Effect on the electron EDM due to abelian gauginos in SUSY extra $U(1)$ models

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Abstract
The electric dipole moment of an electron (EDME) is investigated in the supersymmetric extra $U(1)$ models. Neutralino sector is generally extended in these models and then the neutralino contribution will be important for the analysis of the EDME. Kinetic term mixings of abelian gauginos are taken into account in our analysis. Numerical results for the extra $U(1)$ models show that the EDME can be affected by the extra $U(1)$ in a certain range of soft supersymmetry breaking parameters even if the extra $U(1)$ gauge boson is heavy. The EDME may be a clue to find an extended gauge structure in the supersymmetric models.

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Recently the standard model (SM) has been confirmed in the incredible accuracy through the precise measurement at LEP. Nevertheless, it has still not been considered as the fundamental theory of particle physics and physics beyond the SM is eagerly explored. Along this line supersymmetrization of the SM is now considered as the most promising extension [1]. Even in this minimal supersymmetric standard model (MSSM), however, there remain some theoretically unsatisfactory features in addition to the existence of too many parameters. One of these is known as the $\mu$-problem [2]. The MSSM has a supersymmetric Higgs mixing term $\mu H_1 H_2$. To cause an appropriate radiative symmetry breaking at the weak scale we should put $\mu \sim O(G_F^{-1/2})$ by hand, where $G_F$ is a Fermi constant. Although in the supersymmetric model its typical scale is generally characterized by the supersymmetry breaking scale $M_S$, there is no reason why $\mu$ should be such a scale because it is usually considered to be irrelevant to the supersymmetry breaking. The reasonable way to answer this issue is to consider the origin of $\mu$ scale as a result of the supersymmetry breaking [3]. One of such solution is the introduction of a singlet field $S$ and replace $\mu H_1 H_2$ by a Yukawa type coupling $\lambda S H_1 H_2$ [4]. If $S$ get a vacuum expectation value (VEV) of order 1 TeV as a result of radiative corrections to the soft supersymmetry breaking parameters [5], $\mu \sim O(G_F^{-1/2})$ will be realized dynamically as $\mu = \lambda \langle S \rangle$.

The extra $U(1)$ models can be a simple candidate of this scenario [6, 7]. Moreover, extra $U(1)$s often come from the high energy fundamental theory like superstring [8]. It is very interesting subject to find a signature of such an extra gauge symmetry. Recent LEP precise measurement and Tevatron direct search tell us that extra gauge bosons may be too heavy to find it in near future [9]. In supersymmetric models there are gauginos which may be rather light for certain range of soft breaking parameters even if corresponding gauge bosons are heavy. In such a case we may be able to find a clue of the additional gauge structure through the superpartner sector. In the above mentioned extra $U(1)$ models a relevant noticable sector is the neutralino sector, which is extended in comparison with that of the MSSM [1] at least by two components, that is, an abelian gaugino and a superpartner fermion of the singlet Higgs $S$.

There may be some interesting phenomena in which the neutralino sector can play an important role. Such a representative example is the electric dipole moment of an electron (EDME) and a neutron. In supersymmetric models it has been known that there
are one-loop contributions to the EDME due to the co-operation of the superpartners (e.g. charginos, neutralinos and so on) and the additional CP violating phases in the soft supersymmetry breaking parameters. In the MSSM a lot of works for the EDM of a neutron and an electron have been done[10, 11]. Through such studies it has been suggested that the contributions from charginos and neutralinos can become important in the suitable parameter region. In the case of EDME there are no contribution coming from colored fields\(^1\) and then the effect of the neutralino sector is expected to appear clearly in its estimation. In the models we are considering here, there are some changes from the MSSM in the neutralino sector and the effects induced by this change may be able to appear in the EDME explicitly. As the present experimental bound of the EDME[13] is near the predicted value from the MSSM, it is very interesting to study the influence on the EDME which comes from the existence of an extra \(U(1)\) gauge boson.

In this letter we consider the minimally extended MSSM with an extra \(U(1)\) and a gauge singlet Higgs \(S\) which has a coupling \(\lambda SH_1H_2\) with doublet Higgses \(H_1\) and \(H_2\). We note here an additional feature required in the treatment of the neutralino sector of the multi \(U(1)\) models. That is, there can be gauge invariant kinetic term mixings among abelian vector multiplets.\(^2\) We derive the general formulas for the EDME in such models taking account of this gaugino mixing between \(U(1)_Y\) and \(U(1)_X\). This formula is investigated numerically and the effect of extra \(U(1)_X\) symmetry on the EDME is discussed to find some clue of the fundamental theory in high energy region.

In the general supersymmetric models with two abelian factor groups, the supersymmetric gauge invariant kinetic terms of the abelian part for these are expressed by using chiral superfields \(\hat{W}_a^a\) and \(\hat{W}_b^b\) for \(U(1)_a \times U(1)_b\) as

\[
\frac{1}{32} (\hat{W}_a^a \hat{W}_a^a)_F + \frac{1}{32} (\hat{W}_b^b \hat{W}_b^b)_F + \frac{\sin \chi}{16} (\hat{W}_a^a \hat{W}_b^b)_F,
\]

where \(\hat{W}^a\) contains a gaugino \(\lambda^a\), a gauge field strength \(F_{\mu\nu}^a\) and an auxiliary field \(D^a\) as the component fields. These can be canonically diagonalized by using the transformation,

\[
\begin{pmatrix}
\hat{W}_a^a \\
\hat{W}_b^b
\end{pmatrix} =
\begin{pmatrix}
1 & -\tan \chi \\
0 & 1/ \cos \chi
\end{pmatrix}
\begin{pmatrix}
W_a^a \\
W_b^b
\end{pmatrix}.
\]

\(^1\)Here we assume that there is no R-parity violating term.

\(^2\)It has been pointed out that there can occur abelian gauge kinetic term mixings in the suitable models[14, 15]. Their supersymmetrization is represented by the mixings among abelian vector multiplets. Some works on this phenomenological effects have been done by now[15, 16].
This transformation affects not only the gauge field sector but also the sector of gauginos $\lambda_{a,b}$ and auxiliary fields $D_{a,b}$. The modification in the gaugino interactions can be summarized as

$$g_a Q_a \lambda^a + g_b Q_b \lambda^b = g_a Q_a \lambda^a + (g_{ab} Q_a + g_b Q_b) \lambda^b,$$

where $\lambda_{a,b}$ are canonically normalized gauginos. $Q_a$ and $Q_b$ represent the charges of $U(1)_a$ and $U(1)_b$. The couplings $g_a$, $g_{ab}$ and $g_b$ are related to the original ones $g_a^0$ and $g_b^0$ as,

$$g_a = g_a^0, \quad g_{ab} = g_a^0 \tan \chi, \quad g_b = \frac{g_b^0}{\cos \chi}.$$

Using this canonically normalized basis, we can write down the modified quantities relevant to the neutralino sector in the present models. Here we give the concrete forms of the neutralino mass matrix and gaugino-fermion-sfermion interactions. If we take the canonically normalized neutralino basis as $N^T = (-i\lambda W_3, -i\lambda Y, -i\lambda X, \tilde{H}_1, \tilde{H}_2, S)$ and define their mass terms as $L_n^{\text{mass}} = -\frac{1}{2} N^T M N + h.c.$, the $6 \times 6$ neutralino mass matrix $M$ can be expressed as

$$
\begin{pmatrix}
M_W & 0 & 0 & m_Z c_W \cos \beta & -m_Z c_W \sin \beta & 0 \\
0 & M_Y & C_1 & -m_Z s_W \cos \beta & m_Z s_W \sin \beta & 0 \\
0 & C_1 & C_2 & C_3 & C_4 & C_5 \\
m_Z c_W \cos \beta & -m_Z s_W \cos \beta & C_3 & 0 & \lambda u & \lambda v \sin \beta \\
-m_Z c_W \sin \beta & m_Z s_W \sin \beta & C_4 & \lambda u & 0 & \lambda v \cos \beta \\
0 & 0 & C_5 & \lambda v \sin \beta & \lambda v \cos \beta & 0
\end{pmatrix},
$$

where $v$ and $u$ are defined as $v = (|\langle H_1^0 \rangle|^2 + |\langle H_2^0 \rangle|^2)^{1/2}$ and $u = |\langle S \rangle|$. Matrix elements $C_1 \sim C_5$ are affected by the kinetic term mixing. They are represented as

$$C_1 = -M_Y \tan \chi + \frac{M_Y \chi}{\cos \chi}, \quad C_2 = M_Y \tan^2 \chi + \frac{M_X}{\cos^2 \chi} - \frac{2M_Y \sin \chi}{\cos^2 \chi},$$

$$C_3 = \frac{1}{\sqrt{2}} \left( g_Y \tan \chi + \frac{g_X Q_1}{\cos \chi} \right) v \cos \beta, \quad C_4 = \frac{1}{\sqrt{2}} \left( -g_Y \tan \chi + \frac{g_X Q_2}{\cos \chi} \right) v \sin \beta,$$

$$C_5 = \frac{1}{\sqrt{2}} \frac{g_X Q_S}{\cos \chi} u,$$

where $M_W, M_Y$ and $M_X$ are soft supersymmetry breaking gaugino masses. $Q_1, Q_2$ and $Q_S$ are the extra $U(1)$ charges of Higgs chiral superfields $H_1, H_2$ and $S$. Neutralino mass

\[ \text{In this expression we introduce the effect originated from the abelian gaugino mass mixing as } M_{YX}, \text{ which may exist at the Planck and may also be yielded through the low energy quantum effects.} \]
eigenstates \( \tilde{\chi}_i^0 \) \((i = 1 \sim 6)\) are related to \( N_j \) through the mixing matrix \( U \) as

\[
\tilde{\chi}_i^0 = \sum_{j=1}^{6} U_{ij}^T N_j. \tag{7}
\]

The change in the gaugino interactions can be confined into the extra \( U(1)_X \) gaugino sector and by using eq. (3) new interaction terms can be expressed as,

\[
i \sqrt{2} \left[ \tilde{\psi} \left( -g_Y \tan \chi + \frac{g_X Q_X}{\cos \chi} \right) \lambda_X \psi - \left( -g_Y \tan \chi + \frac{g_X Q_X}{\cos \chi} \right) \tilde{\lambda}_X \tilde{\psi} \right. \\
\left. + H^* \left( -g_Y \tan \chi + \frac{g_X Q_X}{\cos \chi} \right) \lambda_X \tilde{H} - \left( -g_Y \tan \chi + \frac{g_X Q_X}{\cos \chi} \right) \tilde{\lambda}_X \tilde{H} \tilde{H} \right] \tag{8}
\]

where \( \psi \) and \( \tilde{\psi} \) represent the quarks/leptons and the squarks/sleptons, respectively. Higgs fields \( (H_1, H_2, S) \) are summarized as \( H \) and the corresponding Higgsinos \( \tilde{H}_1, \tilde{H}_2 \) and \( \tilde{S} \) are denoted as \( \tilde{H} \). \( Y \) and \( Q_X \) stand for \( U(1)_Y \) and \( U(1)_X \) charges of \( \psi \) and \( H \). Noting these modifications, the gaugino-fermion-sfermion vertex can be expressed by using the following factors,

\[
Z^L_i(Y,Q_X) = -\frac{1}{\sqrt{2}} \left[ g_W \tau_3 U_{1i} + g_Y Y U_{2i} + \left( -g_Y Y \tan \chi + \frac{g_X Q_X}{\cos \chi} \right) U_{3i} \right],
\]

\[
\overline{Z^R_i}(Y,Q_X) = \frac{1}{\sqrt{2}} \left[ g_Y Y U_{2i} + \left( -g_Y Y \tan \chi + \frac{g_X Q_X}{\cos \chi} \right) U_{3i} \right], \tag{9}
\]

where we used the left-handed basis for chiral superfields. It is also useful to define the chargino mass eigenstates for the calculation of the EDME. The chargino mass term is given with the matrix form as

\[
L_{\text{mass}}^n = - \left( H^-_1, -i\lambda_Y \right) \begin{pmatrix} -\lambda u & \sqrt{2} m_Z c_W \cos \beta \\ \sqrt{2} m_Z c_W \sin \beta & M_W \end{pmatrix} \begin{pmatrix} H^+_2 \\ -i\lambda_Y \end{pmatrix} + \text{h.c..} \tag{10}
\]

The mass eigenstates are defined in terms of weak interaction eigenstates through the unitary transformations,

\[
\begin{pmatrix} \tilde{\chi}^+_1 \\ \tilde{\chi}^+_2 \end{pmatrix} = W^{(+)^\dagger} \begin{pmatrix} H^+_2 \\ -i\lambda_Y \end{pmatrix}, \quad \begin{pmatrix} \tilde{\chi}^-_1 \\ \tilde{\chi}^-_2 \end{pmatrix} = W^{(-)^\dagger} \begin{pmatrix} H^-_1 \\ -i\lambda_Y \end{pmatrix}. \tag{11}
\]

The effective interaction contributing to the EDME is expressed as

\[
L_{\text{eff}} = i \frac{\mathcal{F}_e \bar{\psi}_e \sigma_{\mu \nu} \gamma^5 \psi_e F^{\mu \nu}}{2}, \tag{12}
\]
where $\psi_e$ stands for the electron field. The EDME is given by using this effective coupling $F_e$ as $d_e = \text{Im}(F_e)$. This effective coupling has the contribution from the one-loop diagrams shown in Fig.1. Neutralino contributions come from diagram (a) and the chargino contribution is represented by (b). The effective coupling induced by these diagrams can be calculated as,

$$
F_e = \frac{-e}{16\pi^2} \sum_{\tilde{\chi}_i^0} \frac{m_{\tilde{\chi}_i^0}^2}{M_e^2} \left\{ \frac{g_W m_e}{\sqrt{2} m_W \cos \beta} U_{4i} \left( Z_{2i}^L(-1, Q_{\ell L}) + Z_{2i}^R(2, Q_{\ell R}) \right) \right\}
+ \left( Z_{2i}^L(-1, Q_{\ell L}) Z_{2i}^R(2, Q_{\ell R}) \right) \frac{g_W^2 m_e^2}{2 m_W^2 \cos^2 \beta} \frac{M_{\nu_{\ell L}}^2}{M_e^2} \right\} F \left( \frac{m_{\tilde{\chi}_i^0}^2}{M_e^2} \right)
+ \sum_{\tilde{\chi}_i^+} \frac{m_{\tilde{\chi}_i^+}^2}{M_{\nu}^2} \frac{m_e g_W^2}{\sqrt{2} m_W \cos \beta} \left( W_{2i}^{(+)(-)} \right) J \left( \frac{m_{\tilde{\chi}_i^0}^2}{M_{\nu}^2} \right),
$$

(13)

where $m_{\tilde{\chi}_i^0}$ and $m_{\tilde{\chi}_i^+}$ are the $i$-th mass eigenvalue of the neutralino and the chargino, respectively. We derived this formulûs in the lepton mass matrix diagonal basis $m_{\ell} = m_{\ell}^0 \delta_{\alpha \beta}$. Under this basis the slepton mass matrix is not diagonal in general. For simplicity, these matrix elements may be assumed to follow the conditions,

$$
(M_{\ell L}^2)_{\alpha \beta} = (M_{\ell R}^2)_{\alpha \beta} = M_{\ell}^2 \delta_{\alpha \beta}, \quad (M_{\nu L}^2)_{\alpha \beta} = M_{\nu}^2 \delta_{\alpha \beta} \quad (M_{\nu R}^2)_{\alpha \beta} = m_{\nu}^0 (A_{\nu} + \lambda^* u \tan \beta) \delta_{\alpha \beta},
$$

(14)

where $A_{\nu}$ is a soft supersymmetry breaking parameter associated with the charged lepton Yukawa coupling. Using these assumptions, we adopted the mass insertion approximation for the left-right mixing slepton mass in the derivation of eq.(13). This approximation is expected to be rather good because of the strong experimental constraints on the flavor changing neutral current and the smallness of lepton masses $m_{\ell}^0$. In this formulûs CP-violating phases are confined in the left-right mixing slepton mass $M_{\ell R}^2$ and mixing matrix elements $U_{ij}$ and $W_{ij}^{(\pm)}$ due to the phases of $A_{\nu}$ and $\lambda$ after making gaugino masses real by using the R-transformation. It should be noted that the superpartner of $\nu_R$ is assumed to be heavy enough to decouple from this calculation and then the chargino contribution

$^4$These assumptions are realized in the $N = 1$ minimal supergravity with the supersymmetry breaking in the hidden sector. We do not consider the lepton flavor violating interaction in this analysis.

$^5$This may be justified by the fact that the solar neutrino problem suggests that $\nu_{\nu}8$ have the large supersymmetric mass to make the seesaw mechanism applicable.
becomes very simple. Kinematical functions $I(r)$, $J(r)$ and $F(r)$ are defined by

$$I(r) = \frac{1}{2(1-r)^2} \left[ 1 + r + \frac{2r}{1-r} \ln r \right] ,$$

$$J(r) = \frac{1}{2(1-r)^2} \left[ -3 + r - \frac{2}{1-r} \ln r \right] ,$$

$$F(r) = \frac{1}{2(1-r)^4} \left[ 1 + 4r - 5r^2 + 2r(r+2) \ln r \right] .$$

(15)

Our formula includes the additional parameters besides the ones contained in the MSSM formula: $(\tan \beta, M^2_e, M^2_\nu, A_t, M_W, M_Y)$. They include new gaugino masses $(M_X, M_{YX})$, the kinetic term mixing parameter $\sin \chi$, the extra $U(1)$ coupling $g_X$ and charges ($Q_1, Q_2$) and the $\mu$-term relevant parameters $(\lambda, u)$. Eq.(13) results in the MSSM formula\[10, 11\] by putting these additional parameters zero instead of keeping $\mu = \lambda u$ constant.

Before proceeding to the numerical analysis it will be useful to make some remarks on the neuralino dominance condition for the EDME. In eq.(13) the neutralino mass dependence is extracted as $r^{1/2}I(r)$ and $r^{1/2}F(r)$ where $r = (m_\nu^2/M_e)^2$. The chargino mass contribution is also represented as $r^{1/2}J(r)$ where $r = (m_\tau^2/M_e)^2$. These functions satisfy the approximate relation $r^{1/2}J(r) \sim 4r^{1/2}I(r) \sim 4r^{1/2}F(r)$ at least except for the region near $r \sim 0$. Thus the condition for the neutralino dominance can be roughly estimated as

$$|A_t + \lambda^* u| \gtrsim \frac{4\sqrt{2}M_e^2}{m_W \cos \beta},$$

(16)

where we assumed $M_e \sim M_\nu$. On the other hand, in the present models the vacuum expectation value $u$ of the singlet Higgs $S$ is relevant to the extra $Z$ mass in addition to determining the $\mu$-scale. The mixing between the ordinary $Z$ and the $U(1)_X$ boson is severely constrained by the precise measurement at LEP\[9\]. This constraint requires that the mass of the $U(1)_X$ boson is large enough\[7\] and in such a case the mass eigenvalue of the extra $U(1)_X$ boson is given as\[6\],

$$m^2_{Z'} \approx \frac{1}{2 \cos^2 \chi} g_X^2 (Q_1^2 v_1^2 + Q_2^2 v_2^2 + Q_S^2 u^2).$$

(17)

Although the large $u$ value is necessary to make $m_{Z'}$ large enough, the smallness of $\lambda$ may be required to give $\mu$ an appropriate value for the large $u$.

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\(\text{6}\)It should be noted that $Q_1 + Q_2 + Q_S = 0$ is satisfied because of the form of superpotential.

\(\text{7}\)The mixing element of the mass matrix can be small enough for the special value of $\tan \beta$ and $\sin \chi$.

In such a case this requirement is not necessary to be satisfied and $u$ may be able to take the rather small value.
Table 1  The charge assignments of extra $U(1)$s induced from $E_6$. These charges are normalized as $\sum_{i\in 27} Q_i = 20$. Only relevant fields to our study are listed from 27 of $E_6$.

<table>
<thead>
<tr>
<th>fields</th>
<th>$Q$</th>
<th>$U^c$</th>
<th>$D^c$</th>
<th>$L$</th>
<th>$E^c$</th>
<th>$H_1$</th>
<th>$H_2$</th>
<th>$S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$</td>
<td>$\frac{1}{3}$</td>
<td>$-\frac{4}{3}$</td>
<td>$\frac{2}{3}$</td>
<td>$-1$</td>
<td>$2$</td>
<td>$-1$</td>
<td>$1$</td>
<td>$0$</td>
</tr>
<tr>
<td>$Q_{\eta}$</td>
<td>$\frac{2}{3}$</td>
<td>$\frac{2}{3}$</td>
<td>$\frac{1}{3}$</td>
<td>$\frac{1}{3}$</td>
<td>$-\frac{2}{3}$</td>
<td>$\frac{1}{3}$</td>
<td>$\frac{4}{3}$</td>
<td>$-\frac{5}{3}$</td>
</tr>
</tbody>
</table>

Taking account of these aspects, we adopt the parameter set as

$$
\tan \beta = 1.5, \quad |A| = 1500 \text{ GeV}, \quad \text{Arg}(A) = 4 \times 10^{-3}, \quad \lambda = 0.5,
M_e = M_\nu = 100 \text{ GeV}, \quad M_Y = M_X = \frac{5}{3} \tan^2 \theta_W M_W, \quad M_{YX} = 0,
$$

where we assumed the unification relation for the gaugino masses. For simplicity, $\lambda$ is assumed to be real and then the CP-phase is included only in $M_{LR}^c$. As the extra $U(1)_X$ group, we take the $\eta$-model induced from $E_6$ and their charge assignments for the relevant fields are listed in Table 1. Here we should remember the allowed region of the $(\mu, M_W)$ plane obtained from the neutralino and chargino search at LEP[17]. We confine our study to the $\mu > 0$ region so that $\mu, M_W \gtrsim 100$ GeV should be satisfied for $\tan \beta = 1.5$. This corresponds to $u' > 2$ for $\lambda = 0.5$. Additionally, if $m_{Z'} \gtrsim 400$ GeV, the rough estimation with the use of eq.(17) requires $u' \gtrsim 14$. Under this parameter setting, the EDME of this model is plotted in Fig.2 for $M_W = 80, 180$ GeV and $\sin \chi = 0, 0.3$ as a function of $u$ where $u = 50(u' + 2)$. As seen from this figure, our parameter set brings the EDME around the present experimental bound. In Fig.3 the ratio of this EDME against the one of the MSSM is drawn for the comparison with the MSSM.

At first we can see the non-negligible deviation of the EDME from the MSSM value from Fig.3. The deviation becomes larger for the larger gaugino mass for $\sin \chi = 0$ but the situation is reversed in the case of $\sin \chi = 0.3$. In the large $u$ region where the above mentioned small mixing constraint is automatically satisfied, the derivation is monotonically decreases with $u$. However, there is $\sim 4\%$ enhancement for $\sin \chi = 0$ and also $\sim 8\%$ enhancement for $\sin \chi = 0.3$ around $u' \sim 14$. This suggests that even in the large $u$ region we may find the effects of new ingredients $\lambda_X$ and $\tilde{S}$ in the neutralino sector on the EDME at the level of $O(10^{-27\sim-28})$ in the suitable parameter range. In the smaller
u region this deviation is amplified. In particular, the gaugino kinetic term mixing shows the larger amplification of the EDME there. It is very interesting that the kinetic term mixing effect may be seen through the EDME in the present parameter region. Anyway, we may fortunately have a chance to find some clue of the existence of the extra gauge structure through the study of the EDME if the experimental bound is improved by order one.

Some brief comments are useful to be ordered on the parameter dependence of the EDME on $\lambda$ and $\tan \beta$ here. Although there is no significant difference in the absolute value of the EDME between $\tan \beta = 1.5$ and $\tan \beta = 50$, there can be seen its slight dependence on $\lambda$. For example, for the case of $\lambda = 0.07$, we can find some enhancement of the EDME for $M_W = 80$ GeV compared with $\lambda = 0.5$. However, we cannot see such a substantial change for $M_W = 180$ GeV. On the ratio $R$ of the EDME, we cannot see the significant dependence of the EDME on both of $\lambda$ and $\tan \beta$ at least in the large $u$ region (for example, $u' \gtrsim 14$). In the present analysis we assumed $\lambda$ is real and only the origin of the CP violating phase is $A_t$ in $M_{LR}^2$. Since $\lambda u \tan \beta$ in $M_{LR}^2$ is irrelevant to the EDME under such an assumption, the $\lambda$ and $\tan \beta$ dependence come only through the diagonalization matrices $U$ and $W^{(\pm)}$ of the neutralino and chargino mass matrices. Because of this reason, the ratio of the EDME of the $\eta$-model against the MSSM is considered not to be sensitive to these parameters except for the small $u$ region. If we introduce the phase into $\lambda$ which seems to be more general situation, the behavior of the EDME is expected to be more complicated. This aspect will be beyond the scope of the present study and we will present it elsewhere.

In summary we investigated the EDME in the extra $U(1)$ models which can potentially solve the $\mu$-problem. We pointed out that these models may be distinguished from the MSSM through the measurement of the EDME and we showed it concretely for a certain parameter region in the $\eta$-model derived from $E_6$. It is noticeable that the abelian gaugino kinetic term mixing can have rather large effects on the value of EDME. It may be possible to find some clue of the extra gauge structure by investigating the EDME if the experimental bound is improved. Our numerical study in this paper has been done in the rather restricted parameter region of a typical model where the neutralino dominance is expected. However, it will be necessary to investigate this process in more wide parameter region of various extra $U(1)$ models to give the basis of the experimental study. It will
be also useful to do the combined study with other process like $\mu \to e\gamma[18]$ where the neutralino sector is expected to play the important role. We will present them elsewhere.

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References

[1] For a review, see for example,


[8] For a review, see for example,


ALEPH collaboration, Z. Physik **C72** (1996) 549.

[18] D. Suematsu, KANAZAWA-97-06.
Figure Captions

Fig. 1

One-loop diagrams for the EDME. Fig.(a) represents the neutralino contribution and Fig.(b) represents the chargino contribution. CP violating phases are included in the slepton mass insertion which is expressed by $\bullet$ and vertex factors $\gamma_i$. It should be noted that the chirality flip occurs at the vertices and/or the internal line.

Fig. 2

The EDME as a function of $u$ in the $\eta$-model. The vertical axis stands for $d_e \times 10^{26}$ e cm and the horizontal axis $u'$ should be understood as $u = 50(u' + 2)$. Each line corresponds to the parameter settings for $(M_W, \sin \chi)$ and their values are taken as $A(80, 0)$, $B(180, 0)$, $C(80, 0.3)$ and $D(180, 0.3)$.

Fig. 3

The ratio $R$ of the EDME of the $\eta$-model against the MSSM as a function of $u$. $R = d_e^{\eta}(M_W, \sin \chi)/d_e^{MSSM}(M_W)$. Each line corresponds to the same parameter settings in Fig.2.
Fig. 1