The Weak Charges and Weak-Mixing Angles

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Abstract: Here, using the Scale-Symmetric Theory (SST), we calculated the weak charges of the proton, neutron, electron, neutrinos, and of a few atomic nuclei and we compared them with experimental data. The known carriers of the weak interactions contain lighter components with fixed masses (two invariants). The sine squared of the weak-mixing angle for the parity violating lepton-proton scattering is 0.24005, for the atomic parity violation the mean is 0.23508, and for the momentum scales equal to $W^{\pm}$ and higher the mean is 0,23106 = constant.

1. Introduction

In this paper we have shown how weak charges result from the structure and internal dynamics of particles described in the Scale-Symmetric Theory (SST) [1]. Then, to make it possible to compare theoretical and experimental results, we defined the weak-mixing angle via the weak charge as it is in the Standard Model (SM). Such a scheme leads to a full understanding of the nature of the weak interactions.

The SST model of the electroweak interactions is based on the atom-like structure of baryons and on the SST structure of the electron and neutrinos [1].

In SST, the weak charge of the proton and electron follows from the radius-circle transition of the positive part of the virtual weak field $E_{weak\text{-}field}$ (then energy decreases 2π times) and such energy is normalized by mass of the particle/object M_{object}

$$Q_{w,particle} = [E_{weak\text{-}field} / (2\pi)] / M_{object} . \tag{1}$$

The definition of the sine squared of weak-mixing angle

$$s_i^2 = \sin^2 \Theta_{w,i} \tag{2}$$

in the SST model of weak interactions, is as follows

$$s_i^2 = (1 - |Q_w|) / 4 , \tag{3}$$

where $|Q_w|$ is the absolute value of weak charge.

2. Weak charges of the proton, neutron, electron, and neutrinos in the SST model

SST shows that in the centre of proton is the scalar spacetime condensate (the source/weak-field of the nuclear weak interactions) with a mass of $Y = 424.12176$ **MeV**. Such source creates the virtual Y spacetime condensates that can be exchanged. From (1) we obtain the weak charge of the proton

$$Q_{w(p),SST} = [Y / (2\pi)] / p = 0.0719419 . \quad (4)$$

It is consistent with experimental data [3]: $Q_{w(p),exp} = 0.0719(45)$.

SST shows that in the centre of the SST electroweak structure of the electron is the spacetime condensate with a mass equal to a half of the bare mass of the electron $m_{e,bare}/2 = 0.2552035$ **MeV** [1]. According to SST, the electroweak structure of the electron contains the real bare electron and only one virtual bare electron-positron pair [1]. Since the positive mass of the virtual pair is higher than the real bare electron so probability of emission of one or two the spacetime condensate(s) of the electron (ESC(s)) by the virtual pair is higher. We see that the weak interactions of the electrons are via the virtual bare electron-positron pairs (it concerns also dark matter (DM)), so there are two possibilities, i.e. there can be exchanged one ESC or two ESCs. In the parity violating lepton-proton scattering is exchanged one ESC while in the proton-proton or proton-antiproton scattering are exchanged two ESCs because there is needed the $pp \rightarrow 2$ **ESC** symmetry. By an analogy to the proton, for one ESC we have (it is the weak charge of the electron)

$$Q_{w(e-),SST} = [(m_{e,bare} / 2) / (2\pi)] / (2 m_e) = 1 / (8\pi) = -0.0397887 . \quad (5)$$

This value is consistent with experimental data [2]

$$Q_{w(e-),exp.} = -0.0403(53) . \quad (6)$$

It means that in the experiment, there dominated the exchanges of the single ESCs.

Notice that the Standard Model (SM) value of the weak charge of the electron ($Q_{w(e-),SM} = -0.0473(2)$ [2]) is inconsistent with experimental data.

For two ESCs (for the pp and pp_{anti} collisions) we have

$$Q^*_{w(e-),SST} = [(2 m_{e,bare} / 2) / (2\pi)] / (2 m_e) = 1 / (4\pi) = -0.0795775 . \quad (7)$$

In this paper we will use the central value of the arithmetic mean as well because in the atomic nuclei, besides the electron-proton scattering there appear also the proton-proton collisions

$$Q_{w(e-),mean,SST} = -0.0596831 \pm 0.0198944 . \quad (8)$$

On the other hand, the QED electromagnetic version of the electron neglects the weak interactions (<u>it does not concern the Standard-Model electron</u>), so we have

$$Q_{w(e-),QED} = 0 . \quad (9)$$

It is inconsistent with experimental data.

Structure of the SST neutrinos cannot change [1], so for the electron-<u>anti</u>neutrino we have

$$Q_{w(\nu,e,anti),SST} = -1 . \quad (10)$$

The beta decay of the neutron looks as follows

$$n \rightarrow p + W^{-}_{virtual} \; \{\text{in } W^{-}_{virtual}, \text{ there are the Y and } m_{e,bare}/2 \text{ spacetime condensates}\} \rightarrow$$

$$\rightarrow p + e^{-} + \nu_{e,anti} \,. \qquad (11)$$

The neutron in the weak interactions behaves like an object composed of a proton, an electron, and an electron-antineutrino. In the SST model, the weak charge must be conserved.

On the basis of the expression (11), we can calculate the weak charge of the neutron

$$Q_{w(n),SST} = Q_{w(p),SST} + Q_{w(e-),mean,SST} + Q_{w(\nu,e,anti),SST} =$$

$$= 0.0719419 - 0.0596831 - 1 = -0.9877412 \,. \qquad (12)$$

3. Weak charges of atomic nuclei

In the SST scheme, the weak charge of atomic nucleus we can calculate from following formula

$$Q_{w(nucleus),SST} = Q_{w(n),SST} \cdot N + Q_{w(p),SST} \cdot Z =$$

$$= -0.9877412 \cdot N + 0.0719419 \cdot Z \,, \qquad (13)$$

where N is the number of neutrons, and Z is the number of protons.

For ${}_{20}Ca^{48}$ we obtain $Q_{w(Ca48),SST} = -26.218$.

Our result is the same as the experimental result [4]: -26.22.

For ${}_{55}Cs^{133}$ we obtain $Q_{w(Cs133),SST} = -73.087$.

This result is consistent with experimental data [5]: $-72.94(43)$.

For ${}_{81}Tl^{205}$ we obtain $Q_{w(Tl205),SST} = -116.653$.

It is consistent with experimental data [2]: $-116.4(3.6)$.

For a chain of ytterbium (Yb) isotopes [7] they used the SM Q_w scaling [8]

$$Q_{w,SM} = -0.989 \cdot N + 0.071 \cdot Z \,. \qquad (14)$$

It differs only a little from our formula (13).

The weak-charge distances between the $Q_{w,SM}$ and (13) are only about $\Delta Q_w \approx 0.2$, so we need much more precise results for atomic nuclei to choose the correct scheme/model. But emphasize that our results are closer to the experimental central values for Ca, Cs and Tl.

4. Weak-mixing angles

Here we will use our definition (see formula (3))

$$s_i^2 = (1 - |Q_w|) / 4 \,, \qquad (15)$$

From (15) and (4) we obtain the weak-mixing angle for the exchanged Y spacetime condensate in pp and pp_{anti} collisions

$$s_Y^2 = 0.2320145\ . \tag{16}$$

Such a value should be valid for the nuclear weak interactions for following momentum scales

$$\textbf{Momentum-scale } \mu \geq Y\ . \tag{17}$$

In the pp and pp_{anti} collisions, we have two ESCs, so from (15) and (7) we obtain

$$s_{pair}^2 = \{1 - 0.0795775\} / 4 = 0.23011\ . \tag{18}$$

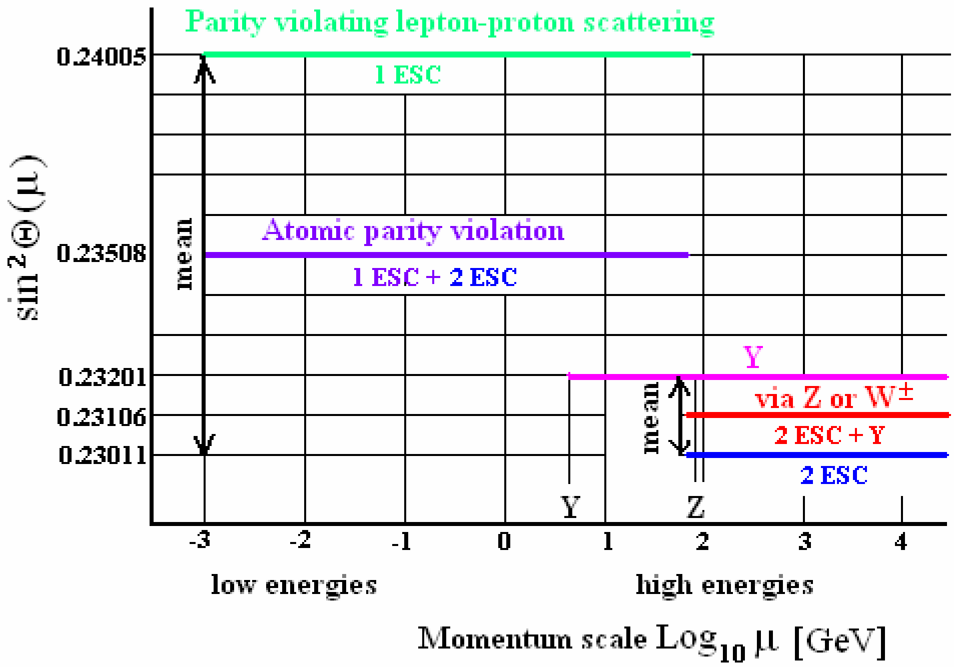

Fig.1. Scale dependence of the weak-mixing angle defined in the SST model.

For weak interactions via single ESC, we have (see (15) and (5)) – it is for the parity violating lepton-proton scattering

$$s_{single}^2 = \{1 - 0.0397887\} / 4 = 0.24005\ . \tag{19}$$

The Z and $W^{\pm}$ vector bosons contain both the Y condensates and the ESC pairs so we have – it is a mean value for the pp and pp_{anti} collisions

$$\hat{s}_Z^2 = (s_Y^2 + s_{pair}^2) / 2 = 0.23106\ . \tag{20}$$

It is value of the fundamental parameter for the weak interactions at following momentum scales

$$\textbf{Momentum-scale } \mu \geq W^{\pm}\ . \tag{21}$$

Our result is equal to the central value for the $M_{W,Z} + \Gamma_{W,Z} + m_t$ experimental data set [2].

From (15) and (8), we obtain the mean weak-mixing angle for the atomic parity violation

$$s_{atomic}^{2} = \{1 - 0.0596831\} / 4 = (s_{single}^{2} + s_{pair}^{2}) / 2 = 0.23508 . \quad (22)$$

Our results are collected in Fig.1.

The SST vector-boson weak-mixing angle is

$$s_{vector}^{2} = 1 - (W^{\pm} / Z)^{2} = 0.2230339 \approx 0.22303 . \quad (23)$$

Notice that the weak interactions of the $\pi^{+}\pi^{-}=2\pi^{\pm}$ pair are similar to the weak interactions of the electron-positron pair. On the other hand, we have

$$G_F \approx \alpha_{w(e)} / (2\,\pi^{\pm})^{2} \approx 1.2 \cdot 10^{-5}\ \mathbf{GeV}^{-2} , \quad (24)$$

where G_F is the Fermi coupling constant, and $\alpha_{w(e)} = 0.951118 \cdot 10^{-6}$ is the SST weak coupling constant for electrons [1].

It means that there are some overlapping areas in the Scale-Symmetric Theory and the Standard Model but the SM is an incomplete theory.

5. Summary

SST shows that the weak charges of the proton and electron follow from the radius-circle transition of the virtual spacetime condensates, and such resultant energy is normalized by mass of the particle/object.

Only the Z and $W^{\pm}$ vector bosons contain both the Y spacetime condensates and the condensate(s) placed in centre of the electrons and positrons (two invariants), so they can carry both the nuclear weak interactions ($\alpha_{w(p)} \approx 0.02$) and the weak interactions of electrons/positrons ($\alpha_{w(e)} \approx 10^{-6}$). The nuclear weak coupling constant $\alpha_{w(p)}$ and the weak coupling constant for the electrons $\alpha_{w(e)}$ are the invariants and lead to $\hat{s}_Z^{2} = 0.23106$ that is the fundamental value at high energies.

Emphasize that the weak interactions can be also via the single scalar spacetime condensates with the masses Y and $m_{e,bare}/2$, especially at lower energies.

Our weak charges of proton and neutron lead to the correct values for the weak charges of atomic nuclei

$$Q_{w(nucleus),SST} = - 0.9877412 \cdot N + 0.0719419 \cdot Z .$$

We can test the SST model of the nuclear weak interactions via very precise measurements of the weak charges of atomic nuclei.

Presented here the SST model of weak interactions is beyond the Standard Model because the SST value of the weak charge of the proton 0.0719419 is inconsistent with the SM value 0.0711(2) [6]. Moreover, our weak charge of the electron is consistent with experimental data while the SM value is inconsistent with both the SST value and the experimental one.

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