The Structure of Type-X Particles

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Abstract: Here, using the Scale-Symmetric Theory (SST), we have described all Type-X particles that are defined by the following quantum quantities: IG (JPC) = 0+ (1++).

1. Introduction

The X(3872) particle (also known as $\chi_{c1}(3872)$) is an exotic meson candidate with a mass of 3871.65(6) **MeV** [1]. The origin of this particle is still not fully understood.

The last data concerning its prompt production at $(s_{NN})^{1/2} = 5.02$ **TeV** are presented in [2].

The quantum numbers of the Type-X particles (today they are called $f_1(\ldots)$, $\chi_{c1}(\ldots)$ and $\chi_{b1}(\ldots)$) are defined as follows: $I^G(J^{PC}) = 0^+(1^{++})$ [1], [3]. There are nine such particles [1].

Here we will show that the internal structure of the Type-X mesons applies to all three types of interactions described in the Standard Model (SM), i.e. strong and weak and electromagnetic interactions, which allows for their better understanding. It is therefore a very important problem.

In order to present our very simple model, we need to briefly recall the structure and dynamics of the core of baryons detailed in the Scale-Symmetric Theory (SST) (see book [4]).

In SST, in the nuclear plasma at very high energy, the Titius-Bode (TB) orbits for the nuclear strong and electroweak interactions are destroyed so the intrinsic dynamics of the cores of baryons dominates [4]. Recently, the Type-X particles scientists detected in very hot nuclear plasma [2] so their creation must follow from structure of the core.

According to SST, in very hot nuclear plasma, the cores of baryons, for a short time, are packed to the maximum so they are moving slowly – then are created the Type-X and other particles so the coupling constant for the nuclear strong interactions inside baryons is not running and is $\alpha_s = 1$ [4]. **On the other hand, the running coupling constant for nuclear strong interactions concerns relativistic baryons. Such a scenario greatly simplifies the dynamics of collisions at high energies.**

The core consists of the torus/electric-charge, $X^{\pm} = 318.29553(31)$ **MeV** [4], which produces the bare electron-positron pairs – they are responsible for the electromagnetic interactions defined by the fine-structure constant $\alpha_{em} = 1 / 137.035998889019$ [4].

Inside the torus/electric-charge are produced the fundamental gluon loops (FGLs), $m_{FGL} = 67.54441$ **MeV** [4], which are responsible for the nuclear strong interactions. Between nucleons in atomic nuclei or colliding nucleons are exchanged pions, so we can say that the neutral pion, π^o = 134.9767(2) **MeV** (it is a pair of FGLs) [4], is the ground state of the nuclear strong interactions. The coupling constant for the nuclear strong interactions depends on energy so it is the running coupling [4].

In centre of the torus/electric-charge, there is the spin-0 spacetime condensate Y = 424.1217 **MeV** ≈ $4\mu^{\pm}$, where $\mu^{\pm}$ = 105.65838(10) **MeV** [4] denotes the muon. The spacetime condensates are built of the carriers of photons which are the rotational energies of the carriers. Photons and the bare electron-positrons pairs carry the electromagnetic interactions so the spacetime condensates can interact due to the electroweak interactions. When spins of the carriers of photons in a spacetime condensate do not rotate then the condensate interacts only due to the nuclear weak interactions defined by the coupling constant $\alpha_{w(p)}$ = 0.018722909 [4]. At higher energies of colliding protons or atomic nuclei, there are created spacetime condensates with masses higher than Y.

Here we use also the following quantities.
*Mass of electron: $m_e \equiv e^{\pm}$ = 0.51099880(49) **MeV** [4].
*Bare mass of electron: $m_{e,bare} \equiv e^{\pm}{}_{bare}$ = 0.51040691(49) **MeV** [4].
*Lifetime of the muon: $\tau_{muon} = 2.194937 \cdot 10^{-6}$ **s** [4].
*Mass of the condensate in muon: $M_{Con,Muon} \approx 52.77$ **MeV** [4].
*Mass of the charged core of baryons: $H^{\pm}$ = 727.4387 **MeV** [4].

Notice that our theoretical results [4] are very close to the central values of the experimental data [1].

In the core of baryons, most important are following transitions

$$m_{FGL} \rightarrow 2\pi\, m_{FGL} \text{ (or } 3.14159\ldots \cdot \pi^o) \rightarrow Y \rightarrow 4\,\mu^{\pm} \rightarrow k\, m_{e,bare} \;(k \approx 828) \qquad (1)$$

and there is involved at least one electron-positron pair $2m_{e,bare}$.

Our model of the Type-X particles is as follows.

A) **SST shows that the FGLs in nuclear strong fields, despite the fact that they are the bosons (not fermions), behave as electrons in atoms so we can use the Pauli Exclusion Principle and the Hund's rule – it follows from the fact that both the nuclear strong fields and gluons have internal helicity [4].** In reality, gluons have two internal helicities and one external helicity, i.e. they have three "colours" so there are 8 different gluons [4]. In atoms, the first shell (K) can hold up to two electrons, the second one (L) can hold up to eight electrons (2 + 6), and so on. The K shell has one subshell called 1s – when it is fully filled there are **two** electrons ($1s^2$). The next L shell has two subshells called 2s and 2p – when it is fully filled there are eight electrons ($2s^2 2p^6$). The fully filled two first shells contain **ten** electrons ($1s^2 2s^2 2p^6$).

Most stable should be particles with fully filled nuclear shells, i.e. a ground state should contain two FGLs, while the first excited state should contain ten FGLs.

Masses of the central spacetime condensate in the Type-X particles must be different. It follows from the fact that all particles are created simultaneously so mass of central condensate in the ground state also must be unique.

The spacetime condensates interact weakly and electromagnetically so the product $\alpha_{w(p)}\alpha_{em}$ relates to the ground state (when interactions occur one after the other, the total coupling constant is the product of the coupling constants).

B) Assume that the X(3872) is the most ground state of the $I^G(J^{PC}) = 0^+(1^{++})$ particles. There should be a spacetime condensate, $M_{Con,EW}$ ($M_{Con,EW}$: $J^{PC} = 0^{++}$), two separated FGLs ($2m_{FGL}$: $J^{PC} = 0^{++}$), and a pair of one real and one virtual spin-1 $e^+e^-{}_1$ pairs, Q ($Q = e^+e^-{}_1 + [e^+e^-{}_1]_{virtual} = 1.022$ **MeV**). On the other hand, in decays of X(3872) we sometimes observe only one electron-positron pair or only one particle-antiparticle pair composed of charged particles – it leads to conclusion that the observed J of Q is 1. The observed parity and charge parity of the Q both should be +1. So we have for Q: $(J^{PC})_{Observed} = 1^{++}$. The Q is exchanged between the spacetime condensate and the FGLs.

The Q is a quadrupole of fermions – the four-fermion symmetry dominates in the core of baryons [4].

C) Quantization of the mass $M_{Con,EW}$ follows from the condition that its electroweak mass is equal to mass of the bare electron.

2. Mass of the spacetime condensate $M_{Con,EW}$

In SST, when interactions of a particle with a mass M are defined by a coupling constant α_i then there are created objects with masses equal to M_i

$$M_i = \alpha_i M . \qquad (2)$$

When interactions occur one after the other, the total coupling constant is the product of the coupling constants

$$M_{Total} = \Pi_i \alpha_i M . \qquad (3)$$

From point C) in Paragraph **1** and from (3) we have

$$M_{Con,EW} \alpha_{em} \alpha_{w(p)} = m_{e,bare} \qquad (4)$$

so we obtain

$$M_{Con,EW} = 3735.75 \textbf{ MeV} . \qquad (5)$$

3. Structure and quantum numbers of X(3872)

From the point B) in Paragraph 1 we have

$$M_{Con,EW}(3735.75 \text{ MeV}) + 2\, m_{FGL} + Q = 3871.86 \textbf{ MeV} \text{ and } (J^{PC})_{Observed} = 1^{++} . \qquad (6)$$

It is the X(3872) = 3871.65(6) **MeV** [1].

4. Lifetime of X(3872)

There is obligatory following formula for lifetime [4]

$$\tau_{Lifetime} \sim 1 / \alpha . \qquad (7)$$

Range of the nuclear strong interactions in baryons is ~3.0 **fm** [4] so a typical lifetime for such interactions is $\tau_s \approx 3.0$ [fm] / c = 10^{-23} **s**.

The **X(3872)** decays due to the transition from the strong interactions of FGLs to the weak interactions of the spacetime condensate $M_{Con,EW}$, so we have

$$\tau_{X(3872)} = \tau_s \, \alpha_s / \alpha_{w(p)} \approx 5.3 \cdot 10^{-22} \, \mathbf{s} \, . \tag{8}$$

This lifetime relates to the full width $\Gamma \approx 1.2$ **MeV** ($\Gamma = \hbar / \tau_{Lifetime}$) – it is consistent with experimental data [1].

5. Masses of particles defined by $I^G (J^{PC}) = 0^+ (1^{++})$

We have 9 such particles: four χ_{c1} and three χ_{b1} (see Table 1) and two f_1.

We claim that their basic states/particles (they are not the ground states with lowest energy/mass) are as follows: $\chi_{c1}(3872)$, $\chi_{b1}(2P)$ with a mass of 10255.46(72) **MeV** and $f_1(1285) = 1281.9(5)$ **MeV** [1] – we prove it below.

To conserve the quantum numbers of the basic states, there can be realized following scenarios.

*The basic particles can absorb a pair of pions. When the pions are charged then there is produced a virtual spin-0 electron-positron pair. For such objects is $J^{PC} = 0^{++}$. Then mass of the basic particles increases by 269.95 **MeV** for two neutral pions and by 279.14 **MeV** for $\pi^+\pi^-$ pair with virtual spin-0 electron-positron pair. The mean value is $F_{\pi,mean} = 274.55$ **MeV**.

*Next they can both absorb two separated FGLs with a total mass of $F_{FGL} = 2m_{FGL} = 135.09$ **MeV**, or emit the X^+X^- pair with virtual spin-0 electron-positron pair – then the mass decreases by $F_{X(\pm)} = 636.59$ **MeV**. For such objects is $J^{PC} = 0^{++}$.

The basic state of χ_{c1} is (it is the $1s^2$ state for the FGLs – the K shell)

$$\chi_{c1,basic} = M_{Con,EW} + 2 \, m_{FGL} + Q = 3871.86 \, \mathbf{MeV} \, . \tag{9}$$

Calculate mass of a spacetime condensate when two electromagnetic interactions occur one after the other – from (3) we have

$$M_{Con,EE} \, \alpha_{em}^{\;2} = m_{e,bare} \tag{10}$$

so we obtain

$$M_{Con,EE} = 9584.86 \, \mathbf{MeV} \, . \tag{11}$$

The basic state of χ_{b1} is (it is the $1s^2 2s^2 2p^6$ state for the FGLs – the K plus L shells)

$$\chi_{b1,basic} = M_{Con,EE} + 10 \, m_{FGL} + Q = 10261.32 \, \mathbf{MeV} \, . \tag{12}$$

Assume that electromagnetic mass of a spacetime condensate $M_{Con,E}$ is equal to the mass of bare electron

$$M_{Con,E} \, \alpha_{em} = m_{e,bare} \tag{13}$$

so $M_{Con,E}$ = 69.944 **MeV**.

Table 1 *The particles chi_c and chi_b with* I^G $(J^{PC}) = 0^+$ (1^{++})

Structure	χ_{c1} **Theory [MeV]**	χ_{c1} **Exper. [1] [MeV]**	χ_{b1} **Theory [MeV]**	χ_{b1} **Exper. [1] [MeV]**
Basic	3871.86	3871.65(6)	10261.32	10255.46(72)
Basic+$F_{\pi,mean}$	4146.41	4146.8(2.4)	10535.87	10513.4(7)
Basic+$F_{\pi,mean}$+F_{FGL}	4281.50	4274^{+8}_{-4}	10670.96	~10648 ?
Basic+$F_{\pi,mean}$–$F_{X(\pm)}$	3509.82	3510.67(5)	9899.28	9892.76(57)

Assume also that in the basic state of f_1, there is fully filled the M shell (it is the $3s^2 3p^6 3d^{10}$ state, i.e. there are 18 the FGLs)

$$f_{1,basic} = f_1(1285) = M_{Con,E} + 18\ m_{FGL} + Q = 1286.77\ \textbf{MeV}\ . \qquad (14)$$

The $f_1(1285)$ cannot emit the $F_{X(\pm)}$ as it is doing by the chi_c and chi_b particles because $M_{Con,E} << F_{X(\pm)}$. But the $f_1(1285)$ meson can fully fill the K shell for the FGLs ($1s^2$) so we have

$$f_1(1420) = f_1(1285) + 2\ m_{FGL} = 1421.85\ \textbf{MeV}\ . \qquad (15)$$

Probably the $f_1(1420)$ meson can fully fill the L shell for the FGLs ($2s^2 2p^6$) so we have

$$f_1(1959) = f_1(1420) + 8\ m_{FGL} = 1962.21\ \textbf{MeV}\ . \qquad (16)$$

We predict also a new I^G $(J^{PC}) = 0^+$ (1^{++}) chi_b particle with a mass of (see Table 1)

$$\chi_{b1}(10659) \approx 10648 \div 10671\ \textbf{MeV}\ . \qquad (17)$$

The second proposal for the chi_b1 mesons, that leads to similar a little lower masses, we present in [4] (see Section **5.2** in [4]) – masses of them are closer to experimental data because they are created at lower energies nearly the edge of the strong fields, not in the cores of baryons.

To conserve the quantum numbers of the basic chi_c and chi_b mesons presented here, there must be absorbed or emitted the pairs composed of uncharged particles, i.e. $2m_{FGL}$ or $2\pi^o$, or the quadrupoles of charged particles, i.e. $2(\pi^\pm + m_{e,virtual})$ or $2(X^\pm + m_{e,virtual})$. From Table 1 results that probability of absorption and emission of heavier pairs by the basic X particles is higher – it follows from the fact that lifetime of heavier pair is shorter so coupling constant is bigger and vice versa.

There are absorbed associations of gluons and there are emitted quadrupoles of fermions – it follows from the fact that there are the shells for FGLs while quadrupoles of fermions are emitted by spacetime condensates when they are excited by the absorbed FGLs. Probably the first absorption (of $2\pi^o$ or $2(\pi^\pm + m_{e,virtual})$) forces the emission of the X^+X^- pair of fermions by the spacetime condensate.

By the way, notice that coupling constants for electroweak interactions of condensates are weaker than the strong interactions of FGLs so the electroweak interactions are slower. When we neglect the hyperon Σ^o, the hyperons are created quickly due to the strong interactions and decay slowly due to the weak interactions [4].

We can see that the stronger/faster interactions of the particles are, generally, realized first.

6. The other possibilities

Assume that nuclear weak mass of a spacetime condensate $M_{Con,W}$ is equal to the mass of bare electron

$$M_{Con,W} \alpha_{w(p)} = m_{e,bare} \tag{18}$$

so $M_{Con,W} = 27.261$ **MeV**.

But SST shows that to create a metastable spacetime condensate, it should have mass equal or higher than the mass of the spacetime condensate in muon $M_{Con,Muon} \approx 52.77$ **MeV** [4]. It leads to conclusion that we should not observe some X particles containing $M_{Con,W}$.

Calculate mass of a spacetime condensate when two nuclear weak interactions occur one after the other – from (3) we have

$$M_{Con,WW} \alpha_{w(p)}{}^2 = m_{e,bare} \tag{19}$$

so we obtain

$$M_{Con,WW} = 1456.03 \text{ MeV} . \tag{20}$$

But this mass is very close to mass of the $H^+H^- = 1454.88$ **MeV** pair so the condensate $M_{Con,WW}$ very quickly decays into such pair so some X particles containing such a condensate are not created.

Probability of creation of spacetime condensates due to three or more interactions occurring one after the other is very low so here we do not investigate them.

7. Summary

The strength of our model is simplicity and consistency of theoretical results with experimental data.

Very important is the fact that mass of the spacetime condensate in **X(3872)** is due to a ***resonance*** between its electroweak mass and mass of the bare electron! Therefore, there are no accidental coincidences in the presented model.

Emphasize that our theoretical masses for particles defined by the $I^G(J^{PC}) = 0^+(1^{++})$ quantum numbers are very close to experimental data – it validates our model of the core of baryons described within the Scale-Symmetric Theory. In the Standard Model, the calculate masses of particles are *much worse* than in SST, and in SM, we must apply much more parameters.

We showed that we can apply the Pauli Exclusion Principle and the Hund's rule to the FGL shells around the spacetime condensates.

We predict two new Type-X particles.

The SM is incomplete and partially incorrectly describes Nature. We are not only unable to define the structure and dynamics of dark matter and dark energy within SM, find the cause of the matter-antimatter asymmetry or explain why gravity and the SM interactions cannot be described within the same methods, but we are also unable to calculate the exact masses, spin and magnetic moments of the proton and neutron, so of the basic building blocks of ordinary matter. The origin of masses of neutrinos also cannot be explained within SM, also origin of physical constants and we cannot solve tens of fundamental problems. Contrary to the mainstream scientific community, we can safely say that in practice basic physics is in its infancy. Some physicists say we know almost everything, and the truth is, we know almost nothing. It really is time to come to your senses. Time for radical changes and the SST is an effective solution.

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