Journal of Modern Physics, 2023, 14, 1437-1451
https://www.scirp.org/journal/jmp
ISSN Online: 2153-120X
ISSN Print: 2153-1196

Matter-Antimatter Asymmetry from Preon Condensation Prior to the Hadron Epoch

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How to cite this paper: Holmes, R.B. (2023) Matter-Antimatter Asymmetry from Preon Condensation Prior to the Hadron Epoch. *Journal of Modern Physics*, **14**, 1437-1451.
https://doi.org/10.4236/jmp.2023.1411083

Received: September 2, 2023
Accepted: October 20, 2023
Published: October 23, 2023

Abstract

A universe consisting of protons, neutrons, and electrons with electrical neutrality is consistent with an equal number of c and $\bar{c}$ preons, assuming the rishon preon theory of Shupe and Harari. Similarly, a universe consisting of antiprotons, antineutrons, and positrons with electrical neutrality is consistent with an equal number of c and $\bar{c}$ preons. Hence, any combination of such matter-antimatter compositions is also consistent with an equal number of c and $\bar{c}$ preons and overall electrical neutrality. It is proposed that the difference observed in baryon-antibaryon number density relative to photon number density, $\sim 5 \times 10^{-10}$, is due to allocation of preons between matter and antimatter during preon condensation into normal matter. Three approaches of increasing rigor and complexity are considered: 1) an allocation at times corresponding to the Planck temperature due to fluctuations, 2) an allocation at times corresponding to quark formation due to preon bonding, and 3) an allocation at times corresponding to the electroweak scale. All approaches can give the correct order of magnitude of the asymmetry assuming out-of-equilibrium freeze-out and a slight and allowed charge (C) asymmetry in preon condensation in a self-consistent quantum field theory. Sakharov's baryon non-conservation condition is evidently circumvented with these approaches, because they assume another level of matter (preons) which is present before quark formation. Thus, preons can provide an elementary explanation of primordial matter-antimatter asymmetry. A relationship between Higgs boson states and preons is proposed.

Keywords

Matter-Antimatter Asymmetry, Cosmology, Astroparticle Physics, Quantum Field Theory, Global Symmetries

1. Introduction

As is well known, the question of cosmological matter-antimatter asymmetry

("MAA") lacks a good answer at this time. "Why does the universe consist predominantly of matter, when presumably there were equal quantities of matter and antimatter in the early universe?" This paper proposes three potential answers. All three retain equal quantities of "matter" and "antimatter" in the early universe, and all can yield the observed magnitude of the asymmetry within a factor of 2 or better.

In this letter, the development assumes the rishon form of preons [1] [2] [3]. It also assumes that there were, and are, an equal number of charge e/3 preons, each denoted $\boldsymbol{c}$, and charge $-e/3$ preons, each denoted $\bar{\boldsymbol{c}}$. With this form of preons, there are only two other fundamental particles: the chargeless $\boldsymbol{o}$ and $\bar{\boldsymbol{o}}$ preons (antiparticles will be indicated by an overbar throughout this paper). The first approach, due to fluctuations, utilizes at least one of the three Sakharov conditions [4]: an interaction out of thermal equilibrium. It also requires either charge (C) asymmetry or correlated fluctuations. The second and third approaches require both out-of-equilibrium and C-asymmetry conditions. These latter approaches rely on a specific version of the preon model that is evidently a self-consistent, anomaly-free quantum field theory [5]. This theory stems from an earlier attempt to build a consistent theory from permutational symmetry of mass matrices [6]. In that earlier attempt, self-consistency was difficult because left-right states were not formulated and the full degrees of freedom involving the unitary matrices were not utilized for the Yukawa couplings.

There have been many past efforts to address this asymmetry [7]-[16]. The key issue is baryon conservation, which is typically overcome by placing the origin of the asymmetry in time before baryons had mass, e.g. in the electroweak era in which typical particle energies are of the order of 100 GeV. In this development, this asymmetry must also occur before baryon formation.

The above-referenced quantum field theory upon which this paper is largely based [5] utilizes 3 × 3 mass matrices that have permutational symmetry. This is the primary assumption that is beyond the standard model (SM) in this theory. These 3 × 3 mass matrices are isomorphic to Hamiltonians for 3 potential wells arranged in a circular loop, as are found in solid-state physics. It is natural to attempt to identify the particles that occupy these potential wells with preons, as is done in Chapters 11 and 12 of [5]. This is the second key assumption beyond the SM upon which the theory and this paper are based. These mass matrices are successfully integrated with Dirac's equation and are shown to match and substantiate a $U(1) \times SU(2)_L$ symmetry. The theory provides *extensive additional explanation* for observations over the SM at lower energies, including most of the input parameters of the SM. This is furthered in this paper at high energies, > 100 GeV, with a potential match to the observed MAA, and a match of preons to the Higgs states prior to symmetry breaking. Details of the two key assumptions of [5] listed above are given in Section 3 below. The limit to the assumption of 3 × 3 mass matrices is that these mass matrices only apply to a universe in which there are at most 3 distinct generations of particles for each fermion family (e.g., down, strange, bottom for the down quark family). The limit to the assumption of anti-commutating rishon preons is that it applies only to a universe with three generations per fermion family *and also* 4 and only 4 families of fermions (*i.e.*, up, down, electron, and neutrino families in our universe).

Our universe of charged matter today consists of protons, neutrons, and electrons. The preon content of the electron is ($\bar{c}\bar{c}\bar{c}$), the preon content of the proton is (***cco***, ***cco***, $\bar{c}\bar{o}\bar{o}$), and the preon content of the neutron is (***cco***, $\bar{c}\bar{o}\bar{o}$, $\bar{c}\bar{o}\bar{o}$). In a charge-neutral universe, there are N electrons and protons, and M neutrons, yielding an equal number of ***c***'s and $\bar{c}$'s with zero net charge:

$$\begin{aligned} &N\times(\bar{c}\bar{c}\bar{c})+N\times(cco,cco,\bar{c}\bar{o}\bar{o})+M\times(cco,\bar{c}\bar{o}\bar{o},\bar{c}\bar{o}\bar{o}) \\ &\rightarrow(4N+2M)\times c-(4N+2M)\times\bar{c}=0 \text{ net charge.} \end{aligned} \tag{1}$$

Here we apply a rule that requires that preon particles can only be in a triplet with particles, and preon antiparticles can only be in a triplet with antiparticles, else annihilation would occur. In this preon theory the preon ordering does not matter, due to permutational symmetry. There can only be three preons in a grouping, due to the underlying three-potential-well model and their fermionic (anticommuting) character. In an antimatter universe consisting of N positrons and antiprotons and M antineutrons, the charge-reversed universe also has an equal number of ***c***'s and $\bar{c}$'s with zero net charge:

$$\begin{aligned} &N\times(ccc)+N\times(\bar{c}\bar{c}\bar{o},\bar{c}\bar{c}\bar{o},coo)+M\times(\bar{c}\bar{c}\bar{o},coo,coo) \\ &\rightarrow(4N+2M)\times c-(4N+2M)\times\bar{c}=0 \text{ net charge.} \end{aligned} \tag{2}$$

Hence any combination of these universes also has zero net charge and equal numbers of ***c***'s and $\bar{c}$'s. Viewed in terms of rishon preons, *there is no matter-antimatter asymmetry*. One might also note that if M neutrinos (***ooo***) are included for the matter equations and M antineutrinos ($\bar{o}\bar{o}\bar{o}$) for the antimatter equations, then there is o-$\bar{o}$ neutrality in both cases as well, and baryon number (B) equals lepton number (L), *i.e.*, $B - L = 0$. This observation will play a role later in this development. One can add c-$\bar{c}$ or o-$\bar{o}$ in pairs without changing this result.

The observed baryon asymmetry (and therefore also lepton asymmetry in a charge-neutral universe with protons) is typically given as a fraction of photon number density or entropy density. The experimentally inferred fractional baryon asymmetry is given by [6] [7] [8]

$$\eta \equiv (n_B - n_{\bar{B}})/n_\gamma = \alpha(n_B - n_{\bar{B}})/s = 6.1 \pm 0.4\times10^{-10}. \tag{3}$$

Here n_B is the average baryon number density, $n_{\bar{B}}$ is the average antibaryon number density, n_γ is the average photon number density, and s is the average entropy density. The symbol α is a constant equal to 7.04 using current values. So, the next question is "How might preons aggregate into ordinary matter to produce the observed MAA?" Section 2 provides a qualitative explanation in terms of fluctuations. Section 3 provides a more quantitative explanation in terms of preon bonding. This can be achieved with a very slight and allowed C-symmetry violation of the mass matrices of ([5], Ch. 2) in the quark sector. Section 4 provides a yet more quantitative and rigorous explanation prior to the quark epoch that conserves *B-L*. Section 5 summarizes the results and conclusions. The explanation in terms of fluctuations is based on the observation that in the absence of physical constraints or energetic preferences, there is an equal preference for a matter-based universe or an antimatter-based universe. This preference can be broken by statistical fluctuations. These fluctuations at some point in time freeze in as the universe cools. The second explanation, in terms of preon bonding, provides a rationale for an energetic preference for a matter-based universe rather than an antimatter universe. However, the implied *C*-asymmetry is not consistent with the constraint of charge-parity-time (*CPT*) symmetry that is nominally required for both the SM and the theory of [5]. The third explanation overcomes this difficulty and the difficulty of baryon non-conservation by putting the *C*-asymmetry at a time when baryons do not exist in the conventional sense (because they lack mass before the Higgs condensation). This time is at or before the primordial electroweak epoch at which particle energies are in excess of 100 GeV. This last explanation evidently satisfies both theoretical constraints as well as current experimental constraints.

2. Approach 1—Fluctuations

One answer for MAA is that this very small matter-antimatter asymmetry could be caused by a fluctuation. Assume an entity, e.g., a particle state, with a mass equal to the Planck mass scale,

$$m_{\text{Planck}} = \sqrt{\hbar c/G} = 2.18\times10^{-8}\ \text{kg} = 1.30\times10^{19}\, m_{\text{proton}}, \tag{4}$$

where $\hbar$ is Planck's constant, c is the speed of light, and G is the gravitational constant. Here m_{proton} is the mass of a proton. A fluctuation of this entity with an equal number of preons $\boldsymbol{c}$ and $\bar{\boldsymbol{c}}$ that aggregate into N_p proton-like particles with effective masses comparable to that of the proton will have a fluctuation of the order of $1/N_p^{1/2}$:

$$\eta_{fluc} \sim \pm 2/\sqrt{1.30\times10^{19}} = 5.53\times10^{-10}. \tag{5}$$

A factor of 2 is needed here because the definition of η involves $n_B - n_{\bar{B}}$, and because the total number of baryons in an entity with an energy equal to the Planck mass should satisfy $n_B + n_{\bar{B}} \equiv n_{Bo} \approx 1.30\times10^{19}$, if the products are only baryons or antibaryons (so that $n_B - n_{\bar{B}} = 2n_B - n_{Bo}$). Note the similarity of the magnitude of the estimate in Equation (5) to the measured value. However, the sign of the above fluctuation is not determined with this approach.

There would have been many such entities at the Planck mass scale in the emergent universe to account for the mass of our current universe. In the case of preon aggregation fluctuations from many such entities, the fluctuations would average out to a much smaller number than the value given in Equation (5), unless they were well-correlated. Hence the above approach by itself is not immediately a convincing explanation unless there are either correlations or there is C asymmetry for consistent fluctuations across such Planck-mass entities. Evidently, this approach requires out-of-equilibrium matter freeze-out and either correlated fluctuations or C asymmetry in the aggregation fluctuations. This provides a clue for a more quantitative explanation of how such an asymmetry might arise with the assumptions of this paper.

3. Approach 2—Preon Bonding

To address the needed C asymmetry more precisely, a second explanation involving a more detailed model is utilized. This model is derived from a generalization of the diagonal mass matrices of the standard model to matrices with permutational symmetry [5]. That quantum field theory utilizes 3 × 3 Hermitian mass matrices of the form:

$$H = H\left(m_f, d, \phi\right) = m_f\left[I + d\mathrm{e}^{\mathrm{i}\phi}P + d\mathrm{e}^{-\mathrm{i}\phi}P^{-1}\right], \tag{6}$$

where the family mass parameter m_f has units of MeV/c^2, I is the 3 × 3 identity matrix, and $d\mathrm{e}^{\mathrm{i}\phi}$ is the normalized complex "hop" amplitude. The matrix P is the 3 × 3 positive permutation matrix, given by

$$P = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}. \tag{7}$$

Note that $P^{-1} = P^2$ is also a permutation matrix in the reverse direction. The parameter m_f of Equation (6) is denoted the "mass parameter". It can be shown that they equal the average of the experimentally-derived or otherwise inferred three masses of the family, e.g., m_{fd} = average of down, strange, and bottom masses for the down family. The other two parameters, d and ϕ, are used to match the mass eigenvalues of the matrices to the measured masses in a family. One finds m_{fu} = 58127.4 MeV, m_{fd} = 1426.9 MeV, m_{fe} = 627.676 MeV, and $m_{f\nu}$ = 0.02273 × 10^{-6} MeV, for the up, down, electron, and neutrino families, respectively, using the 2016 PDG values of the masses (for the neutrinos, masses of 0.0054, 0.0102, and 0.0515 eV are assumed). It is found that all families have the same sets of eigenstates (within signs and permutations), as might be expected from considerations of symmetry. Once the eigenstates are known, the matches can be made exact to any set of three masses.

By assuming that the three potential wells corresponding to the mass matrices are occupied by preons, the mass parameters of the 4 families can be derived from preon bonds. The 4 mass parameters m_f of the 4 families of matrices gives 4 equations in terms of the three bonds: ***c***-***c***, ***c***-***o***, and ***o***-***o***, with respective bond energies e_1, e_2, and e_3. Also, electrostatic repulsion e_4 must contribute, so there are 4 equations in 4 unknowns. Let e_4 denote the electrostatic repulsion energy of a ***c*** and another ***c*** that is already in a ***c***-***c*** preon bond. Hence, by inspection of the arrangements of preons in the three potential wells for each particle family, one obtains:

$$3e_1 - 2e_4 = m_{f,\bar{e}},$$
$$3e_2 = m_{f,\nu},$$

$$
\begin{aligned}
1e_1 + 2e_3 &= m_{f,u}, \\
1e_2 + 2e_3 &= m_{f,\bar{d}}.
\end{aligned} \tag{8}
$$

Solving this equation for the binding energy vector $\boldsymbol{e}$ yields

$$[e_1, e_2, e_3, e_4] = [56735.83, 7.577777 \times 10^{-9}, 713.2999, 84789.92]\,\mathrm{MeV}/c^2 . \tag{9}$$

Based on the electrostatic repulsion e_4 above, it is worth noting that one can estimate the preon bond length for the electron. One finds that it is ~10^{-21} meters, consistent with current observational bounds on the electron size, including the electron electric dipole moment [17] [18] [19]. This implies a non-zero "size" of the electron.

The above equation is the "$\boldsymbol{c}$" version of the equations. There is also a "$\bar{\boldsymbol{c}}$" version of Equation (8), which involves $\bar{\boldsymbol{c}}$-$\bar{\boldsymbol{c}}$, $\bar{\boldsymbol{c}}$-$\bar{\boldsymbol{o}}$, and $\bar{\boldsymbol{o}}$-$\bar{\boldsymbol{o}}$ bonds. The "$\boldsymbol{c}$" and "$\bar{\boldsymbol{c}}$" versions are two separate, independent sets of equations, which nominally use the same mass parameters on the right-hand-side to ensure C symmetry. The Equations (6) to (8) are seen to allow for limited variations of the masses—one can input a set of masses on the r.h.s. and simply solve for the bonds. This is in accord with the requirement that the masses run with energy scale in any modern quantum field theory [20].

Hence one may apply Equation (8) to the antimatter version (the "$\bar{\boldsymbol{c}}$" version) with small perturbations in the mass parameters, providing a violation of C-symmetry in the preon bonding energy. The well-known, observed violation of CP symmetry primarily involves the down quark family with kaons and B mesons. One then might posit a small mass difference between matter and antimatter mass parameters in the down quark families only. Note that any slight difference in the mass of a bound quark and the corresponding antiquark might be unobservable, but also appears to be forbidden by the standard CPT symmetry (e.g., [21] [22]) for fermions. There is no obvious means to compensate for this particular form of C asymmetry with P and T asymmetries to maintain overall CPT symmetry in this theory.

Next, one may use Boltzmann factors in an equilibrium condition just before freeze-out to solve for the required mass difference Δm. Setting the probability difference between matter and antimatter for the observed asymmetry gives,

$$\left[1 - \exp\left(-\Delta mc^2 / k_{\mathrm{B}} T\right)\right] \Big/ \left[1 + \exp\left(-\Delta mc^2 / k_{\mathrm{B}} T\right)\right] = 6.1 \times 10^{-10} . \tag{10}$$

Here k_{B} is Boltzmann's constant and T is the relevant temperature. One might tentatively set $k_{\mathrm{B}} T = 1$ GeV, at which nucleons start to coalesce, and which is close to the down-quark mass parameter. One then obtains the required mass difference,

$$\Delta mc^2 \sim 1.22\ \mathrm{eV} . \tag{11}$$

This is much less than the running mass variations of the d quark at energies between 1 and 2 GeV since such variations are of the order of 500 keV [23]. One could also choose $k_{\mathrm{B}} T$ close to the maximum preon bond energy, which is about 90 GeV. This is perhaps a more appropriate choice, as indicated in Section 4, so that then all preon bonds can participate in order to maintain electrical neutrality considering all families. One then obtains

$$\Delta mc^2 \sim 110\ \text{eV}, \tag{12}$$

which is still quite small. As noted above, the preon bonds nominally should be identical for the "$\boldsymbol{c}$" and the "$\bar{\boldsymbol{c}}$" versions, providing C and CPT symmetry in the extended-color theory. However, it seems that such identical bonds and corresponding identical masses are not otherwise required in this theory. That said, in view of CPT symmetry, even the slightest particle-antiparticle fermion mass differences are definitely questionable, and this is addressed in the next section.

4. Approach 3—Higgs Bonding

Earlier theories of preons [24] [25] use structured spin-1/2 states to avoid the possibility of spin-3/2 fundamental fermions and spin-orbit coupling. On the other hand, such theories have difficulty with the formulation of the electroweak sector, as well as specific predictions regarding the origin of the fermion and boson masses, which is not the case here. As mentioned above, in the extended-color quantum field theory (QFT) of [5] the nominal choice for the 4 preons are anticommuting scalars. This is a match to the 4 "extraneous" Faddeev-Popov ghosts in the standard model. Such charge-free ghosts could be a match for $\boldsymbol{o}$ and $\bar{\boldsymbol{o}}$ preons, but they most likely are not a match for charged $\boldsymbol{c}$ and $\bar{\boldsymbol{c}}$ preons. Other relevant scalars in the standard model include the 4 Higgs bosons [20]. Before symmetry breaking the Higgs scalars are massless. Two have charge of $\pm 1e$ and two are uncharged [20], which matches the proposed preons except for a factor of three for the charge of the charged preons. To address this, one may assert that initial Higgs states are *quasi-bound* states, e.g., ($\boldsymbol{ccc}$) and ($\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}$). The former has charge e, comprising 3 preons, each with charge 1/3 e. These are *quasi-bound* because if they were instead bound, they would have the mass of an electron or neutrino family member, respectively, via the preon binding energies, rather than being massless. One might also imagine other combinations of quasi-bound preons that match the nominally massless charged Higgs states, e.g., $\left(3^{1/2}/2\right)\left|\boldsymbol{c}\text{-}\boldsymbol{c}\text{-}\boldsymbol{o}\right\rangle\left|\boldsymbol{c}\text{-}\boldsymbol{o}\text{-}\boldsymbol{o}\right\rangle + 1/2\left|\boldsymbol{c}\text{-}\boldsymbol{c}\text{-}\boldsymbol{c}\right\rangle\left|\boldsymbol{o}\text{-}\boldsymbol{o}\text{-}\boldsymbol{o}\right\rangle$ for the Higgs with charge $+1e$. Also, a quasi-bound $\left|\boldsymbol{c}\text{-}\boldsymbol{o}\text{-}\boldsymbol{o}\right\rangle$ or $\left|\boldsymbol{c}\text{-}\boldsymbol{c}\text{-}\boldsymbol{o}\right\rangle\left|\bar{\boldsymbol{c}}\text{-}\bar{\boldsymbol{o}}\text{-}\bar{\boldsymbol{o}}\right\rangle$ would have charge $+1/3e$. The massless character of the quasi-bound states is justifiable within the standard model if the primordial particle amplitudes ϕ are such that the $|\phi|^2$ term of the Higgs potential can be neglected compared to the $|\phi|^4$ term. Thus, the Higgs particles and ghosts in the standard model can match the number and expected basic properties of preons or their combinations. Of course, after symmetry breaking is applied, 3 of the Higgs states contribute the longitudinal component to the massive W^+, W^-, and Z bosons.

Also, baryon and lepton number conservation are evidently exact in the QFT of [5] at the classical level. As in the standard model, in this QFT it can be shown that SU(3) color obeys a classical global $\text{U}(1)_V$ symmetry in the quark sector, which is known to be responsible for baryon number conservation in the standard model [22] [26]. More specifically, it is readily found from Noether's theorem for the quark families that

$$\sum_m \partial_\mu \left(\overline{\psi}_{c,m} \gamma^\mu \psi_{c,m} \right) = 0 \text{, for } c = r, g, \text{ or } b, \tag{13}$$

where the sum is over Dirac vectors $\psi_{c,m}$ for all 3 masses m of both quark families of fixed color c, c = red (r), green (g), or blue (b). Here γ^μ are the standard gamma matrices in Dirac's equation, using the Dirac-Pauli representation. The sum is over 3 mass generations and not less in this case because of the non-diagonal 3 × 3 mass matrices for each color of the extended-color theory. The sum is over masses in both quark families because of the requirement of consistency of the $\mathrm{U}(1)_V$ phase in the charged-current portion of the electroweak Lagrangian (a consistency property apparently overlooked in the past). Hence color is conserved exactly in this extended-color theory at the classical level. Conservation of total baryon number B then follows, since the addition of a colorless rgb triplet must be accompanied by creation of a colorless $\overline{rgb}$ anti-triplet. Color is a derived property of bound preons in the extended-color theory since it is associated with the bound preon wavefunctions. Thus, once preons are bound, color and baryon number are conserved at the classical level. Preons by themselves do not have the color property in this theory. Conservation of total lepton number L also follows from similar arguments in this theory ([5], Chs. 6, 11, 13) since they are extended-color singlets, and again because of consistency across both lepton families due to the charged-current portion of the electroweak Lagrangian. With the consideration of anomalies in the quantum theory, it is B-L that is an anomaly-free conservation law [26] as in the standard model (and moreover because there is a right-handed neutrino in extended color, albeit at small amplitudes). Hence, with B and L conservation laws at the classical level, Sakharov's baryon non-conservation condition seems to be impossible after preon bonding, in accord with observations. This requirement can be circumvented during bonding of preons and/or the associated Higgs states if either (a) baryon and lepton numbers are not defined for them, or (b) they are assigned zero baryon number and zero lepton number. In the latter case the universe would have $B - L = 0$ both before preon condensation and also after, from the discussion in the Introduction, in accord with B-L conservation.

To identify a cause for a potential C-asymmetry the known slight CP asymmetries of the standard model provide a clue. The origins of the observed CP asymmetry arise in the charged electroweak current for quarks in the standard model in all observations to date. This current involves the W^+ and W^- particles. In the extended-color theory, these particles can be written as composite states of preons as ([5], Ch. 11)

$$W^+ = \left| \boldsymbol{cco} \right\rangle \left| \boldsymbol{coo} \right\rangle_{\boldsymbol{wb}}, \quad W^- = \left| \overline{\boldsymbol{c}}\,\overline{\boldsymbol{c}}\,\overline{\boldsymbol{o}} \right\rangle \left| \overline{\boldsymbol{c}}\,\overline{\boldsymbol{o}}\,\overline{\boldsymbol{o}} \right\rangle_{\boldsymbol{wb}}, \tag{14}$$

where the subscript "wb" denotes a weak-force bound state, which uses the preon bond energies identified above in Section 3 for the correct W mass. The CP-violating interactions involve the combined effect of the W^+ and W^- in the standard model (e.g., [27]). It should be noted that W-boson pair production is commonly observed for center-of-mass energies greater than 161 GeV [28]. Hence one might posit such a state in the electroweak epoch that involves the combination W^+W^-,

$$W^+W^- = |\boldsymbol{cco}\rangle|\boldsymbol{coo}\rangle_{wb}|\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle_{wb}, \tag{15}$$

Then, as discussed in ([5], Ch. 12), $\boldsymbol{c}$ and $\boldsymbol{o}$ preons are swapped in electroweak interactions involving parity violation. The resulting state, denoted by subscript "1", is:

$$\left(W^+W^-\right)_1 = |\boldsymbol{ccc}\rangle|\boldsymbol{ooo}\rangle_{wb}|\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\rangle|\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle_{wb}, \tag{16}$$

This provides states for the electron and neutrino families. Next, one might also delocalize $\boldsymbol{c}$ and $\bar{\boldsymbol{c}}$ preons in neighboring triplets. The resulting $\boldsymbol{c}\bar{\boldsymbol{c}}$ combinations in single triplets annihilate to form $\boldsymbol{o}\bar{\boldsymbol{o}}$ combinations, and the resulting state, denoted by subscript "2", is:

$$\begin{aligned}\left(W^+W^-\right)_2 &= |\boldsymbol{c}(\boldsymbol{c}\bar{\boldsymbol{c}})\boldsymbol{o}\rangle|\boldsymbol{coo}\rangle_{wb} = |\boldsymbol{coo}\rangle|\boldsymbol{coo}\rangle_{wb} \\ &\quad |\bar{\boldsymbol{c}}(\bar{\boldsymbol{c}}\boldsymbol{c})\bar{\boldsymbol{o}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle_{wb} = |\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle_{wb}?\end{aligned} \tag{17}$$

This category of decays is better explained as a result of Z-boson pair decay. One could also perform this same delocalization operation with $\boldsymbol{coo}$ and $\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}$ to produce an $\boldsymbol{ooo}$ and $\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}$ pair.

A third possibility is the addition of a free $\boldsymbol{c}\bar{\boldsymbol{c}}$ pair to Equation (15). Given the rules of combining preons, in which preons and anti-preons cannot be in the same triplet, one possible set of results, denoted by subscript "3", is

$$\begin{aligned}\left(W^+W^-\right)_3 &= \begin{bmatrix} |\boldsymbol{cco}\rangle|\boldsymbol{coo}\rangle_{wb} \\ |\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle_{wb} \end{bmatrix} + \begin{bmatrix} \boldsymbol{c} \\ \bar{\boldsymbol{c}} \end{bmatrix} \\ &= \begin{bmatrix} |\boldsymbol{ccc}\rangle|\boldsymbol{coo}\rangle_{wb} \\ |\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle_{wb} \end{bmatrix} \text{or} \begin{bmatrix} |\boldsymbol{cco}\rangle|\boldsymbol{cco}\rangle_{wb} \\ |\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle_{wb} \end{bmatrix}?\end{aligned} \tag{18}$$

Both of these outcomes require an annihilation or release of an $\boldsymbol{o}\bar{\boldsymbol{o}}$ pair using this representation. Both outcomes might also be better explained as a result of Z-boson pair decay. Using preon-bond arguments, the second of the two possibilities in Equation (18) is energetically favored in this case, since the up-quark family has the largest mass parameter, implying the deepest potential wells. Therefore, with high probability using this beyond-standard-model (BSM) argument,

$$\left(W^+W^-\right)_3 = \begin{bmatrix} |\boldsymbol{cco}\rangle|\boldsymbol{cco}\rangle_{wb} \\ |\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle_{wb} \end{bmatrix}. \tag{19}$$

It can be seen that these four versions of the W^+W^- aggregate state, W^+W^-, $(W^+W^-)_1$, $(W^+W^-)_2$, and $(W^+W^-)_3$, indeed provides the needed triplets for protons, neutrons, electrons, and neutrinos as well as their antiparticles, and in the needed proportions, to zeroth order. This includes 3 times as many quark states as lepton states. Note that Equations (15) to (19) have a non-zero inner product with Z states in the extended-color theory's re-interpretation of the standard model Z in terms of preons ([5], Ch. 11), supporting an interpretation as Z-boson pair decays.

For energies above about 160 GeV at which the W^+W^- combination would be formed, a Higgs-Higgs interaction is required [29] to create such pairs on-shell, based on the measured energy of the Higgs boson at about 125 GeV. **Figure 1** shows example two-Higgs interactions that produce W^+W^- or ZZ combinations for each of Equations (15), (16), (17), and (19). The figure also shows a W^+W^- diagram responsible for the neutral kaon oscillation [27] [30]. Note that a single Higgs particle can decay off-shell to a W^+W^- combination. The diagrams are similar but are not shown here.

Freeze-in for conventional matter starts at energies at about the time W^+W^- pairs start to freeze out and ends when the probabilities of W^+W^- pairs are low. Accelerator data indicates that the former occurs at kinetic energies of about 250 GeV and ends at energies of about 160 GeV. The corresponding values of $k_B T$ = (2/3)(kinetic energy) range from about 167 GeV down to about 100 GeV. The duration of this epoch ranges from about 36 picoseconds to about 100 picoseconds after infinite redshift, based on the approximate relationship between time and temperature in this era assuming a radiation-dominated expansion, as provided by Perkins [31] for example. It should be noted that calculations have been

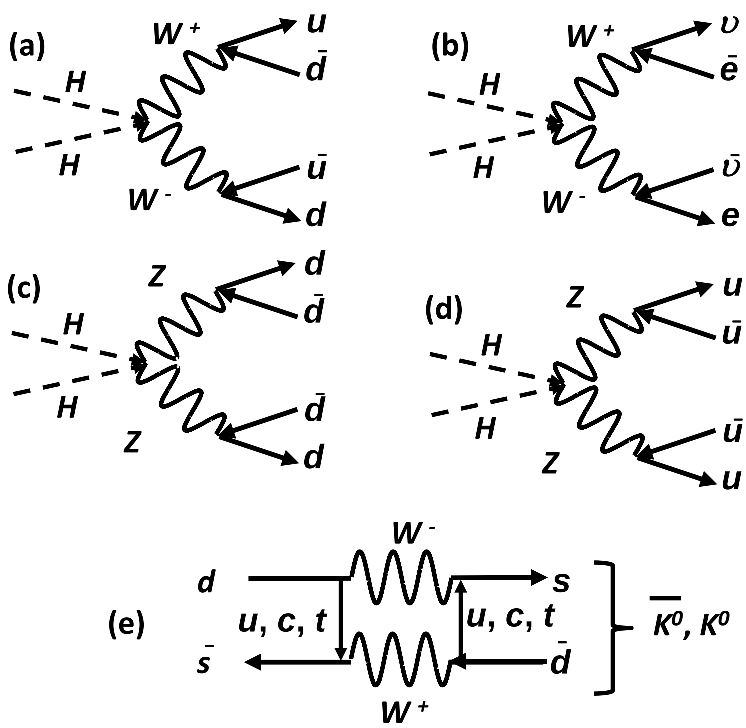

Figure 1. Representative Feynman diagrams for Higgs interactions to W^+W^- and ZZ combinations, along with a W^+W^- diagram responsible for the neutral kaon oscillation. Figures (a) through (d) are for Equations (15), (16), (17), and (19), respectively. In Figures (a) through (d), the labels u, d, e, and ν refer to any member of the respective families.

done for the Higgs transition which indicate a much tighter range of temperature and time for the transition [32], but this does not substantially alter the conclusions of this letter. Reference [32] shows a smooth cross-over for the electroweak phase transition in the standard model. In this letter, however, the preon bond energies indicate that this is a first-order phase transition through which free preons enter bound states as the universe cools. Both the specific enthalpy and the specific entropy changes are negative with decreasing temperature, much as in the well-known ice-water transition.

Now, one might be tempted to use the quasi-bound neutral kaon states of **Figure 1(e)** to estimate the MAA. However, even though the decay of the long-lived neutral kaon produces a net matter-antimatter asymmetry [27] [30], the interaction obeys $\Delta B = \Delta L = \Delta(B - L) = 0$, as expected from all experimental evidence to date, as well as from the global symmetries discussed in an earlier paragraph. Hence any such process cannot provide a violation of Sakharov's third condition in the context of this theory.

One may also note that the processes from Equations (16) to (19) have $\Delta B = \Delta L = \Delta(B - L) = 0$. There is at least one BSM alternative, however, as one may note from Equation (18):

$$\begin{aligned}\left(W^+W^-\right)_3 &= \begin{bmatrix} |\boldsymbol{cco}\rangle|\boldsymbol{coo}\rangle_{wb} \\ |\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle_{wb} \end{bmatrix} + \begin{bmatrix} \boldsymbol{c} \\ \bar{\boldsymbol{c}} \end{bmatrix} \\ &= \begin{bmatrix} |\boldsymbol{cco}\rangle|\boldsymbol{cco}\rangle_{wb} \\ |\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\bar{\boldsymbol{o}}\rangle_{wb} \end{bmatrix} \text{ or } \begin{bmatrix} |\boldsymbol{ccc}\rangle|\boldsymbol{coo}\rangle_{wb} \\ |\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle|\bar{\boldsymbol{c}}\bar{\boldsymbol{c}}\bar{\boldsymbol{o}}\rangle_{wb} \end{bmatrix}.\end{aligned} \tag{20}$$

The processes of Equation (20) are not reported in W-boson pair production in accelerators [28] but they may not have been part of the searches. The experimental signature would consist of a high-energy charged lepton (l) together with three quark (q) jets or a high-energy baryon of opposite sign. Such $lqqq$ outputs were evidently *explicitly excluded* in the searches in order to suppress a high background. Equally significantly, the processes of Equation (20) evidently require the interaction between a W^+W^- pair and a $\boldsymbol{c}\bar{\boldsymbol{c}}$ preon pair. It is questionable whether such an interaction would be observed in accelerators because a W and a Higgs or high energy photon are rarely present at the same time and place. One might speculate that quark-gluon plasmas might have interactions such as Equation (20), with Pb-Pb collisions at LHC with center-of-mass-energy per nucleon $s_{NN}^{1/2} = 2.7\ \text{TeV}$ or more. However, apparently the measured temperatures of such plasmas are only in the neighborhood of 300 MeV/k_B [33], well below the electroweak scale.

The two processes of Equation (20) are not expected in the standard model. Both of these outcomes require an annihilation or release of an $\boldsymbol{o}\bar{\boldsymbol{o}}$ pair, as in Equation (18). For both of the possible outcomes in Equation (20), one lepton is created, and one baryon is created. For the first of the two outcomes, $\Delta B = \Delta L = 1$ and $\Delta(B - L) = 0$. In the second case, $\Delta B = \Delta L = -1$ and $\Delta(B - L) = 0$. In the extended-color paradigm, one expects that the two interactions are equally likely if the preon bonds are the same between the "$\boldsymbol{c}$" and "$\overline{\boldsymbol{c}}$" versions. The states of Equation (20) do not incur the issue of *CPT* violation as in the previous section because the differences in preon binding energy are not applied here to fermions that obey Dirac's equation but instead to spin-one entities similar to the W^+ and W^-. As in the prior section, if one argues that there is a slight difference in the preon bond energy in the "$\boldsymbol{c}$" and "$\overline{\boldsymbol{c}}$" versions of Equation (20), one finds a thermodynamic preference for matter over antimatter (or vice versa). In particular, at temperatures of about 100 GeV/k_B at freeze-out, one finds that a binding energy difference of the order of 100 eV is sufficient for the observed MAA as given by Equation (12).

This section provides a rationale for a preon explanation of MAA when it arises in the electroweak epoch. Although the discussion here is closer to a standard model rationale, it apparently requires at least one BSM interaction, Equation (20), involving preons and/or the associated Higgs states. This circumvents the requirement for baryon-number violation for MAA, since quarks and baryons have not yet been created when violation occurs. It also circumvents the *CPT* issue since the *C*-asymmetry in bonding energy occurs before fermions are formed.

5. Summary

Three answers are offered to the question, "Why does the universe consist of matter, when there were equal quantities of matter and antimatter in the early universe?" These answers provide semi-quantitative agreement with the observed asymmetry. These answers assume that there are preons of the rishon form. An equal number of charge $1/3e$ preons and charge $-1/3e$ preons are assumed now and also in the initial universe. All three answers ("fluctuations", "preon bonding" and "Higgs bonding") utilize the first of Sakharov's three conditions: out-of-equilibrium freeze-out as the preons aggregate into ordinary matter. The latter two approaches seem to require a slight *C*-symmetry violation in the condensation process, e.g., due to a slight difference in preon bond energies, particularly at interaction energies of the order of 100 GeV or more.

The first approach, "fluctuations", does not require *C*-asymmetry if the fluctuations between Planck-mass entities are well-correlated. It is possible that correlated fluctuations could play a role in the second and third approaches as well. Regarding Sakharov's third condition, baryon non-conservation, all evidence indicates that B and L are conserved in the modern universe after preon bonding and this is consistent with the theory. The assumption of free or quasi-bound preons circumvents this, since then B and L can change as preons bond before B and L are fully defined. If the aggregate of such preons is assumed to have initial electrical neutrality and $\boldsymbol{o}$-$\overline{\boldsymbol{o}}$ neutrality, one finds $B - L = 0$ always, if preons are assigned $B = L = 0$ (if in addition the net number of neutrinos equals the number of neutrons in the modern universe). The use of preons evidently provides a particularly simple explanation for primordial matter-antimatter asymmetry that is consistent with electrical neutrality both now and in the early universe. The preon-condensation process is evidently a classic first-order phase transition from free particles to bound states which involves a decrease in specific enthalpy and entropy for a transition from a free state to a bound state.

In Sections 4, it is proposed that the preons of this theory are top-level matches with standard model entities, *i.e.*, the massless Higgs Goldstone bosons and Faddeev-Popov ghosts. In accord with this match, one may note that at high energies with large Higgs amplitude $|\phi|$, the $|\phi|^2$ term of the Higgs potential, $-\mu^2|\phi|^2 + \lambda|\phi|^4$, is negligible compared to the $|\phi|^4$ term. Here μ and λ are positive constants. In this case, the minimum of the Higgs potential is then approximately zero. This corresponds to approximately massless, quasi-bound Higgs particles. As the mean energy per particle drops below twice the Higgs mass, the near-zero-mass preons condense into a massive Higgs and massive W and Z bosons in accord with the standard model formalism of spontaneous electroweak symmetry breaking. Because the hypothesized preons are intrinsically anti-commuting fermion-like particles, the composite ([5], Ch. 11) W and Z bosons will naturally decay to a final state that consists of the fermions that are observed today.

There are several challenges and implications of these research results for current physical phenomena and theoretical frameworks. The key implications are: 1) that the results of this paper provide a straightforward explanation of MAA, and 2) that preons may be able to provide a more physical explanation of the Higgs states of the standard model than the standard model itself. Also, it is found that the quantum field theory of [5] has conservation laws for baryon number and lepton number that are almost identical to that of the standard model, and in accord with observations. The key challenges for these results are to: 1) find better experimental evidence for the proposed C-asymmetry at the electroweak scale given by Equation (20); 2) to better understand the hypothesized relationship between the proposed preons and the more-accepted scalar Higgs and Faddeev-Popov states; and 3) understand the proposed mechanisms more precisely by a combination of measurement and theory.

Acknowledgements

This paper is dedicated to the memory of Michael Shupe, a preon pioneer who passed away in December 2022. Portions of this paper were given in paper H14.00008 at the 2023 APS April meeting.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Harari, H. (1979) *Physics Letters B*, **86**, 83-86.

https://doi.org/10.1016/0370-2693(79)90626-9

[2] Shupe, M. (1979) *Physics Letters B*, **86**, 87-89. https://doi.org/10.1016/0370-2693(79)90627-0

[3] D'Souza, I.A. and Kalman, C.S. (1992) Preons: Models of Leptons, Quarks, and Gauge Bosons as Composite Objects. World Scientific Press, Singapore. https://doi.org/10.1142/1700

[4] Sakharov, A.D. (1967) *JETP Letters*, **5**, 24-27. https://doi.org/10.1070/PU1991v034n05ABEH002497

[5] Holmes, R. (2021) A Quantum Field Theory with Permutational Symmetry. 2nd Edition, Lambert Academic Press, Riga. https://doi.org/10.5281/zenodo.5047237

[6] Harrison, P.F. and Scott, W.G. (1994) *Physics Letters B*, **78**, 471-475. https://doi.org/10.1016/0370-2693(94)90170-8

[7] Weinberg, S. (2008) Cosmology. Oxford University Press, Oxford. https://doi.org/10.1086/10.1086/163168

[8] Kolb, E. and Turner, M. (1990) The Early Universe. CRC Press, Boca Raton. https://doi.org/10.1201/9780429492860

[9] Zyla, P.A. Barnett, R.M., Beringer, J., Dahl, O., Dwyer, D.A., *et al.* (2020) *Progress in Theoretical and Experimental Physics*, **2020**, 083C01. Big Bang Cosmology. https://doi.org/10.1093/ptep/ptaa104

[10] Farrar, G.R. and Shaposhnikov, M.E. (1993) *Physical Review Letters*, **70**, 2833-2836. https://doi.org/10.1103/PhysRevLett.70.2833

[11] Farrar, G.R. and Shaposhnikov, M.E. (1993) Technical Report RU-93-11, CERN-TH.6732/92, Rutgers/CERN.

[12] Huet, P. and Sather, E. (1995) *Physical Review D*, **51**, 379-394. https://doi.org/10.1103/PhysRevD.51.379

[13] Morrissey, D.E. and Ramsey-Musolf, M.J. (2012) *New Journal of Physics*, **14**, Article ID: 125003. https://doi.org/10.1088/1367-2630/14/12/125003

[14] Bruggisser, S., Konstandin, T. and Servant, G. (2017) *Journal of Cosmology and Astrophysics*, **11**, 034. https://doi.org/10.1088/1475-7516/2017/11/034

[15] Fukugita, M. and Yanagida, T. (1986) *Physics Letters B*, **174**, 45-47. https://doi.org/10.1016/0370-2693(86)91126-3

[16] Fong, S.C., Nardi, E. and Riotto, A. (2012) *Advances in High Energy Physics*, **2012**, Article ID: 158303. https://doi.org/10.1155/2012/158303

[17] Workman, R.L., Burkert, V.D., Crede, V., Klempt, E., Thoma, U., *et al.* (2022) *Progress in Theoretical and Experimental Physics*, **2022**, 083C01. Electron. https://doi.org/10.1093/ptep/ptac097

[18] Bourilkov, D. (2001) *Physical Review D*, **64**, 071701R. https://doi.org/10.1103/PhysRevD.64.071701

[19] Fan, X., Myers, T.G., Sukra, B.A.D. and Gabrielse, G. (2023) *Physical Review Letters*, **130**, Article ID: 071801. https://gabrielse.physics.harvard.edu/gabrielse/overviews/ElectronSubstructure/ElectronSubstructure.html https://doi.org/10.1103/PhysRevLett.130.071801

[20] Peskin, M.E. and Schroeder, D.V. (2016) An Introduction to Quantum Field Theory. Westview Press, Boulder. https://doi.org/10.1201/9780429503559

[21] Griffiths, D. (2008) Introduction to Elementary Particles. 2nd Edition, Wiley-VCH, Weinheim, 150. https://doi.org/10.1002/9783527618460

[22] Peccei, R.D. (1999) Discrete and Global Symmetries in Particle Physics. In: Mathelitsch, L. and Plessas, W., Eds., *Broken Symmetries*, Lecture Notes in Physics, Vol. 521, Springer, Berlin, Heidelberg, 1-50. https://doi.org/10.1007/BFb0105521

[23] Xing, Z., Zhang, H. and Zhou, S. (2008) *Physical Review D*, **77**, Article ID: 113016. https://doi.org/10.1103/PhysRevD.77.113016

[24] Harari, H. and Seiberg, N. (1982) *Nuclear Physics B*, **204**, 141-167. https://doi.org/10.1016/0550-3213(82)90426-6

[25] Zenczykowski, P. (2008) *Physics Letters B*, **660**, 567-572. https://doi.org/10.1016/j.physletb.2008.01.045

[26] Tong, D. (2018) Gauge Theory. 173-256. http://www.damtp.cam.ac.uk/user/tong/gaugetheory/gt.pdf

[27] Thomson, M. (2013) Modern Particle Physics. Cambridge University Press, Cambridge, Sec. 14.5. https://doi.org/10.1017/CBO9781139525367

[28] Archard, P., Adriani, O., Aguilar-Benitez, M., Alcaraz, J., Alemanni, G., *et al.* (2004) *Physics Letters B*, **600**, 22-40. https://doi.org/10.1016/j.physletb.2004.08.060

[29] de Florian, D., Grojean, C., Maltoni, F., Mariotti, C., Nikitenko, A., *et al.* (2017) CERN Report 2017-002, Appendix A (2016). https://doi.org/10.23731/CYRM-2017-002

[30] Workman, R.L., Burkert, V.D., Crede, V., Klempt, E., Thoma, U., *et al.* (2022) *Progress in Theoretical and Experimental Physics*, **2022**, 083C01. "K_0^L." https://doi.org/10.1093/ptep/ptac097

[31] Perkins, D.H. (2000) Introduction to High Energy Physics. 4th Edition, Cambridge University Press, Cambridge, Ch. 10. https://doi.org/10.1017/CBO9780511809040

[32] D'Onofrio, M. and Rummukainen, K. (2016) *Physical Review D*, **93**, Article ID: 025003. https://doi.org/10.1103/PhysRevD.93.025003

[33] Acharya, S., Adamová, D., Adler, A., Aglieri-Rinella, G., Agnello, M., *et al.* (2022) The ALICE Experiment: A Journey through QCD. CERN EP-2022-227. https://doi.org/10.48550/arXiv.2211.04384