Eur. Phys. J. C 17, 107–111 (2000)
Digital Object Identifier (DOI) 10.1007/s100520000453

THE EUROPEAN
PHYSICAL JOURNAL C

Can four-fermion contact interactions at one-loop explain the new atomic parity violation results?

A. Gusso

Instituto de Física Teórica, Universidade Estadual Paulista, Rua Pamplona 145, CEP 01405–900 São Paulo, Brazil
(e-mail: gusso@ift.unesp.br)

Received: 28 March 2000 / Revised version: 12 May 2000 /
Published online: 9 August 2000 – © Springer-Verlag 2000

Abstract. We investigate the possibility that four-fermion contact interactions give rise to the observed deviation from the standard model prediction for the weak charge of cesium, through one-loop contributions. We show that the presence of loops involving the third generation quarks can explain such a deviation.

1 Introduction

For the last fifty years, most of the activity in particle physics relied on the use of large particle accelerators. These devices, allowing the scientists to break matter down to its most elementary constituents, have been fundamental in helping particle physicists reveal the secrets of matter. However, besides these high-energy experiments, low-energy experiments were also carried out, giving very important contributions, like the confirmation of parity violation in weak interactions. In fact, low-energy experiments always played a important role in particle physics. But now there are perspectives that during the first decade of the next century the importance of low-energy experiments must increase significantly. Until LHC collects enough data, the measurement of the anomalous magnetic moment of the muon [1] and atomic parity violation (APV) in heavy atoms [2] are going to be a source of significant new results [3].

The measurement of APV in heavy atoms is one of the most important and ambitious low-energy experiments being carried out. The aim is to achieve a 0.1% accuracy in the measurement of the weak charge of cesium in the next few years. Recently a new step was given in this direction; the weak charge of cesium was reported to 0.6% [4] to be

$$Q_{\rm W}({}^{133}_{55}{\rm Cs}) = -72.06 \pm (0.28)_{\rm exp} \pm (0.34)_{\rm theor}. \tag{1}$$

We must compare this result with the prediction of the standard model (SM). Including radiative corrections, it is conveniently expressed in terms of the oblique parameters as

$$Q_{\rm W}^{\rm SM} = -72.72 \pm 0.13 - 102\epsilon_3^{\rm rad}, \tag{2}$$

where the hadronic-loop uncertainty has been included. The value of $\epsilon_3^{\rm rad}$ depends on the top quark and on the Higgs boson mass. For $m_{\rm top} = 175\,{\rm GeV}$ we have [5]

$$\epsilon_3^{\rm rad} = 5.110 \times 10^{-3} (M_H = 100\,{\rm GeV}), \tag{3}$$

$$\epsilon_3^{\rm rad} = 6.115 \times 10^{-3} (M_H = 300\,{\rm GeV}). \tag{4}$$

In the calculations hereafter we assume the $\epsilon_3^{\rm rad}$ given in (3). It is important to stress that our final conclusions are not going to depend in a significant way on the $\epsilon_3^{\rm rad}$ dependence on the Higgs mass. Comparing the theoretical prediction and the experimental value of $Q_{\rm W}$ we conclude that

$$Q_{\rm W}^{\rm exp} - Q_{\rm W}^{\rm SM} = 1.18 \pm 0.46. \tag{5}$$

This result implies that the SM prediction and the experimental result are 2.6σ apart. From (5) we see that the allowed range of variation for the total new physics contribution to the weak charge, $\Delta Q_{\rm W}$, is

$$0.28 \le \Delta Q_{\rm W} \le 2.08 \tag{6}$$

at 95% CL. This result is quite interesting. In fact, as noted in [5], it can be shown that taking serious the new result for $Q_{\rm W}({}^{133}_{55}{\rm Cs})$ we can exclude the SM at 99% CL.

In [4] the authors see no justification to believe that such a discrepancy originates from some experimental or theoretical mistake. They suggest instead that the new value of $Q_{\rm W}$ may have originated from the presence of some kind of new physics beyond the SM. This possibility has already been explored to some extent in [5,6], where it is shown that the observed deviation in $Q_{\rm W}$ can be explained by the presence of a new neutral gauge boson. Leptoquarks and certain four-fermion contact interactions can also account for the present discrepancy [5]. We point out that all these new contributions are at tree level. No analysis was done considering the effects of new physics through one-loop effects. With the intention of partially filling this gap we here analyze the problem if four-fermion contact interactions that do not contribute at tree level can lead to sizable contributions to $Q_{\rm W}$ through one-loop level diagrams.

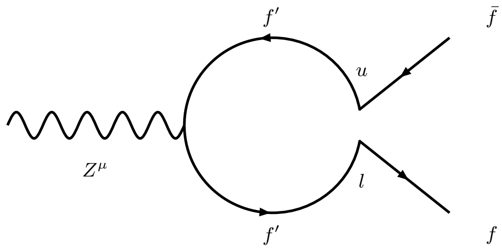

Fig. 1. s-channel diagram

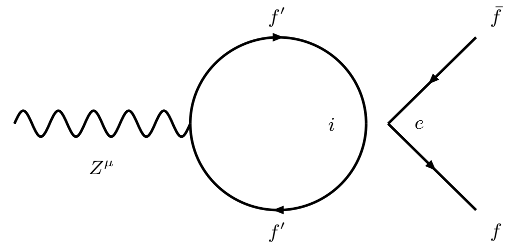

Fig. 2. t-channel diagram

2 One-loop effects of four-fermion contact interactions

Presently, the bounds on new physics are such that the new particles, if they exist, must be very heavy. Under these conditions the effects of these new particles intermediating interactions involving four fermions can be approximated as contact interactions. In the specific case of APV, the contact interactions that can contribute at tree level have the form $g(\bar{e}\Gamma e)(\bar{q}\Gamma q)$, where g is the coupling constant, Γ denotes an adequate combination of gamma matrices, e is the spinor for the electron in the electrosphere, and q corresponds to the spinor of a quark in the atomic nucleus. When we want to deal with one-loop effects we can consider more general expressions for the four-fermion interactions. We can consider scalar, vectorial, and tensorial interactions involving not only two leptons and two quarks, as shown above, but also interactions involving only quarks, or only leptons. In general, these interactions can be expressed in terms of the following Lagrangians [7]:

$$\mathcal{L}_{\rm scalar} = \eta\frac{g^2}{\Lambda^2}[\bar{\psi}_m(V_{\rm S}^m - {\rm i}A_{\rm S}^m\gamma_5)\psi_m] \times [\bar{\psi}_n(V_{\rm S}^n - {\rm i}A_{\rm S}^n\gamma_5)\psi_n], \quad (7)$$

$$\mathcal{L}_{\rm vector} = \eta\frac{g^2}{\Lambda^2}[\bar{\psi}_m\gamma^\mu(V_{\rm V}^m - A_{\rm V}^m\gamma_5)\psi_m] \times [\bar{\psi}_n\gamma_\mu(V_{\rm V}^n - A_{\rm V}^n\gamma_5)\psi_n], \quad (8)$$

$$\mathcal{L}_{\rm tensor} = \eta\frac{g^2}{\Lambda^2}[\bar{\psi}_m\sigma^{\mu\nu}(V_{\rm T}^m - {\rm i}A_{\rm T}^m\gamma_5)\psi_m] \times [\bar{\psi}_n\sigma_{\mu\nu}(V_{\rm T}^n - {\rm i}A_{\rm T}^n\gamma_5)\psi_n], \quad (9)$$

where Λ is the energy scale of the effective interaction, $V_{\rm S,V,T}^{m,n}$ and $A_{\rm S,V,T}^{m,n}$ are real constants with m and n being the lepton and quark flavors, and g is the coupling constant which can depend on the fermion flavors. The parameter η can assume the values ± 1 in order to allow a constructive or destructive interference with the standard contribution for a given process. Here we have assumed the most general four-fermion interactions, in which the new physics present at high energies must respect only a $U(1)$ symmetry. Such a choice allows us to parametrize not only interactions that respect the $SU(2)\times U(1)$ symmetry of the SM, but also, and more accurately, the interesting case of extensions based on extra $U(1)$ symmetries.

The tensorial and scalar interactions are so severely constrained by many experiments [7,8] that we will simply disregard then hereafter. We consider only the one-loop effects of the vectorial four-fermion contact interaction, (9). The diagrams that contribute to $Q_{\rm W}$ are represented in Figs. 1 and 2. In these diagrams the fermion f can be either an electron of the electrosphere or a quark of the nucleus, and we allow f' to be any fermion present in the SM. The only restriction, obviously, is that the four-fermion interaction cannot have any significant contribution at tree level. This implies that we do not consider interactions like $\bar{e}\gamma e\bar{q}\gamma q$ ($q = u, d$ quarks). The effect of the two diagrams is to modify the form factors F_i, $i = {\rm v}, {\rm a}$ in the following Z boson current:

$$J^\mu = e\bar{u}_f(p_1)(F_{\rm v}\gamma^\mu + F_{\rm a}\gamma^\mu\gamma_5)v_f(p_2). \quad (10)$$

The form factors are functions of Q^2, with $Q = p_1 + p_2$. $F_{\rm v}$ and $F_{\rm a}$ are present at tree level in the SM

$$F_{\rm v}^{\rm tree} \equiv G_{\rm V} = \frac{1}{2s_{\rm W}c_{\rm W}}(T_3^f - 2Q_f s_{\rm W}^2), \quad (11)$$
$$F_{\rm a}^{\rm tree} \equiv -G_{\rm A} = -\frac{1}{2s_{\rm W}c_{\rm W}}T_3^f,$$

where $s_{\rm W}(c_{\rm W}) = \sin(\cos)\theta_{\rm W}$, and T_3^f is the third component of the fermion weak isospin. The contributions of the diagrams presented in Figs. 1 and 2 to $F_{\rm v}$ and $F_{\rm a}$ have already been evaluated in [7], and are similar to the results of [9,10].

The contribution of the interaction written in (9) to the s-channel is

$$\delta F_{\rm v} = \eta\frac{g^2}{48\pi^2\Lambda^2}\{[6G_{\rm A}M_{f'}^2 - (G_{\rm V}+G_{\rm A})Q^2] \times (V_{\rm V}^{\rm l} + A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} + A_{\rm V}^{\rm u}) + [6G_{\rm A}M_{f'}^2 + (G_{\rm V}-G_{\rm A})Q^2] \times (V_{\rm V}^{\rm l} - A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} - A_{\rm V}^{\rm u})\}\log\left(\frac{\Lambda^2}{\mu^2}\right),$$

$$\delta F_{\rm a} = -\eta\frac{g^2}{48\pi^2\Lambda^2}\{[6G_{\rm A}M_{f'}^2 - (G_{\rm V}+G_{\rm A})Q^2] \times (V_{\rm V}^{\rm l} + A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} + A_{\rm V}^{\rm u}) + [6G_{\rm A}M_{f'}^2 + (G_{\rm V}-G_{\rm A})Q^2] \times (V_{\rm V}^{\rm l} - A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} - A_{\rm V}^{\rm u})\}\log\left(\frac{\Lambda^2}{\mu^2}\right), \quad (12)$$

and to the t-channel,

$$\delta F_{\rm v} = \eta\frac{g^2}{12\pi^2\Lambda^2}V_{\rm V}^e[6G_{\rm A}^iA_{\rm V}^iM_{f'}^2$$

$$- (G^i_{\mathrm{A}} A^i_{\mathrm{V}} + G^i_{\mathrm{V}} V^i_{\mathrm{V}}) Q^2] \log\left(\frac{\Lambda^2}{\mu^2}\right),$$

$$\delta F_{\mathrm{a}} = -\eta \frac{g^2}{12\pi^2 \Lambda^2} A^e_{\mathrm{V}} [6 G^i_{\mathrm{A}} A^i_{\mathrm{V}} M^2_{f'} - (G^i_{\mathrm{A}} A^i_{\mathrm{V}} + G^i_{\mathrm{V}} V^i_{\mathrm{V}}) Q^2] \log\left(\frac{\Lambda^2}{\mu^2}\right). \quad (13)$$

Here, the indices u(l) denote the coupling constants associated to the upper (lower) vertices of Fig. 1 and the index i refers to the coupling constants of the internal fermion running in the loop, and e refers to the external fermion (cf. Fig. 2). The parameter μ corresponds to the characteristic energy scale of the physical process under consideration.

3 Contributions to Q_{W}

The one-loop contributions, δF_{v} and δF_{a}, are going to contribute to the APV in cesium by modifying the coefficients of the Lagrangian that conventionally parametrizes the parity violating terms in the electron–nucleus interaction [11],

$$\mathcal{L}^{\mathrm{PV}} = \frac{G_{\mathrm{F}}}{\sqrt{2}} (C_{1u} \bar{e}\gamma^\mu\gamma^5 e \bar{u}\gamma_\mu u + C_{2u} \bar{e}\gamma^\mu e \bar{u}\gamma_\mu\gamma^5 u + C_{1d} \bar{e}\gamma^\mu\gamma^5 e \bar{d}\gamma_\mu d + C_{2d} \bar{e}\gamma^\mu e \bar{d}\gamma_\mu\gamma^5 d + \cdots), \quad (14)$$

where the ellipsis represent heavy-quark terms $q = s, c, b, t$. In heavy atoms, as in the case of cesium, coherence effects make the dominant source of parity violation to be proportional to the weak charge given by

$$Q_{\mathrm{W}} = -2[(2Z + N) C_{1u} + (Z + 2N) C_{1d}], \quad (15)$$

where Z and N are the number of protons and neutrons in the atomic nucleus, respectively. So we only need to evaluate the one-loop effects of four-fermion contact interactions to the first and third terms in (14), neglecting all other contributions. Denoting the new physics contributions to C_{1q} by δC_{1q}, $q = u, d$, we can calculate the effect on $Q_{\mathrm{W}}(^{133}_{55}\mathrm{Cs})$,

$$\Delta Q_{\mathrm{W}} = -376 \delta C_{1u} - 422 \delta C_{1d}. \quad (16)$$

From the s-channel diagram corrections to the Zee vertex of the electron–nucleus interaction, one finds the result that

$$\delta C_{1q} = \eta N_c \frac{g^2}{4\pi^2} (I^q_3 - 2Q^q s^2_{\mathrm{W}}) I^{f'}_3 [(V^{\mathrm{l}}_{\mathrm{V}} + A^{\mathrm{l}}_{\mathrm{V}})(V^{\mathrm{u}}_{\mathrm{V}} + A^{\mathrm{u}}_{\mathrm{V}}) + (V^{\mathrm{l}}_{\mathrm{V}} - A^{\mathrm{l}}_{\mathrm{V}})(V^{\mathrm{u}}_{\mathrm{V}} - A^{\mathrm{u}}_{\mathrm{V}})] \left(\frac{M_{f'}}{\Lambda}\right)^2 \log\left(\frac{\Lambda}{\mu}\right)^2, \quad (17)$$

and from the t-channel

$$\delta C_{1q} = \eta N_c \frac{g^2}{\pi^2} (I^q_3 - 2Q^q s^2_{\mathrm{W}}) I^{f'}_3 (A^e_{\mathrm{V}} A^{f'}_{\mathrm{V}}) \times \left(\frac{M_{f'}}{\Lambda}\right)^2 \log\left(\frac{\Lambda}{\mu}\right)^2. \quad (18)$$

Table 1. ΔQ_{W} for bottom quark in the loop

Channel	Quark		
	u	d	$u + d$
s	0.003	0.002	0.005
t	0.003	0.002	0.005
$s + t$	0.006	0.004	0.010

From the s-channel corrections to the Zqq vertex we have

$$\delta C_{1q} = \eta N_c \frac{g^2}{4\pi^2} I^e_3 I^{f'}_3 [(V^{\mathrm{l}}_{\mathrm{V}} + A^{\mathrm{l}}_{\mathrm{V}})(V^{\mathrm{u}}_{\mathrm{V}} + A^{\mathrm{u}}_{\mathrm{V}}) - (V^{\mathrm{l}}_{\mathrm{V}} - A^{\mathrm{l}}_{\mathrm{V}})(V^{\mathrm{u}}_{\mathrm{V}} - A^{\mathrm{u}}_{\mathrm{V}})] \left(\frac{M_{f'}}{\Lambda}\right)^2 \log\left(\frac{\Lambda}{\mu}\right)^2, \quad (19)$$

and from the t-channel

$$\delta C_{1q} = \eta N_c \frac{g^2}{\pi^2} I^e_3 I^{f'}_3 (V^q_{\mathrm{V}} A^{f'}_{\mathrm{V}}) \left(\frac{M_{f'}}{\Lambda}\right)^2 \log\left(\frac{\Lambda}{\mu}\right)^2. \quad (20)$$

Here N_c denotes the color factor which depends on the number of quarks present in each graph. To get (17)–(20) we have assumed $Q^2 = 0$. This is a reasonable assumption because the binding energy of the cesium electron which is considered in the experiments (the outermost one) is of order of fractions of an electronvolt.

To proceed with our analysis, the first thing we must do is to choose the model or models for the four-fermion interactions. This is done by choosing the values of the constants η, g, V_{V}, and A_{V} in (9). We are going to consider the case that the four-fermion interactions originate from fermion compositeness. Since the exchange of constituents among the fermions takes place in a strong interaction regime, we are led to consider $g^2 = 4\pi$ (see, e.g. [9,12]). In this case, the new physics scale, Λ, corresponds to the compositeness scale.

Initially, we estimate the contributions to ΔQ_{W} considering the present limits on the new physics scale for contact interactions involving two electrons and two other SM fermions [7,13,14]. We consider now only contributions to the Zee vertex (see (17) and (18)) and assume the following choice of parameters:

$$(V^{\mathrm{l}}_{\mathrm{V}} + A^{\mathrm{l}}_{\mathrm{V}})(V^{\mathrm{u}}_{\mathrm{V}} + A^{\mathrm{u}}_{\mathrm{V}}) + (V^{\mathrm{l}}_{\mathrm{V}} - A^{\mathrm{l}}_{\mathrm{V}})(V^{\mathrm{u}}_{\mathrm{V}} - A^{\mathrm{u}}_{\mathrm{V}}) = 1, \quad A^e_{\mathrm{V}} A^{f'}_{\mathrm{V}} = \frac{1}{4}. \quad (21)$$

With this choice the s- and t-channel contributions are equal. We note that such a choice is very reasonable since it is similar to models like LL, RR, and others usually considered in the literature [7,12,14]. We assume such a model because what is really important for our estimates is only the order of magnitude of the couplings. In our calculations we take η so that the final contribution for Q_{W} is positive, since negative contributions are completely excluded. In Table 1 we have the value of ΔQ_{W} considering a b quark running in the loop, calculated separately for each

Table 2. $\Delta Q_{\rm W}$ for top quark in the loop

Channel	Quark		
	u	d	$u+d$
s	0.42	0.27	0.69
t	0.42	0.27	0.69
$s+t$	0.84	0.54	1.38

possible quark in the nucleus and for the different channels, and for the sum of all contributions. We assumed $m_b = 4.5\,\mathrm{GeV}$, $\Lambda = 3\,\mathrm{TeV}$, and $\mu = m_e$, were m_e is the electron mass. The choice of the value of Λ was based on the results of [7,14]. We can see that the contributions are quite small because of the smallness of the b quark mass. In fact, because of the dependence on $M_{f'}^2$ in (17) and (18) we obtain even smaller results for lighter fermions in the loop. The results of the same calculation considering a t quark in the loop can be found in Table 2. In this case we used $m_t = 175\,\mathrm{GeV}$, $\Lambda = 10\,\mathrm{TeV}$ and $\mu = m_e$. The choice of the value of Λ was based on the results obtained in [7] which come from the constraints set by the very precise measurement of $\Gamma_{\ell\ell}$. In this case, the results we obtained are really very interesting. $\Delta Q_{\rm W}$ is of the order of magnitude of the expected correction and even if we assume that the different contributions in the first two columns and rows of Table 2 interferes destructively instead of constructively, we have a result which falls into the interval in (6).

The absence of good limits on the compositeness scale of $qqq'q'$ interactions, involving at least one pair of heavy quarks, does not allow us to make for the Zqq vertex the same estimates as we did for the contributions to $\Delta Q_{\rm W}$ from the $eeqq$ interactions present in a Zee vertex. What we can do is to determine bounds on the range of possible values of the compositeness scale compatible with (6). We assume that

$$(V_{\rm V}^{\rm l} + A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} + A_{\rm V}^{\rm u}) - (V_{\rm V}^{\rm l} - A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} - A_{V}^{\rm u}) = 1, \quad V_{\rm V}^{q} A_{\rm V}^{f'} = \frac{1}{4}, \tag{22}$$

in (19) and (20). This implies that the s- and t-channel contributions are equal. We choose η so that δC_{1u} and δC_{1d} are always negative, which implies $\delta C_{1u} = \delta C_{1d}$. Such assumptions allow us to get the most stringent bounds on Λ. In Tables 3 and 4 we have, respectively, for a bottom and a top quark in the loop, the values of Λ which give the deviations expressed in (6) (we assumed $\mu = \Lambda_{\rm QCD} \approx 300\,\mathrm{GeV}$). We evaluated Λ considering the contributions resulting from the u and d quarks present in the nucleus as we did in Tables 1 and 2. The results are shown for one and two channels contributing. The results in Table 3 show us that $Q_{\rm W}$ is reasonably sensitive to the presence of b quark loops. This implies that the presence of these loops can possibly explain the observed deviation in $Q_{\rm W}$. As expected, $Q_{\rm W}$ is very sensitive to the presence of t quark loops, as can be seen from the results in Table 4.

Table 3. Limits on Λ, in GeV, for a bottom quark in the loop. In the first three columns we consider the contribution of only one channel (s or t). In the last three columns both channels are taken into account

$\Delta Q_{\rm W}$	Quark					
	u	d	$u+d$	u	d	$u+d$
0.28	540	580	810	780	830	1200
2.08	180	200	280	270	280	400

Table 4. Limits on Λ, in TeV, for a top quark in the loop. In the first three columns we consider the contribution of only one channel (s or t). In the last three columns both channels are taken into account

$\Delta Q_{\rm W}$	Quark					
	u	d	$u+d$	u	d	$u+d$
0.28	26	28	38	37	40	55
2.08	9.0	9.6	13	13	14	19

It is worth mentioning that in the previous analysis it is reasonable to assume that the new physics scale, Λ, present in the s- and t-channel diagrams is the same, because the contact interactions result from the exchange of the fermion constituents in a strong interaction regime. But, in the case we consider massive bosons (e.g. leptoquarks and Z's) to be responsible for the contact interaction, this generally is not a valid assumption. In fact, the s-channel diagram can originate from the exchange of leptoquarks, diquarks or dileptons and the t-channel diagram from the exchange of ordinary massive gauge bosons, like a Z' associated to an extra $U(1)$ gauge symmetry. We are going now to consider some implications of the possible presence of these bosons.

We note that in the case of the most popular models for new massive vectorial bosons (W', Z' and leptoquarks) the present bounds on their masses always satisfy the condition $M > 1\,\mathrm{TeV}$ [13]. Based on this fact we assume, conservatively, the existence of four-fermion contact interactions with $\Lambda = 1\,\mathrm{TeV}$, and estimate the allowed values for the coupling constants. More exactly, what we do here is to estimate the allowed values of

$$\begin{aligned} & g^2[(V_{\rm V}^{\rm l} + A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} + A_{\rm V}^{\rm u}) + (V_{\rm V}^{\rm l} - A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} - A_{\rm V}^{\rm u})], \\ & g^2(A_{\rm V}^{e} A_{\rm V}^{f'}), \\ & g^2[(V_{\rm V}^{\rm l} + A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} + A_{\rm V}^{\rm u}) - (V_{\rm V}^{\rm l} - A_{\rm V}^{\rm l})(V_{\rm V}^{\rm u} - A_{\rm V}^{\rm u})], \\ & g^2(V_{\rm V}^{q} A_{\rm V}^{f'}), \end{aligned} \tag{23}$$

in (17)–(20). We denote these constants generically by G^2. Considering that only δC_{1u} or δC_{1d} contributes to $\Delta Q_{\rm W}$, we obtained the results shown in Table 5, where f' is the top quark. We would get smaller allowed values in the case that the contributions from the s- and t-channel were summed as well as if δC_{1u} and δC_{1d} contributed at the same time. Notice that the values in Table 5 are compati-

Table 5. Limits on G^2 for contributions through the s-channel. The results in the first two columns are from contributions to the Zee vertex. The results in the last two columns are from contributions to the Zqq vertex. To obtain the corresponding results for the t-channel divide the present values by 4

ΔQ_{W}	Quark			
	u	d	u	d
0.28	0.039	0.059	0.026	0.026
2.08	0.29	0.44	0.19	0.19

ble with the coupling constants of the models in [13]. For other lighter fermions in the loops, the resulting coupling constants must be unacceptably large. For instance, for a b quark it should be of the order of 4π, as expected in the compositeness scenario.

4 Final discussion and conclusions

In this article we investigated the one-loop effects arising from four-fermion contact interactions that do not appear in the standard model. We assumed that no new physics contributes at the tree level to the weak charge. This situation arises, for example, when the contributions from tree-level diagrams[1] interfere destructively (see, e.g. [15]). This allows us to consider the new physics in a sense universal, affecting all quarks and leptons and yet not contributing to Q_{W} at tree level. Another possibility is that the new physics leads to negligible couplings among light quarks and leptons but sizable ones in interactions involving heavy quarks.

We estimated the effects of the contact interactions on Q_{W} analyzing the contributions to the vectorial and axial form factors. We concluded that four-fermion interactions containing the top quark can lead to sizable contributions through the Zee and Zqq vertices when fermion compositeness is assumed. Four-fermion interactions that contain the bottom quark can also lead to sizable results through the Zqq vertex if the compositeness scale is in the range of few hundred GeV to 1 TeV.

We showed, at the end of the previous section, that the presence of new massive vectorial bosons, like Z's and leptoquarks, contributing at the one-loop level[2], can also explain the observed discrepancy in the measured value of the weak charge of cesium. In this scenario also the top quark loops are responsible for sizable contributions to Q_{W}. In fact, it is not surprising that Q_{W} is very sensitive to top quark loops; radiative corrections from the SM contribute with 1.3% of the value in (2).

We conclude by noting that in spite of the fact that our results are only approximate, for the very nature of the calculation of one-loop diagrams in effective interactions [17], we expect that the actual effects of new physics are not going to be far from what we have obtained. But we must be aware that cancellations among different one-loop diagrams may take place in actual theories, leading to non-observable effects. But our results suggest that one-loop effects of new physics may contribute significantly to the weak charge of cesium, leading to the observed discrepancy between the SM prediction and the experimental determination.

Acknowledgements. The author would like to thank S.F. Novaes and E.M. Gregores for a critical reading of the manuscript. This work was supported by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP).

[1] Here we are concerned with diagrams involving the electron in the atom electrosphere and the u and d quarks in the nucleus. The effects arising from sea quarks are negligible

[2] The Z's appearing in extensions of the standard model based on extra $U(1)_B$ or $U(1)_{L-L'}$ symmetries [16] are examples of bosons that can lead naturally to four-fermion contact interactions that contribute to Q_{W} only through loop diagrams

References

1. B.L. Roberts, Z. Phys. C **56**, S101 (1992)
2. B. Patrick, C.E. Wieman, in Precision tests of the standard model, edited by P. Langacker (World Scientific 1995)
3. M.J. Ramsey-Musolf, hep-ph/0001250
4. S.C. Bennett, C.E. Wieman, Phys. Rev. Lett. **82**, 2484 (1999)
5. R. Casalbuoni, S. De Curtis, D. Dominici, R. Gatto, Phys. Lett. B **460**, 135 (1999); D. Dominici, hep-ph/9909290
6. J.L. Rosner, Phys. Rev. D **61**, 016006 (2000)
7. M.C. Gonzalez-Garcia, S.F. Novaes, Phys. Lett. B **407**, 255 (1997); M.C. Gonzalez-Garcia, A. Gusso, S.F. Novaes, J. Phys. G **24**, 2213 (1998)
8. S. Davidson, D. Bailey, B.A. Campbell, Z. Phys. C **61**, 613 (1994)
9. S. Narison, Phys. Lett. B **167**, 214 (1986)
10. P. Mery, S.E. Moubarik, M. Perrottet, F.M. Renard, Z. Phys. C **46**, 229 (1990)
11. W.J. Marciano, A. Sirlin, Phys. Rev. D **27**, 552 (1983); V. Barger, K. Cheung, D.P. Roy, D. Zeppenfeld, Phys. Rev. D **57**, 3833 (1998)
12. E. Eichten, K. Lane, M.E. Peskin, Phys. Rev. Lett. **50**, 811 (1983)
13. C. Caso, et al., Eur. Phys. J. C **3**, 1 (1998) and 1999 off-year partial update for 2000 edition (URL: http://pdg.lbl.gov/)
14. G. Abbiendi, et al., Eur. Phys. J. C **6**, 1 (1999)
15. L. Giusti, A. Strumia, Phys. Lett. B **410**, 229 (1997)
16. C.D. Carone, H. Murayama, Phys. Rev. Lett. **74**, 3122 (1995); M. Drees, O.J. Éboli, J.K. Mizukoshi, Phys. Lett. B **447**, 116 (1999); X.-G. He, G.C. Joshi, H. Lew, R.R. Volkas, Phys. Rev. D **43**, R22 (1991)
17. C.P. Burgess, D. London, Phys. Rev. D **48**, 4337 (1993)