Weak dipole moments of the charged leptons in models with extended scalar sectors

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Outline

1. Motivation
2. Weak dipole moments (WDM's)
3. Potential new scalar contributions to the WDM's of the charged lepton
4. Conclusions

Is there only one physical Higgs particle?

The mechanism of spontaneous symmetry breaking (SSB) is achieved in the SM by only one complex $SU(2)_L$ scalar doublet. ***However, there is no compelling reason to expect that this minimal Higgs sector is the one realized in nature.***

Therefore, models with an extended scalar sector stand out among the most popular and simple SM extensions.

These models have several motivations and a very interesting phenomenology:

- SUSY- At least two doublets are necessary
- The possibility of accomplishing the see-saw type II mechanism in Higgs triplet models
- Possible dark matter candidates
- They can allow for new sources of CP violation
- New physical scalar states

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Motivation

Anomalous magnetic dipole moments (AMDM)

The study of the static electromagnetic properties of fermions provides a unique opportunity to search for NP effects.

AMDM of μ

$$\Delta a_\mu = a_\mu^{Exp} - a_\mu^{SM} = 288(63)(49) \times 10^{-11} \sim 3{,}5\sigma$$

• [Muon G-2 Collaboration], Phys. Rev. D 73 (2006) 072003

AMDM of τ

$$a_\tau^{SM} = 1177{,}21(5) \times 10^{-6}$$

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Electric Dipole Moments (EDM)

The EDM of leptons is predicted to be negligible in the SM as it is induced up to the four-loop level of perturbation theory

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Weak dipole moments (WDM's)

Affter the study of the electromagnetic properties of a fermion, there has also been great interest in its static weak properties, which are associated with its interaction with the Z gauge boson.

$$\Gamma^{\mu}_{Z\bar{f}f}\left(q^2\right) = F_2\left(q^2\right) i\sigma^{\mu\nu}q_\nu + F_3\left(q^2\right)\sigma^{\mu\nu}\gamma_5 q_\nu. \quad (3)$$

with q the Z transferm momentum.
The AWMDM is defined as $a_f^W = 2m_f F_2(m_Z^2)$ and the WEDM $d_f^W = eF_3(m_Z)^2$.

- **Only the weak dipole moments (WDMs) of heavy fermions are worth studying as those of lighter fermions would be beyond the reach of experimental detection.**

For instance, in the SM $a_\tau^W = -(2{,}10 + 0{,}61i) \times 10^{-6}$ • Nucl. Phys. B436, 474 (1995) and $d_\tau^W < 8 \times 10^{-34}$ ecm • Z. Phys. C43, 117 (1989).

Cuadro: Experimental upper bounds on the static weak properties of the tau lepton τ. • (ALEPH), Eur. Phys. J. C30, 291 (2003)

	Real part	Imaginary part
a_τ^W	$1{,}1 \times 10^{-3}$	$2{,}7 \times 10^{-3}$
d_τ^W (ecm)	$0{,}5 \times 10^{-17}$	$1{,}1 \times 10^{-17}$

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In this work we are interested in the contributions to the WDM's of the charged leptons from new neutral, charged and doubly charged scalar particles, which can arise in several models with an extended scalar sector.

New scalar contributions to the WDM's of the charged leptons

We have done somewhat general calculation, i.e instead of working out the weak dipole moments (WDMs) within a specific model, we will consider the scenario of a theory with several nondegenerate neutral, singly and doubly charged scalar bosons with the most general renormalizable couplings to leptons and the Z gauge boson that can induce the WDMs at the one loop level

Lepton number conserving interactions (LNC)

- Lepton-antilepton pair with a neutral or singly charged scalar particle

$$\mathcal{L} = g\,\bar{\ell}_l\left(S_{ilm} + P_{ilm}\gamma_5\right)\ell_m\phi_i + \text{H.c.}, \tag{4}$$

- Interaction of a Z gauge boson with two nondegenerate neutral or charged scalar bosons ϕ_i and ϕ_j

$$\mathcal{L} = ig\,g_{Z\phi_i\phi_j}Z^\mu\phi_i^\dagger\overleftrightarrow{\partial_\mu}\phi_j + \text{H.c.} \tag{5}$$

- Couplings of the type $ZV\phi_i$, with V a neutral (charged) gauge boson and ϕ_i a neutral (charged) scalar

$$\mathcal{L} = g\,g_{\phi_i V Z}m_Z Z^\mu V_\mu\phi_i + \text{H.c.}, \tag{6}$$

- Lepton-antilepton pair with a neutral or charged gauge boson V

$$\mathcal{L} = g\,\bar{\ell}_l\gamma_\mu\left(g_V^{Vlm} - g_A^{Vlm}\gamma_5\right)V^\mu\ell_m + \text{H.c.} \tag{7}$$

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Scalar contributions to the WDM's of the charged leptons

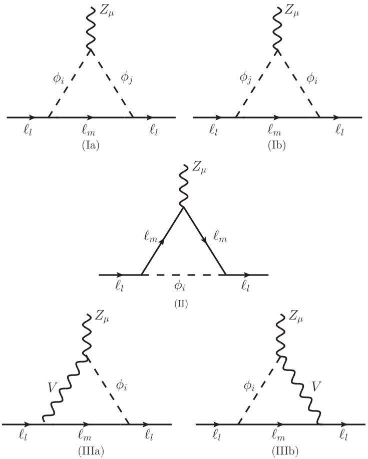

Figura: Generic Feynman diagrams for the contributions of new neutral and charged scalar bosons to the AWMDM and WEDM of a charged lepton. Here l_l stands for a charged lepton, whereas l_m is a lepton whose charge depends on that of the ϕ_i and ϕ_j scalar bosons (diagrams I and II) and that of the V gauge boson and the ϕ_i scalar boson (diagrams III)..

Expressions for AWDM

- We have used the unitary gauge. In order to solve the one-loop integrals we have used both the Feynman parameter technique and the Passarino-Veltman reduction scheme.

$$a_l^{W-I} = \frac{\alpha\sqrt{x_l}}{4\pi s_W^3}\sum_{i,j,m} 16\left(1-\delta_{ij}\right)\,\mathrm{Re}\left[S_{ilm}S^*_{jlm}g^*_{Z\phi_i\phi_j}\right]A_I^{m\phi_i\phi_j} + \begin{pmatrix} \sqrt{x_m} \to -\sqrt{x_m} \\ S_{ilm} \to P_{ilm} \\ S_{jlm} \to P_{jlm} \end{pmatrix}, \quad (8)$$

$$\begin{aligned} a_l^{W-II} &= \frac{\alpha\sqrt{x_l}}{4\pi s_W^3}\sum_{i,m} 16\left(g_V^{Zmm}\|S_{imm}\|^2 A_{II_1}^{\phi_i mm} + g_A^{Zmm}\sqrt{x_l}\,\mathrm{Re}\left[S_{imm}P^*_{imm}\right]A_{II_2}^{\phi_i mm}\right) \\ &+ \begin{pmatrix} \sqrt{x_m} \to -\sqrt{x_m} \\ S_{imm} \leftrightarrow P_{imm} \end{pmatrix}, \end{aligned} \quad (9)$$

y

$$a_l^{W-III} = \frac{\alpha\sqrt{x_l}}{4\pi s_W^3}\sum_{i,m,V}\frac{2g_{\phi_i VZ}}{x_V}\mathrm{Re}\left[S_{ilm}\,g_V^{Vlm*}\right]A_{III}^{m\phi_i V} - \begin{pmatrix} \sqrt{x_m} \to -\sqrt{x_m} \\ S_{ilm} \to P_{ilm} \\ g_V^{Vlm} \to g_A^{Vlm} \end{pmatrix}, \quad (10)$$

- We have verified that our expressions reduce to those reported in • Phys.Rev. D31, 105 (1985). for the AMDM of a lepton in the limit when $m_Z \to 0$ and after replacing the Z couplings with the photon ones.

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Expressions for WEDM

$$d_l^{W-I} = \frac{e\alpha}{4\pi s_W^3 m_Z} \sum_{i,j,m} 4\left(1-\delta_{ij}\right) \mathrm{Im}\left[P^*_{ilm} S_{jlm} g_{Z\phi_i\phi_j}\right] D_I^{m\phi_i\phi_j} + \left(\begin{array}{c} \sqrt{x_m} \to -\sqrt{x_m} \\ S_{jlm} \to P_{jlm} \\ P_{ilm} \to S_{ilm} \end{array}\right), \quad (11)$$

$$d_l^{W-II} = \frac{e\alpha}{4\pi s_W^3 m_Z} \left(\sum_{i,m} 16 g_V^{Zmm} \mathrm{Im}\left[S_{imm} P^*_{imm}\right] D_{II}^{\phi_i mm}\right) + \left(\begin{array}{c} \sqrt{x_m} \to -\sqrt{x_m} \\ S_{imm} \leftrightarrow P^*_{imm} \end{array}\right), \quad (12)$$

and

$$d_l^{W-III} = \frac{e\alpha}{4\pi s_W^3 m_Z} \sum_{i,m,V} \frac{g_{\phi_i VZ}}{x_V} \mathrm{Im}\left[S_{ilm}\, g_A^{Vlm*}\right] D_{III}^{m\phi_i V} - \left(\begin{array}{c} \sqrt{x_m} \to -\sqrt{x_m} \\ S_{ilm} \to P_{ilm} \\ g_A^{Vlm} \to g_V^{Vlm} \end{array}\right), \quad (13)$$

- The fact that our results have been expressed as the imaginary part of products of the coupling constants means that in the case where all the couplings are real there is no contribution to the WEDM.

Lepton number violating interactions (LNV)

$$\mathcal{L}^{\Delta L=2} = g\,\ell_l^T C\left(S'_{ilm} + P'_{ilm}\gamma^5\right)\ell_m \phi^i + \text{H.c} \quad (14)$$

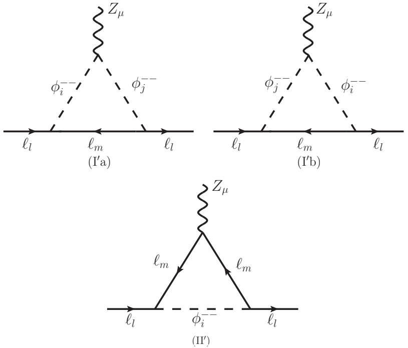

Figura: Generic Feynman diagrams for the contributions of doubly charged scalar bosons to the AWMDM and WEDM of charged leptons. Here l_l and l_m are both charged leptons.

Using the Feynman rules for LNV interacions •Phys.Rev. D31, 105 (1985) we have verified that

$$\begin{aligned} a_l^{W-I'} &\rightarrow (1+\delta_{lm})^2 a_l^{W-I} \\ a_l^{W-II'} &\rightarrow (1+\delta_{lm})^2 a_l^{W-II} \end{aligned} \quad (15)$$

where it is understood that one must replace the appropriate couplings and masses involved in each contribution. Similar expressions hold for the contributions to the WEDM arising from LNV vertices.

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Potential contributions

Scenario	Scalar couplings	Contribution	Model
One neutral CP-even scalar ϕ_i^0	$\phi_i^0 \bar{\ell}_l \ell_m$, $\phi_i^0 ZZ$	II-III	MHDM, TM
One neutral CP-odd scalar $\tilde{\phi}_i^0$	$\tilde{\phi}_i^0 \bar{\ell}_l \ell_m$	II	MHDM, TM
Two neutral scalar $\hat{\phi}_{i,j}^0$	$\hat{\phi}_{i,j}^0 \bar{\ell}_l \ell_m$, $Z \hat{\phi}_i^0 \hat{\phi}_j^0$ $(i \neq j)$, $\hat{\phi}_{i,j}^0 ZZ$	I-III	MHDM
One or two charged scalars $\phi_{i,j}^{\pm}$	$\phi_{i,j}^{-} \bar{\ell}_l \nu_m$, $Z \phi_i^{\pm} \phi_j^{\mp}$	I-III	MHDM, TM
One charged scalar $\phi_i^{\pm}$	$\phi_i^{-} \bar{\ell}_l \nu_m$, $Z W^{\pm} \phi_{i,j}^{\mp}$	III	TM
One or two doubly charged scalars $\phi_{i,j}^{\pm\pm}$	$\phi_i^{--} \ell_l \ell_l$, $Z \phi_i^{\pm\pm} \phi_j^{\mp\mp}$,	I′-II′	TM

Figura: Potential contributions to the AWMDM of a charged lepton arising from new scalar bosons ϕ_i and ϕ_j at the one-loop level. $\phi_{i,j}^0$ ($\tilde{\phi}_{i,j}^0$) stand for neutral CP-even (CP-odd) scalar bosons and $\hat{\phi}_{i,j}^0$ for a mixture of CP-eigenstates. Note that although the vertex $Z \phi_i^0 \tilde{\phi}_j^0$ is not forbidden by CP invariance, the type-I contribution to the AWMDM vanishes.

Conclusions

- We have obtained, at the one loop level, the potential contributions from new hypothetical physical scalar to both the weak anomalous magnetic moment and the weak electric dipole moment of the charged leptons. We have obtained results in terms of both parametric integrals and Passarino-Veltman scalar functions.
- A deeper and precise numerical analysis of some specific extended scalar scenarios is in progress. In particular, we are interested in models with explicit CP violation that could contribute to the WEDM's of the tau lepton.

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Thank you!