabilize the potentials for the SUSY breaking fields.
Table 1: Particle content of the model.

|       | SU(2)$_{B1}$ | SU(2)$_{B2}$ | SU(2)$_S$ | SU(2)$'_{B1}$ | SU(2)$'_{B2}$ | SU(2)$'_{S}$ | SU(5)$_G$ |
|-------|--------------|--------------|-----------|--------------|--------------|--------------|-----------|
| $\Sigma$ | 2            | 2            | 1         | 1            | 1            | 1            | 1         |
| $Q$    | 2            | 1            | 2         | 1            | 1            | 1            | 1         |
| $Q'$   | 1            | 2            | 2         | 1            | 1            | 1            | 1         |
| $q_5$  | 2            | 1            | 1         | 1            | 1            | 1            | 5         |
| $\bar{q}_5$ | 1          | 2            | 1         | 1            | 1            | 1            | 5         |
| $q_1$  | 2            | 1            | 1         | 1            | 1            | 1            | 1         |
| $\bar{q}_1$ | 1          | 2            | 1         | 1            | 1            | 1            | 1         |
| $\Sigma'$ | 1           | 1            | 1         | 2            | 2            | 1            | 1         |
| $Q'$   | 1            | 1            | 1         | 2            | 1            | 2            | 1         |
| $q'_5$ | 1            | 1            | 1         | 2            | 1            | 1            | 5         |
| $\bar{q}'_5$ | 1          | 1            | 1         | 2            | 1            | 1            | 5         |
| $q'_1$ | 1            | 1            | 1         | 2            | 1            | 1            | 1         |
| $\bar{q}'_1$ | 1          | 1            | 1         | 2            | 1            | 1            | 1         |

Assuming a symmetry which interchanges the $[SU(2)]^3$ and $[SU(2)']^3$ sectors (which we call $Z_2^{X\leftrightarrow X'}$ symmetry), the superpotential has the following form:

$$W = y_Q \Sigma \bar{Q} Q + y_5 \Sigma \bar{q}_5 q_5 + y_1 \Sigma \bar{q}_1 q_1 + y_Q (1 + \epsilon_Q) \Sigma' \bar{Q}' Q' + y_5 (1 + \epsilon_5) \Sigma' \bar{q}_5' q_5' + y_1 (1 + \epsilon_1) \Sigma' \bar{q}_1' q_1' + \frac{y_H}{M_*} \text{det} \Sigma H_1 H_2 + \frac{y_H}{M_*} (1 + \epsilon_H) \text{det} \Sigma' H_1 H_2,$$

(12)

where the $\epsilon$'s are the breaking parameters of $Z_2^{X\leftrightarrow X'}$. If all $\epsilon$'s vanish, there is a $Z_2^{X\leftrightarrow X'}$ symmetry.

The symmetry breaking parameters $\epsilon$'s may arise from a VEV of a field $\phi$ which transforms as $\phi \rightarrow -\phi$ under $Z_2^{X\leftrightarrow X'}$, for example. If $\phi$ has a coupling like

$$W \sim y_1 (\Sigma \bar{q}_1 q_1 + \Sigma' \bar{q}_1' q_1') + \frac{\phi}{M_*} (\Sigma \bar{q}_1 q_1 - \Sigma' \bar{q}_1' q_1'),$$

(13)
a small $\epsilon_1$ can be generated if $\phi$ acquires a VEV smaller than $y_1 M_*$. Similar arguments hold for other breaking parameters. Here, we do not specify the origin of the symmetry breaking, and just assume they are somehow generated at the Planck scale.\[^{#1}]

\[^{#1}\]For example, a quantum modified constraint can induce a VEV of the symmetry breaking field $\phi$.\[^{11}\]
In this model, SUSY is dynamically broken because of the quantum modified constraint \[12\]. Concentrating on the flat direction parametrized as \(\Sigma \sim \text{diag}(X, X)\) and \(\Sigma' \sim \text{diag}(X', X')\), the superpotential becomes \[11\]

\[
W = y_Q \Lambda^2 X + y_5 X q_5 q_5 + y_1 X q_1 q_1 + y_Q (1 + \epsilon_Q) \Lambda'^2 X' + y_5 (1 + \epsilon_5) X' q_5' q_5' + y_1 (1 + \epsilon_1) X' q_1' q_1'
\]

\[
+ \frac{y_H}{M_*} X^2 H_1 H_2 + \frac{y_H}{M_*} (1 + \epsilon_H) X'^2 H_1 H_2,
\]

where \(\Lambda\) and \(\Lambda'\) are the strong scales of SU(2)\(_S\) and SU(2)'\(_S\), respectively. Due to \(Z_X \leftrightarrow X^{\prime 2}\), we adopt \(\Lambda = \Lambda'\). Because of the \(\Lambda^2 X\) and \(\Lambda'^2 X'\) terms in the superpotential, \(X\) and \(X'\) have VEVs in \(F\)-components and the SUSY is broken.

Once \(X\) and \(X'\) acquire VEVs, three important parameters are given by

\[
\mu = \frac{y_H}{M_*} \langle X^2 \rangle + \frac{y_H}{M_*} \langle X'^2 \rangle (1 + \epsilon_H),
\]

\[
B_\mu = \frac{2 y_H}{M_*} F_X \langle X \rangle + \frac{2 y_H}{M_*} F_X \langle X' \rangle (1 + \epsilon_H) (1 + \epsilon^*_Q),
\]

\[
m_{G_i} = \frac{g_2^2}{8 \pi^2} c_i \frac{F_X}{\langle X \rangle} + \frac{g_2^2}{8 \pi^2} c_i \frac{F_X}{\langle X' \rangle} (1 + \epsilon^*_Q).
\]

Then, denoting

\[
v \equiv |\langle X \rangle|, \quad v' \equiv |\langle X' \rangle|,
\]

hierarchy between \(v\) and \(v'\) can make the ratio \(B_\mu/\mu\) to be in the required range. This is because, for \(v \ll v'\), \(\mu\)- and \(B_\mu\)-parameters are dominated by the second term, while the gaugino mass is determined by the first one. Adopting, for example, \(|F_X| \sim (10^6 \text{ GeV})^2\), \(v \sim 10^8 \text{ GeV}, y_H \sim 1\), and \(v'/v \sim 10^2 - 10^3\), all the parameters in the SSM sector are in the required range. In the following, we see how the VEVs and their large hierarchy are generated.

At the tree level, the potential for the SUSY breaking fields are completely flat and the minimum of the potential is undetermined. However, once we consider the wave function renormalization of the SUSY breaking fields, the potential has a minimum. Denoting the wave function renormalization for \(\Sigma\) and \(\Sigma'\) as \(Z_\Sigma\) and \(Z_{\Sigma'}\), respectively, the potential is given by

\[
V = \frac{|F_X|^2}{Z_\Sigma} + \frac{|F_{X'}|^2}{Z_{\Sigma'}},
\]
where
\[ F_X^* = y_Q \Lambda^2, \quad F_{X'}^* = y_Q (1 + \epsilon_Q) \Lambda^2 = (1 + \epsilon_Q) F_X^*. \] (20)

Therefore, the potential for the SUSY breaking field has a minimum when \( Z_\Sigma \) and \( Z_{\Sigma'} \) are maximized. The minimum of the potential can be estimated by using the renormalization group equations (RGEs). In our discussion, for simplicity, we take account of the effect of \( g_{B1} \) and \( y_1 \) with \( g_{B1} \) being the gauge coupling constant for \( SU(2)_{B1} \), and neglect the effects of other coupling constants. This approximation is motivated by the fact that \( y_1 \) plays the most important role among the Yukawa coupling constants in determining the minimum of the potential (see Ref. [10]). Then, \( v = |\langle X \rangle| \) is determined by solving
\[ \frac{3}{2} g_{B1}^2 (v) - y_1^2 (v) = 0. \] (21)
Similar argument holds for the potential of \( X' \).

Since the scale dependence of the gauge and Yukawa coupling constants are logarithmic, small modification of the boundary condition at the Planck scale may result in a significant shift of the minimum of the potential. In our analysis, we solve the RGEs numerically to see how the minimum depends on the boundary conditions. For this purpose, we first fix \( g_{B1} \) and \( y_1 \) at the reduced Planck scale \( M_* \). Then, neglecting other coupling constants, we run them down to the low energy scale and find the scale \( v \) where \( Z_\Sigma \) is maximized (i.e., the VEV of \( X \)). In Fig. 2, we show \( v \) as a function of \( y_1 (M_*) \) for several values of \( g_{B1} (M_*) \). As one can see, the VEV of \( X \) is sensitive to \( y_1 (M_*) \), and small modification of \( y_1 (M_*) \) results in a large shift of the minimum of the potential. Fig. 3 shows that \( v \) and \( v' \) can differ by \( 2 - 3 \) orders of magnitude with a small breaking parameter of \( \epsilon_1 \sim 10^{-2} - 10^{-1} \), depending on \( g_{B1} \). Notice that \( \ln(v'/v) \sim \ln[(F_X/\langle X \rangle)/(B_\mu/\mu)] \) is approximately proportional to \( \epsilon_1 \). For example, for \( 10^2 \leq v'/v \leq 10^3 \), \( \epsilon_1 \) is required to be \( 0.02 \leq \epsilon_1 \leq 0.03 \) \( (0.04 \leq \epsilon_1 \leq 0.06, 0.08 \leq \epsilon_1 \leq 0.12) \) for \( g_{B1} (M_*) = 0.3 \) \( (0.4, 0.5) \). Therefore, in order to make the ratio \( (F_X/\langle X \rangle)/(B_\mu/\mu) \) of the order of \( 10^2 - 10^3 \), \( \epsilon_1 \) has to be mildly tuned at \( \sim 50 \% \) level. We believe this is not a serious fine tuning.

Furthermore, most importantly, \( \theta_{\text{phys}} \) becomes suppressed in this model. In order to see this suppression, we have to know the phases of \( \langle X \rangle \) and \( \langle X' \rangle \). So far, the phases of \( \langle X \rangle \) and \( \langle X' \rangle \) are not determined, since they are related to the \( R \)-symmetry. In supergravity
Figure 2: $v \equiv |\langle X \rangle|$ as a functions of $y_1(M_\ast)$. $g_{B1}(M_\ast)$ is taken to be 0.3 (solid), 0.4 (dotted), and 0.5 (dashed).

models, however, a constant term exists in the superpotential to cancel the cosmological constant. This constant term does not respect the $R$-symmetry and fixes the phases \[13\].

The supergravity contributions to the potential are written as

$$V_{\text{SUGRA}} = A_Q F_X^* X + A_Q F_{X'}^* (1 + \epsilon_A) X' + \text{h.c.},$$

where $A_Q$ is a complex SUSY breaking parameter which is of the order of the gravitino mass. With this potential, for example, the phase of $\langle X \rangle$ is determined so that the combination $A_Q F_X^* \langle X \rangle$ becomes real. Then, the relative phase of $\langle X \rangle$ and $\langle X' \rangle$ is given by

$$\text{Arg} \left( \frac{\langle X' \rangle}{\langle X \rangle} \right) \simeq \text{Im}(\epsilon_Q^* + \epsilon_A^*).$$

Therefore, these VEVs are almost aligned irrespective of their absolute values.

By using Eq. \[23\], $\theta_{\text{phys}}$ is calculated as

$$\theta_{\text{phys}} \sim \text{Im} \epsilon_A^*.$$ 

Therefore, with the current constraint \[3\], the electron EDM can be suppressed enough for mild values of $\tan \beta$ (less than about 10) with $\epsilon_A \sim O(10^{-2})$ (see Fig. \[1\]). Even if all
the breaking parameters are of the same order, \( \epsilon \sim O(10^{-2}) \) can induce large enough \( v'/v \). For larger value of \( \tan \beta \), \( \epsilon_A \) as small as \( O(10^{-3}) \) is required.

In fact, \( \theta_{\text{phys}} \) depends only on \( \epsilon_A \) as shown in Eq. (24), while \( \epsilon_1 \) plays the most important role in shifting the VEV. Therefore, if the breaking parameters may have hierarchy, requirements on the model are more relaxed. In particular, in the framework of supergravity, \( \epsilon_A \) vanishes if \( \epsilon_Q \) vanishes and also if the Kähler potential respects \( Z^X \leftrightarrow Z^{X'} \) symmetry. In this case, we avoid the constraint from the EDMs, and \( \epsilon_1 \) can be much larger than \( \epsilon_A \). For example, if the \( Z^X \leftrightarrow Z^{X'} \) symmetry breaking field \( \phi \) and the Yukawa coupling \( y_1 \) have a non-trivial transformation property under some symmetry (like \( R \)-symmetry), \( \epsilon_A \) is expected to be \( O(y_1^2 \epsilon_1) \), which can be suppressed for smaller \( y_1 \).

In our discussion, we assumed that there is no effect of the \( Z^X \leftrightarrow Z^{X'} \) symmetry breaking in the gauge kinetic function. If there is such an effect for the strong gauge groups \( \text{SU}(2)_S \) and \( \text{SU}(2)'_S \), the relative phase of \( \Lambda \) and \( \Lambda' \) becomes \( O(8\pi^2 \epsilon/g^2_S) \), where \( g_S \) is the gauge coupling constant for the strong gauge groups. Therefore, small symmetry breaking effect may induce a large shift of the relative phase of \( F_X \) and \( F_{X'} \), resulting in a large \( \epsilon_{A} \). Therefore, the \( Z^X \leftrightarrow Z^{X'} \) symmetry breaking in the gauge kinetic function is disfavored. This effect can also be killed if non-trivial transformation properties for some symmetry are assigned for the symmetry breaking parameters.

5 Summary

In the first half of this letter, we calculated the EDM of the electron in the framework of the gauge mediated model. If all the phases in the Lagrangian are \( O(1) \), the electron EDM is larger than the current experimental constraint. If all the superparticles have masses of \( O(100 \text{ GeV}) \), for example, the CP violating phase \( \theta_{\text{phys}} \) has to be smaller than \( O(10^{-2}) - O(10^{-3}) \) depending on \( \tan \beta \).

Regarding this tuning as a problem, we considered a mechanism to suppress the CP violating phase. If the \( \mu \)- and \( B_{\mu} \)-parameters originate from the same coupling to the

\#5This may not happen if the coupling constants for the strong gauge groups become non-perturbative at the Planck scale.

\#6Contrary to the strong gauge groups, there may be an effect of the \( Z^X \leftrightarrow Z^{X'} \) symmetry breaking in the balancing gauge groups sector (\( \text{SU}(2)'_S \)'s), since our result is not affected by the phases of the strong scales of these interactions. Of course, the hierarchy between \( v \) and \( v' \) is affected by this effect.
SUSY breaking field in the superpotential, the physical phase is cancelled out. However, the ratio $B_\mu/\mu$ becomes too large in a naive model. Therefore, we introduced another sector to suppress this ratio. Even with the new field, we have seen that the smallness of the physical phase $\theta_{\text{phys}}$ can be realized by a symmetry.

Finally, we note that the strong CP problem cannot be solved in our model. This feature is common to the case of the SSM, and some mechanism is needed to solve this problem, like Peccei-Quinn symmetry \[4\].

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