CHAPTER V

CONCLUSIONS

In contrast to the Standard Model with only one CP-violating phase due to the CKM matrix, the supersymmetric extension of the SM with minimal particle content known as the Minimal Supersymmetric Standard Model (MSSM) contains several new sources of CP violation. However, if we confine ourselves in the constrained MSSM (CMSSM) which imposes severe constraints on the complex parameters of the model, the number of the physical CP-violating phases is reduced to only two: phases of the Higgs mass parameter, φ_μ, and the trilinear scalar coupling parameter, φ_{A_0}. In this thesis, we have studied the electric dipole moment of the electron whose non-zero value requires the violation of CP symmetry, in the framework of the CMSSM. We have found that, at one-loop level, the electron EDM receives supersymmetric contributions resulted from the chargino and the neutralino exchanges. The chargino contribution takes the form

$$\frac{d_e^{\tilde{C}}}{e} = \frac{\alpha_{\text{EM}}}{4\pi\sin^2\theta_W}\frac{\kappa_e Q_e}{m_{\tilde{\nu}_e}^2}\sum_{i=1}^{2} m_{\tilde{C}_i}\text{Im}\left(\mathbf{U}_{i2}^*\mathbf{V}_{i1}^*\right) J\left(\frac{m_{\tilde{C}_i}^2}{m_{\tilde{\nu}_e}^2}, \frac{m_e^2}{m_{\tilde{\nu}_e}^2}\right) \tag{5.1}$$

(see Eq. (4.45)) while the neutralino contribution is given by

$$\frac{d_e^{\tilde{N}}}{e} = \frac{\alpha_{\text{EM}}}{4\pi\sin^2\theta_W}\sum_{j=1}^{2}\sum_{i=1}^{4}\frac{m_{\tilde{N}_i}Q_e}{m_{\tilde{e}_j}^2}\text{Im}\left(\frac{1}{g^2}\left(\Gamma_R^*\Gamma_L\right)_{ij}\right) I\left(\frac{m_{\tilde{N}_i}^2}{m_{\tilde{e}_j}^2}, \frac{m_e^2}{m_{\tilde{e}_j}^2}\right) \tag{5.2}$$

(see Eq. (4.49)), where the explicit forms of the functions $I(r,s)$ and $J(r,s)$ were given in Eqs. (4.32) and (4.37) respectively. The chargino contribution depends explicitly only on the phase φ_μ; its dependence on φ_{A_0} comes only through the renormalization group equations, and is very weak. The neutralino contribution, on the other hand, depends explicitly on both φ_μ and φ_{A_0}.

Estimating the electron EDM numerically is not straightforward because no specific experimental value is available on various supersymmetric parameters such as sparticle masses and mixing phases. Instead, the experimental upper bounds for the EDM are used to constrain the values of parameters. It has been found that in the major part of the parameter space the chargino contribution dominates, and only with the chargino contribution the electron EDM can exceed the current experimental limit. The reason is that the loop function $|J(r,0)|$ in the chargino contribution is larger than $|I(r,0)|$ in the neutralino contribution. Therefore the possibilities for suppressing the EDM have been proposed. The first one is that for a light (below 1 TeV) supersymmetric spectrum, the supersymmetric CP-violating phases have to be small, i.e., $\mathcal{O}(10^{-2} - 10^{-3})$ [3, 4, 5, 6, 7, 9, 10, 39]. The second possibility is that the supersymmetric spectrum which contributes to the EDM has to be sufficiently heavy, i.e.. a few TeV, while the phases of $\mathcal{O}(1)$ are allowed [35, 40, 41, 42]. The third possibility is that the cancellations between chargino and neutralino contributions occur [34, 43]. This cancellation mechanism requires two conditions. First, the two contributions must have opposte sign over some subset of the phase parameter space. This requirement is automatically satisfied over the whole range of φ_μ due to the fact that the μ parameter enters the neutralino and chargino mass matrices with opposite phases. This can be traced back to the antisymmetry of the $SU(2)$ metric $\epsilon_{\alpha\beta}$ appearing in the superpotential. Second, it is required that the chargino and neutralino contributions have to be of the same order of magnitude. Since the chargino contribution is much larger than the neutralino contribution for comparable sizes of φ_μ and φ_{A_0}, then the strong cancellations can occur when φ_μ has a very small value and φ_{A_0} is of a moderate value. In addition, although the presence of the cancellations relaxes the constraints on the phases, it was found that the phase φ_μ is still strongly restricted by the experimental bounds [34, 43, 44, 45, 46].

In this thesis, we have studied only the CMSSM which is a particularly restrictive model in that there are only two new physical CP-violating phases. In more general models, there are more phases contributing to the EDM. For example, supersymmetric models without gaugino mass unification have been studied to examine the new cancellations among EDM contributions due to the presence of additional phases [46, 47], and the EDMs in the MSSM with the most general set of allowed CP-violating phases without generation mixing have been analyzed in [48].

Although there has been no experimental evidence to confirm the value of the electric dipole moments yet, it is still hopeful that the next generation experiments would have enough sensitivity to detect them. For example, the possibility to search for the electron EDM at the level $10^{-28} - 10^{-30}e$ cm has been proposed [49, 50].