A four generation supersymmetric model of particles leading to two extra string dimensions

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Abstract

A previous supersymmetric preon scenario for the first generation particles is extended to include all three generations and the dark sector. The scenario is reformulated as a double field theory (DFT) in 4+4 dimensions. It is proposed that DFT preons are the pointlike limit of string theory below the string scale $\sim 10^{18}$ GeV. The need for extra string theory dimensions is argued to reduce from six to two.

Keywords: Standard Model, Supersymmetry, Dark Matter, Composite models, Double Field Theory, String Theory

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Contents

1 Introduction

A previous supersymmetric preon scenario is (i) extended to include all three generations of fermions and the dark sector, and (ii) reformulated as a double field theory (DFT) in four plus four dimensions. The role of the preons is that they open a door, with some phenomenological freedom, to go beyond the standard model (SM) up to supergravity, and beyond. A connection to bosonic strings is anticipated.

Preons, called here chernons, are free particles above an energy scale Λ_{cr}, provided they do not transform due to increasing resolution to other kind of (stringy) objects. This scale Λ_{cr} is estimated to be close to the reheating temperature of standard cosmology in the early universe, about $T_R \sim 10^{10} - 10^{16}$ GeV. It is also close to the grand unified theory (GUT) scale. Below Λ_{cr} preons make a phase transition into pointlike composite states of SM quarks and leptons.

Chernons have gravitational, electromagnetic, color and Chern-Simons (CS) model interactions. The first generation matter can be built from two preons of charges $\frac{1}{3}$ and 0 and their antiparticles. The baryon (B) and lepton (L) numbers of chernons are zero. This is important for baryon asymmetry. The second and third generation as well as the dark sector require more elaborate structure. The basic symmetry of the model is global supersymmetry. The dark sector consists of one zero charge fermion and axion like particles (ALP). Cosmology is not touched here because of new baffling results from the JWST.

The extension to DFT is used to approach string theory. Due to supersymmetry as the basic symmetry of the model extra string dimensions are reduced from six to two, making string theory more temperate to solve.

This short note is organized as follows. In section 2 we recap, refine and extend our previous preon model. Section 3 discusses chernon-chernon interactions. A model for baryon asymmetry is proposed in section 4. In section 5 we introduce the double field theory in four plus four dimensions. The symmetries of the extended model are discussed in section 6. Conclusions are given in section 7.

This note contains both new material in the brief but important section 2 and in section 6, and review sections. It is hoped that the latter are presented here with more clarity than in our original papers.

2 Wess-Zumino action kinetic terms

The starting point in the chernon model for visible and dark matter is that supersymmetry must be defined so that superpartners are included in the model on the first line together with the base particles.

We briefly recap our chernon scenario of [1, 2], which turned out to have close resemblance to the simplest $N = 1$ globally supersymmetric 1+3D model, namely the free, massless Wess-Zumino model [3] with the kinetic Lagrangian including three neutral fields: a Majorana spinor m, the real fields s and p with $J^P = \frac{1}{2}^+, 0^+$, and 0^-, respectively

$$\mathcal{L}_{\rm WZ} = -\frac{1}{2}\bar{m}\partial\!\!\!/ m - \frac{1}{2}(\partial s)^2 - \frac{1}{2}(\partial p)^2 \tag{2.1}$$

with metric mostly plus. We assume that the pseudoscalar p is the axion [4], and denote it below as a. It has a fermionic superparther, the axino n, a candidate for dark matter but not discussed further here.

In order to include charged matter we assume the following charged chiral field Lagrangian

$$\mathcal{L}_{\rm WZ_{Charge}} = -\frac{1}{2}m^-\partial\!\!\!/ m^- \tag{2.2}$$

We set next color $i = R, G, B$ to the neutral fermion $m = m_i^0$ in (2.1) and introduce s an SU(4) neutral color triplet particle as follows

$$\mathcal{L}_{\rm WZ_{Color}} = -\frac{1}{2}\sum_{i=R;G;B}\left[\bar{m}_i^0\partial\!\!\!/ m_i^0 - \frac{1}{2}(\partial s_i^0)^2\right] \tag{2.3}$$

Now we have the following supermultiplets shown in figure 1.

Are QCD multiplets needed in figure 1? We believe that the SM, including QCD, is not supersymmetric. Only the singlet, 9th gluon g_s contribution is needed in the early topological 3D ($\subset$ 4D) space before reheating. QCD begins to work in 4D after reheating. The $SU(3)_c$ group structure for the 8+1 gluons is formed by the color chernons m_i^0 as follows (with only color indicated)

$$\text{Octet}: \mathrm{R\bar{G}, R\bar{B}, G\bar{R}, G\bar{B}, B\bar{R}, B\bar{G}}, \frac{1}{\sqrt{2}}(\mathrm{R\bar{R} - G\bar{G}}), \frac{1}{\sqrt{6}}(\mathrm{R\bar{R} + G\bar{G} - 2B\bar{B}}) \tag{2.4}$$

Multiplet	Particles; Sparticle
chiral multiplet spins {0; 1/2}	$\{s_i^0; m_i^0\}$ $\{s^-; m^-\}$
vector multiplets spins {1/2; 1}	$\{m^0; \gamma\}$ $\{m_0^0; g_s\}$

Figure 1: The supermulstiplets of the model. This setup allows one to introduce four supermultiplets. s_i^0, m_i^0 are $SU(3)_c \otimes SU(4)$ particles and m^-, m_i^0 are two Weyl spinors. γ is the photon. m_0^0 and g_s are color singlet particles.

G1	Chernon1	G2	Chernon2	G3	Chernon3	Dark	ChernonD
u	$m_R^0 m_G^0 m_B^0 s_1$	c	$m_R^0 m_G^0 m_B^0 s_2$	t	$m_R^0 m_G^0 m_B^0 s_3$	d_1	$m_R^0 m_G^0 m_B^0 s_D$
d	$m^- m_G^0 m_B^0 s_1$	s	$m^- m_G^0 m_B^0 s_2$	b	$m^- m_G^0 m_B^0 s_3$	d_2	$m^- m_G^0 m_B^0 s_D$
e	$m^- m^- m^- s_1$	μ	$m^- m^- m^- s_2$	τ	$m^- m^- m^- s_3$	δ_1	$m^- m^- m^- s_D$
ν_e	$m_R^0 m_G^0 m_B^0 s_1$	ν_μ	$m_R^0 m_G^0 m_B^0 s_2$	ν_τ	$m_R^0 m_G^0 m_B^0 s_3$	δ_2	$m_R^0 m_G^0 m_B^0 s_D$

Figure 2: The three generations G1-G3 of particles, the dark sector and their chernon content.

$$\text{Singlet}: \frac{1}{\sqrt{3}}(\mathrm{R\bar{R}} + \mathrm{G\bar{G}} + \mathrm{B\bar{B}}) \tag{2.5}$$

Let us extend the first generation particles to three generations and the dark sector. We add a broken SU(4) scalars chernon s_i^0 to each generation [5]. The role of this scalar is a generation defining bystander particle below Λ_{cr} to provide the vacuum and the generation excitations. At the string scale the s_i^0 is a closed string or other such object.

Below Λ_{cr} we may physically imagine the s_i^0 to be the center of the composite chernon system and the Weyl fermions circulating around it. We now have the following particles of figure 2 below Λ_{cr}.

3 Chernon-chernon interaction

This section is covered fully in [6, 7]. An appendix A is provided here. The chermon-chermon scattering amplitude in the non-relativistic approximation is obtained by calculating the t-channel exchange diagrams of the Higgs scalar and the massive gauge field. The propagators of the two exchanged particles and the vertex factors are calculated from the action (A.6) [8].

The gauge invariant effective potential for the scattering considered is obtained in [9, 10]

$$V_{\mathrm{CS}}(r) = \frac{e^2}{2\pi}\left[1 - \frac{\theta}{m_e}\right] K_0(\theta r) + \frac{1}{m_e r^2}\left\{l - \frac{e^2}{2\pi\theta}[1 - \theta r K_1(\theta r)]\right\}^2 \tag{3.1}$$

where $K_0(x)$ and $K_1(x)$ are the modified Bessel functions and l is the angular momentum ($l = 0$ in this note). In (3.1) the first term [ ] corresponds to the electromagnetic potential, but its now in behavior like a Yukawa potential, the second one $\{\ \}^2$ contains the centrifugal barrier $\left(l/mr^2\right)$, the Aharonov-Bohm term and the two photon exchange term.

One sees from (3.1) the first term may be positive or negative while the second term is always positive. The function $K_0(x)$ diverges as $x \to 0$ and approaches zero for $x \to \infty$ and $K_1(x)$ has qualitatively similar behavior. For our scenario we need negative potential between equal charge chermons. Being embarrassed of having no data points for several parameters in (3.1) we can give one relation between these parameter values for a negative potential. We must have the condition[1]

$$\theta \gg m_e \tag{3.2}$$

The potential (3.1) also depends on v^2, the vacuum expectation value, and on y, the parameter that measures the coupling between fermions and Higgs scalar. Being a free parameter, v^2 indicates the energy scale of the spontaneous breakdown of the $U(1)$ local symmetry.

4 Baryon Asymmetry

We now examine the potential (3.1) in the early universe [6, 7]. Consider large number of groups of twelve chermons each group consisting of four m^+, four m^- and four m^0 particles. Any bunch may form only electron and proton (hydrogen atoms H), only positron and antiproton ($\bar{\mathrm{H}}$) or some combination of both H and $\bar{\mathrm{H}}$ atoms [1, 2]. This is achieved by arranging the m chermons appropriately (mod 3) using table 2. This way the transition from matter-antimatter symmetric universe to matter-antimatter asymmetric one happens linearly.

Because the Yukawa force (3.1) is the strongest force the light e^-, e^+ and the neutrinos are expected to form first at the very onset of inflation. For one electron made of three m chermons, nine other m chernons form a proton. Accordingly for positrons. One neutrino requires a neutron to be created. The m_C^0 carries in addition color enhancing neutrino formation. This makes neutrinos different from other leptons and the quarks.

Later, when the protons were formed, because chermons had the freedom to choose whether they are constituents of H or $\bar{\mathrm{H}}$ there are regions of space of various sizes dominated by H or $\bar{\mathrm{H}}$ atoms. Since the universe is the largest statistical system it is expected that there is only a very slight excesses of H atoms (or $\bar{\mathrm{H}}$ atoms which only means a charge sign redefinition) which remain after the equal amounts of H and $\bar{\mathrm{H}}$ atoms have annihilated. The ratio n_B/n_γ is thus predicted to be $\ll 1$.

[1] For applications to condensed matter physics, one must require $\theta \ll m_e$, and the scattering potential given by (3.1) then comes out positive [8].

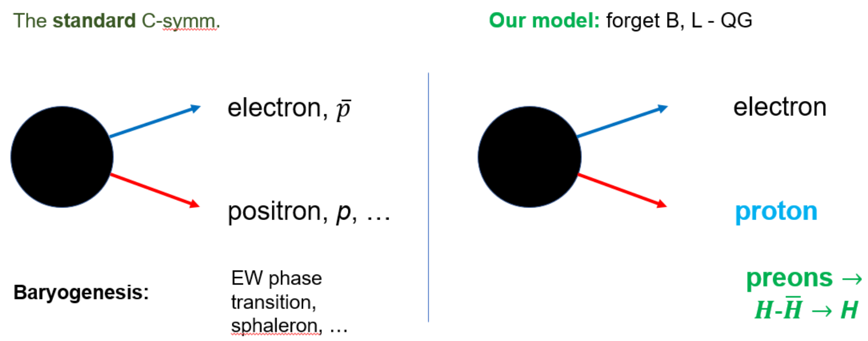

Figure 3: Two different scenarios of Big Bang. On the left, the more common SM picture is indicated with some additional processes. On the right, $n_p \times 12$ ($n_p = 1, 2, 3, ...$) chernons may form both quarks and leptons and the corresponding antiparticles leading much later to both hydrogen and antihydrogen atoms with equal quantum expectation numbers N: $\langle N_H \rangle = \langle N_{\bar{H}} \rangle$. Due to quantum statistical fluctuations these numbers are not actually equal. Suppose there is more hydrogen. Then all antihydrogen atoms get annihilated against hydrogen atoms leaving an excess of hydrogen, or baryons.

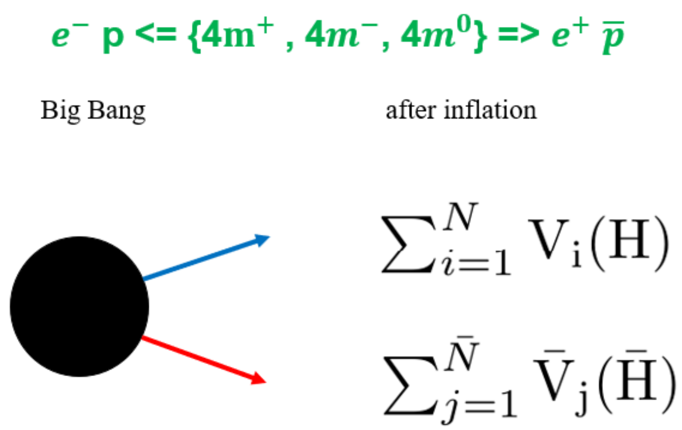

Figure 4: In a quantum statistical system, the number N of H atoms is not actually the number $\bar{N}$ of anti-H atoms though their expectation values are the same, $\langle N_H \rangle = \langle N_{\bar{H}} \rangle$. The volumes V_i and $\bar{V}_j$, containing certain numbers H and anti-H atoms, respectively, are actually also different but their expectation values are the same. Consequently, after $H - \bar{H}$ annihilation a net $\frac{n_B}{n_\gamma} \ll 1$ remains.

As to the order of magnitude of $N-\bar{N}$ we only mention the Eddington number (1931) 10^{80} [11]. Interesting is also the observation of Dirac (1937): the ratio of electrical and gravitational forces between proton and electron in a hydrogen atom is of the order of 10^{40} [12]. The big number discussion was initiated by Weyl [13].

5 Double Field Theory

The mathematical formalism in this section is reviewed in [14]. This section was fully discussed in [15] but it is briefly recapped here with the new features of section 2.

DFT is a mathematical framework that combines general relativity with string theory, and it can be used to describe the motion of point particles. The general idea is that the action for a point particle in DFT is more complicated than the action for a point particle in general relativity. One starts with the action for a string in DFT, and then take a limit in which the string length goes to zero. The general worldline action for a point particle in DFT is

$$S=\int d\tau\left(\frac{1}{2}m\dot{X}^M\dot{X}_N\eta_{MN}+Q_i\dot{X}^M W_{Mi}\right) \tag{5.1}$$

where X^M is the particle position in spacetime, η_{MN} is the metric, Q_i are the particle charges, and W_{Mi} is the double field.

Double Field Theory in 4+4 dimensions can take into account both momentum and the winding modes of a closed loop. Therefore DFT is a low energy effective theory of closed string theory. In addition of the spacetime coordinates X^i, which are conjugate to the momentum modes, there are now 4 new coordinates $\tilde{X}_i$, which are in turn conjugate to the winding modes of the closed string. We assume that the closed string below scale Λ_{cr} is the SU(4) particle s_i^0.

We now deal with 2N dimensional vectors $X^M=(\tilde{x}_i,x^i)$. The index M is lowered and raised by the O(D,D) invariant matrix

$$\eta_{MN}=\begin{pmatrix}0 & \delta_i^j\\ \delta_j^i & 0\end{pmatrix}\text{ and its inverse }\ \eta^{\mathrm{MN}}=\begin{pmatrix}0 & \delta_j^i\\ \delta_i^j & 0\end{pmatrix} \tag{5.2}$$

The action of a DFT in the generalized matrix formulation is [17]

$$S_{DFT}=\int \mathrm{d}^{2\mathrm{D}}\mathrm{e}^{-2\mathrm{d}}\mathcal{R} \tag{5.3}$$

where

$$\begin{aligned}\mathcal{R}=\;&4\mathcal{H}^{MN}\partial_M d\partial_N d-\partial_M\partial_N\mathcal{H}^{MN}-4\mathcal{H}^{MN}\partial_M d\partial_N d+4\partial_M\mathcal{H}^{MN}\partial_N d\\ &+\frac{1}{8}\mathcal{H}^{MN}\partial_M\mathcal{H}^{KL}\partial_N\mathcal{H}_{KL}-\frac{1}{2}\mathcal{H}^{MN}\partial_N\mathcal{H}^{KL}\partial_L\mathcal{H}_{MK}\end{aligned} \tag{5.4}$$

is called the generalized Ricci or curvature scalar and

$$\mathcal{H}^{MN} = \begin{pmatrix} g_{ij} - B_{ik}g^{kl}B_{lj} & -B_{ik}g^{kj} \\ g^{ik}B_{kj} & g^{ij} \end{pmatrix} \tag{5.5}$$

is the generalized metric. It combines the metric g_{ij} and the B-field B_{ij} into an $\mathrm{O}(D,D)$ valued, symmetric tensor fulfilling

$$\mathcal{H}^{MN}\eta_{ML}\mathcal{H}^{LK} = \eta^{NK}\,. \tag{5.6}$$

The dilaton ϕ of the NS/NS sector is encoded in the O(D,D) singlet

$$d = \phi - \frac{1}{2}\log\sqrt{-g} \tag{5.7}$$

It is called generalized dilaton.

6 The Extended Symmetry Model

Physically, the doubling of the local Lorentz symmetries indicates a genuine stringy character that there are two separate locally inertial frames, for both left and right moving modes [16, 17]. Therefore we extend our model, for the present, left-right symmetric. It is possible to reformulate this chernon model as a DFT which couples to a gravitational background and manifests all the existing symmetries at once, including the O(4,4) T-duality, generalized diffeomorphism invariance, and a pair of local Lorentz symmetries, Spin(1,3)×Spin(3,1).

Now every fermion must belong to one of the two spin groups. In the present model the obvious choice is that the left handed chernons belong to the Spin(1,3) and right handed to the Spin(3,1) representation.

The SU(4) scalar particle s_i^0 may at string scale be, in addition to a closed string, a 2-brane or a torus. These objects may naively be thought to be end points to the fermions of the model, now elevated to strings.

The model is consistent with the Big Bang model presented in [14]. This model is singularity-free due to the near Hagedorn temperature thermal string condensate initial state. Thermal inflation from an string condensate fits in our particle scenario as well.

7 Conclusions

We have shown that, without any extra physical degree introduced, the present chernon model can be readily reformulated as a DFT. The extended symmetry model couples to an arbitrary stringy gravitational background in an O(4,4) T-duality covariant manner and manifest two independent local Lorentz symmetries, Spin(1,3) × Spin(3,1). We are tempted to propose that this chernon model is a pointlike low energy limit of string theory. In the absence of SM superpartners the present model is proposed as a noteworthy candidate for ontic particles.

The main results of this work are

- new fundamental, topological level of matter in three generations and the dark sector,
- WZ supersymmetric Lagrangian is extended to charged and colored particles and to include Chern-Simons interaction,
- it explains reason why supersymmetry is hidden below Λ_{cr} [18],
- inevitable quantum statistical mechanism for baryon asymmetry with $\frac{n_B}{n_\gamma} \ll 1$,
- the model economically unifies matter and interactions based on small supersymmetric multiplets rather than large GUT internal symmetries,
- a window to superstrings is open. The 2-brane–string structure is notably simple because only spacetime symmetries exist above Λ_{cr}. In other words, the core of this model is defined as symmetries in spacetime, just where the strings live. We do define two U(1) connections, one for electric charge and another for color singlet supermultiplet, and
- for BSM exploration, all experiments are important.

The question of naturalness and UV sensitivity of this model cannot be answered at the moment. A recent treatment of the 5D Kaluza-Klein model is given in [24, 25], which includes also extensive references to earlier work. In our model the particle content is substantially smaller above Λ_{cr}, as given in figure 1, and we think supersymmetry is not broken.

Acknowledgemet

I warmly thank Grigori Volovik for correspondence and sharing his views on four generation models.

A Chern-Simons Model

The 1+2 dimensional Chern-Simonss (CS) action is [19, 20]

$$S_{\mathrm{CS}} = \frac{k}{4\pi}\epsilon^{\mu\nu\rho}A_\mu\partial_\nu A_\rho = \frac{k}{4\pi}\int_M \mathrm{tr}(\mathrm{A}\wedge \mathrm{dA}) \tag{A.1}$$

where k is the level of the theory and A the connection.

Chern-Simons without matter has no propagating local degrees of freedom, so we add a Dirac fermion and a current term

$$\mathcal{L} = \frac{k}{4\pi}\epsilon^{\mu\nu\rho}A_\mu\partial_\nu A_\rho + \bar{\Psi}(i\partial\!\!\!/ - m)\Psi - eA_\mu\bar{\Psi}\gamma^\mu\Psi \tag{A.2}$$

The action for a Chern-Simons-QED$_3$ model [8] including two polarization $\pm$ fermionic fields (ψ_+, ψ_-), a gauge field A_μ and a complex scalar field φ with spontaneous breaking of local U(1) symmetry is

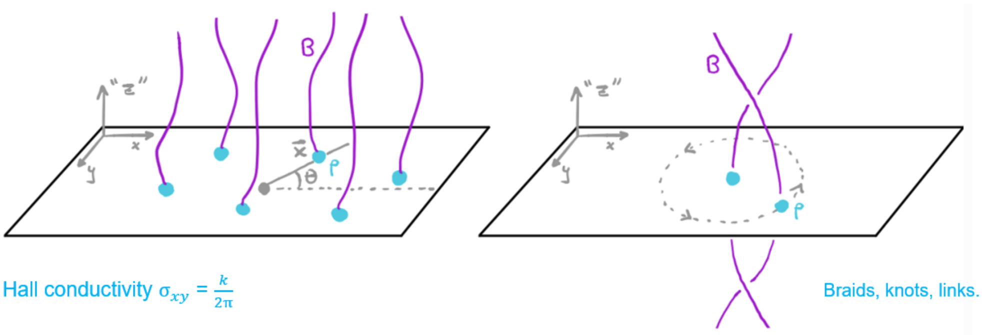

Figure 5: The 1+2 Chern-Simons fields E and B look different from their 4D Maxwellian counterparts. Moving charges generate in-plane (j ∼) E fields, while charges's (ρ ∼) B fields point in an imaginary z-direction! In the right hand picture there is an anyon. Picture from [22].

$$
\begin{aligned}
S_{\mathrm{CS-QED_3}} = \int d^3x\{ -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + i\overline{\psi}_+\gamma^\mu D_\mu\psi_+ + i\overline{\psi}_-\gamma^\mu D_\mu\psi_- \\
+\frac{1}{2}\theta\epsilon^{\mu v\alpha}A_\mu\partial_v A_\alpha - m_e(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-) \\
-y(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-)\varphi^*\varphi + D^\mu\varphi^* D_\mu\varphi - V(\varphi^*\varphi)\},
\end{aligned} \tag{A.3}
$$

where the covariant derivatives are $D_\mu\psi_\pm = (\partial_\mu + ie_3A_\mu)\psi_\pm$ and $D_\mu\varphi = (\partial_\mu + ie_3A_\mu)\varphi$. θ is the important topological parameter and e_3 is the coupling constant of the $U(1)$ local gauge symmetry, here with dimension of (mass)$^{1/2}$. $V(\varphi^*\varphi)$ represents the self-interaction potential,

$$
V(\varphi^*\varphi) = \mu^2\varphi^*\varphi + \frac{\zeta}{2}(\varphi^*\varphi)^2 + \frac{\lambda}{3}(\varphi^*\varphi)^3 \tag{A.4}
$$

which is the most general sixth power renormalizable potential in 1+2 dimensions [21]. The parameters μ, ζ, λ and y have mass dimensions 1, 1, 0 and 0, respectively. For potential parameters $\lambda > 0, \zeta < 0$ and $\mu^2 \leq 3\zeta^2/(16\lambda)$ the vacua are stable.

In 1+2 dimensions, a fermionic field has its spin polarization fixed up by the sign of mass [23]. The model includes two positive-energy spinors (two spinor families). Both of them obey Dirac equation, each one with one polarization state according to the sign of the mass parameter.

The vacuum expectation value v of the scalar field φ is given by:

$$
\langle\varphi^*\varphi\rangle = v^2 = -\zeta/\left(2\lambda\right) + \left[\left(\zeta/\left(2\lambda\right)\right)^2 - \mu^2/\lambda\right]^{1/2} \tag{A.5}
$$

The condition for its minimum is $\mu^2 + \frac{\zeta}{2}v^2 + \lambda v^4 = 0$. After the spontaneous symmetry breaking, the scalar complex field can be parametrized by $\varphi = v + H + i\theta$, where H represents the Higgs scalar field and θ the would-be

Goldstone boson. For manifest renormalizability one adopts the 't Hooft gauge by adding the gauge fixing term $S^{gt}_{R_\xi} = \int d^3x[-\frac{1}{2\xi}(\partial^\mu A_\mu - \sqrt{2}\xi M_A\theta)^2]$ to the broken action. Keeping only the bilinear and the Yukawa interaction terms one has the following action

$$
\begin{aligned}
S^{\mathrm{SSB}}_{\mathrm{CS-QED}} = \int d^3x \Big\{ & -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}M_A^2 A^\mu A_\mu \\
& - \frac{1}{2\xi}(\partial^\mu A_\mu)^2 + \overline{\psi}_+(i\partial\!\!\!/ - m_{eff})\psi_+ \\
& + \overline{\psi}_-(i\partial\!\!\!/ + m_{eff})\psi_- + \frac{1}{2}\theta\epsilon^{\mu v \alpha}A_\mu\partial_v A_\alpha \\
& + \partial^\mu H \partial_\mu H - M_H^2 H^2 + \partial^\mu\theta\partial_\mu\theta - M_\theta^2\theta^2 \\
& - 2yv(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-)H - e_3\left(\overline{\psi}_+ A\!\!\!/ \psi_+ + \overline{\psi}_- A\!\!\!/ \psi_-\right) \Big\}
\end{aligned}
\tag{A.6}
$$

where the mass parameters

$$M_A^2 = 2v^2e_3^2, \quad m_{eff} = m_e + yv^2, \quad M_H^2 = 2v^2(\zeta + 2\lambda v^2), \quad M_\theta^2 = \xi M_A^2 \tag{A.7}$$

depend on the SSB mechanism. The Proca mass, M_A^2originates from the Higgs mechanism. The Higgs mass, M_H^2, is associated with the real scalar field. The Higgs mechanism also contributes to the chermon mass, resulting in an effective mass m_{eff}. There are two photon mass-terms in (A.6), the Proca and the topological one.

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