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# Introduction of concealed photons allows conjecturing a chemical theory of subatomic particles

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## Abstract

Decays and annihilations observed in particle physics have so far prevented unifying subatomic particles into a chemical scheme. Here we hypothesize that photons, rather than being absorbed, are captured by particles, conserving their integrity while remaining undetected. This assumption is compatible with the observations that particles radiate and that alternative decay modes often involve additional photons. Therefrom, an annihilation-free chemical model of leptons, hadrons and gauge bosons is conjectured by introducing concealed photons. Our model conserves and reorganizes indestructible colored subparticles across subatomic reactions, thus constituting a new conservation law. Clues to weak interaction asymmetry naturally emerge from the chemical model. Antimatter particles appear to be more complex than matter particles, possibly suggesting why the former are scarce in the universe. The conservation laws of the standard model are satisfied, and its symmetries investigated. Experiments to verify the existence of overlooked photons are proposed. Confirmation of our theory would convey the principles of chemistry into the world of subatomic particles and reveal a profound unity among all particles.

## Keywords

Particle decays; Particle annihilations; Particle productions; Compositeness models; Weak interaction asymmetry; Antimatter scarcity; Subatomic chemistry.

## 1. Introduction

During the past decades, in their quest to understand the infinitely small, physicists have sought to unravel the fundamental bricks of nature by constructing powerful particle accelerators. Many short-lived subatomic particles [1] have thus been uncovered and their properties determined. Three kinds of subatomic particles have been evidenced in the Standard Model [2], namely the massive hadrons that contain quarks, leptons (or light particles), and gauge bosons, which carry the interactions.

Interestingly, particles of one kind may decay into particles of other kinds. For instance, the three pions  $\pi^0$ ,  $\pi^+$   $\pi^-$ , made of one quark and one antiquark, are hadrons by definition, yet naturally decay into leptons or gauge bosons, as in  $\pi^+ \rightarrow \mu^+ + \nu_\mu$  or  $\pi^0 \rightarrow 2\gamma$ , where  $\mu^+$ ,  $\nu_\mu$  and  $\gamma$  respectively designate the anti-muon, muonic neutrino and photon. Similarly, the weak interaction bosons  $W^+$ ,  $W^-$

and  $Z^0$  may decay into leptons or into gluons  $g$ , the strong interaction bosons, as in  $W^+ \rightarrow \mu^+ + \nu_\mu$  or  $Z^0 \rightarrow 3g$ . Remarkably, hadrons, leptons and gauge bosons further share the same elementary units of electric charge ( $e$ ) and spin ( $\hbar$ ). Also, subatomic particles do not transform arbitrarily into one another; rather, their decays obey strict conservation laws, such as the conservation of leptonic or baryonic quantum numbers.

Leptons and hadrons can be further categorized as matter particles or antimatter particles, which appear to resemble matter particles in most aspects, yet possess opposite charges. However, a non-zero mass difference was recently recorded between matter and antimatter particles [3]. Moreover, antimatter particles are scarce in the universe, and it seems this observation cannot be explained in terms of the Standard Model alone [4]. Accounting for this asymmetry might therefore require the development of an entirely new physics.

Also, for aesthetic reasons, some physicists believe that the high number of different subatomic particles could suggest the existence of a lower layer of description. Accordingly, Grand Unification Theories [5] proposed that leptons and quarks be constituted of a limited set of some more elementary bricks and attempted to unify all fundamental particles and interactions. The first models of sub-constituents stemmed from the discovery of quarks and the remarkable organization of fundamental particles into three generations. To date, many compositeness models [6-14] have been built. More recently, the substructure of subatomic particles has been compared to that of molecules [13] (even if the model still relied on annihilation ultimately), and  $e/6$  charges [14] and *indestructible subparticles* [15] have been envisaged. To validate and possibly decide among these models, additional constraints are needed. The prospect that a compositeness model could satisfy a chemistry of subatomic particles conserving indestructible subparticles across reactions, following the assertion ‘nothing is lost, nothing is created, everything is transformed’, would constitute a significant constraint.

However, such a subatomic chemistry has long been dismissed. Particles can annihilate into photons or conversely be created from photons alone. Thus, we reckoned photons could possibly be composed of the same subparticles that form leptons and hadrons. Therefrom, would it be possible to conjecture for each subatomic particle a unique composition in terms of subparticles that would fit all subatomic reactions, so that these subparticles would be conserved and reorganized across all subatomic reactions? Then matter, conceived as the set of underlying subparticles, would be conserved, thus constituting an additional conservation law.

In this study, we propose such an annihilation-free subatomic chemistry and discuss its properties. It is based on two main hypotheses: (i) the possible presence of concealed photons within particles and (ii) the existence of six kinds of elementary subparticles hereafter denoted *Sparks*. Therefrom, we create a *compositeness model* in which all subatomic particles are constituted of instances of sparks. We show that the introduction of concealed photons allows representing *subatomic reactions*, by making our compositeness model fit decays, particle productions and annihilations involving leptons, pions, nucleons and gauge bosons, in the sense that *indestructible* sparks are conserved and reorganized across reactions. The conservation laws observed in particle physics are satisfied in our model, and symmetries investigated.

Incidentally, we regard this manuscript as a *chemical study*, only applying to objects belonging to the world of particle physics. The study proposes an alternative world view as it focuses on the corpuscular aspect and compositeness of particles, not on the way particles interact, and thus only captures chemical reactions. A chemical model is presented here without demonstration — just as Schrödinger’s equation, whose justification lies in its predictions — to illustrate the possible existence of a subatomic chemistry. We feel our theory should be appraised for its own merits with regard to mathematical coherence, agreement with observed phenomena, elegance, and its original qualitative and quantitative predictions, rather than assessed with respect to criteria specific to QFT. Experiments are proposed to validate or invalidate the existence of concealed photons, making the theory *refutable*. Extensive comparisons with the Standard Model or the construction of a Lagrangian related to the fields are beyond the scope of the present article.

Taken together, the compositeness model and subatomic reactions constitute a genuine chemical model of subatomic particles and provide natural interpretations to many physical phenomena. In our model, strong interaction colors are true charges rather than quantum states, and particles of higher generations correspond to excited states. Heavy particles can also be created from radiation. Remarkably, subatomic reactions involving the weak interaction appear to be asymmetric with respect to concealed photons under charge conjugation. In agreement with a recent observation [3], a fundamental asymmetry is predicted between matter and antimatter. Antimatter particles are found to be more complex than their corresponding matter particles, suggesting a possible explanation for antimatter scarcity. Altogether, our theory unifies all subatomic particles into a single chemical scheme, revealing their profound underlying unity.

## 2. Possible existence of a subatomic chemistry

At first sight, decays, annihilations and particle productions observed in particle physics seem to be incompatible with the existence of a subatomic chemistry. Indeed, subatomic particles appear to disintegrate or be created out of radiation. An electron  $e^-$  and positron  $e^+$  for instance annihilate to produce two, sometimes three photons depending on their respective spins. Conversely, a single photon heading onto an atom sometimes yields an electron-positron pair. Additionally, some transformations are observed in different ways: for instance, the neutron  $n$  decaying into a proton  $p^+$  and electron may emit an electronic anti-neutrino  $\bar{\nu}_e$  or absorb an electronic neutrino  $\nu_e$ . Taken together, the observed transformations:

$$e^- + e^+ \rightarrow 2\gamma, \tag{r1}$$

$$e^- + e^+ \rightarrow 3\gamma, \tag{r2}$$

$$Atom + \gamma \rightarrow Atom + e^- + e^+, \tag{r3}$$

$$n \rightarrow p^+ + e^- + \bar{\nu}_e, \tag{r4}$$

$$n + \nu_e \rightarrow p^+ + e^-, \tag{r5}$$

seem incoherent and suggest subatomic particles cannot possess a structure of constituents.

Nonetheless, these transformations are often one photon short to being consistent. They may actually be corrected to constitute a coherent set of chemical reactions, if we hypothesize that interacting photons are not detected. In this perspective, photons could be somehow carried by subatomic particles, captured rather than absorbed, conserving their integrity while remaining undetected (*the concealed photon hypothesis*). This assumption is compatible with photon absorption and with radiation, which occurs when particles are accelerated — radiation could indeed be interpreted as the concrete detachment of concealed photons. It is also consistent with the numerous instances of alternative decay modes [16] that often involve additional photons or particles like  $\pi^0$  or  $\bar{\nu}\nu$ , which presumably amount to whole photons. The boson  $Z^0$  for example decays [16] into  $e^-e^+$  with probability  $p = 3.363 (\pm 0.004) \%$ , but alternatively into  $e^-e^+\gamma$  ( $p < 5 \times 10^{-4}$ ) or  $e^-e^+\gamma\gamma$  ( $p < 7 \times 10^{-6}$ ), suggesting  $Z^0$  might occasionally carry photons. Denoting  $\gamma^*$  the concealed photon, reactions (r2-r4) could be modified to:

$$(e^- + \gamma^*) + e^+ \rightarrow 3\gamma \quad (r2')$$

$$(Atom + \gamma^*) + \gamma \rightarrow Atom + e^- + e^+, \quad (r3')$$

$$n + \gamma^* \rightarrow p^+ + e^- + \bar{\nu}_e \quad (r4')$$

restoring coherence with reactions (r1; r5), if the electron and positron together compare to two photons, and the electronic neutrino and anti-neutrino together to a single photon. Reactions like (r3') are compatible with the fact that highly energetic photons are capable of producing heavy particles [17]. Note that a neutron must encounter a photon in reaction (r4'), suggesting why neutrons may be stable inside atomic nuclei, wherein they are protected from incoming photons, and unstable outside. The fact that recent measurements of free-neutron lifetime, performed in various environments photon-wise, exhibited important discrepancies [18] could indicate that overlooked photons take part in the reaction.

### 3. Introduction of colored subparticles

Herein is conjectured the existence of six kinds of subparticles that we call *sparks* and denote  $\xi$ , possessing electric charge  $\pm e/6$  (see **Appendix A**) and a true specific color charge: *green*, *blue* or *red* — not merely a quantum state (*existence of sparks hypothesis*). Although leptons and some bosons are colorless, their constituents could possess strong interaction color charges to account for the presence of color within quarks, provided their color charges cancel. Neutrons for instance are made of charged particles (quarks) but remain electrically neutral overall because their electric charges cancel. Similarly, strong interaction color charges could cancel in the photon, leptons, and weak interaction bosons. The strong interaction being stronger than electromagnetism, we reckon sparks could assemble beforehand in colorless triples. The aforementioned colorless particles could be composed of such triples only and would thus only be subject to electromagnetism. This is actually the hypothesis we made to construct a realist model of the electron [19].

Now, in order to create a coherent set of chemical reactions, many configurations have been investigated, but we could only come out with a single successful chemical model in the end. For example, considering reactions:

$$p^+ \rightarrow n + e^+ + \nu_e \quad (r6)$$

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu \quad (r7)$$

$$\pi^0 \rightarrow 2\gamma, \quad (r8)$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \quad (r9)$$

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu \quad (r10)$$

where  $\mu$  is the muon and  $\bar{\nu}_\mu$  the muonic anti-neutrino, we had to opt for definite conjectures, otherwise no coherent chemical model could be constructed. Using  $N_{particle(s)}$  to designate the number of sparks present in *particle(s)*, we conjectured that leptons of different generations should bear the same number of sparks:

$$\begin{cases} N_{lepton} \equiv N_{e^-} = N_{\mu^-} = N_{\tau^-} \\ N_{neutrino} \equiv N_{\nu_e} = N_{\nu_\mu} = N_{\nu_\tau} \\ N_{antilepton} \equiv N_{e^+} = N_{\mu^+} = N_{\tau^+} \\ N_{antineutrino} \equiv N_{\bar{\nu}_e} = N_{\bar{\nu}_\mu} = N_{\bar{\nu}_\tau} \end{cases} \quad (e1)$$

suggesting that particles of higher generations are but excited states of first-generation particles, constituted of the same kinds and numbers of sparks, only assembled in a different structure. This possibility (see e.g. [20]) is corroborated by the fact for instance that the muonic Compton wavelength is much smaller than that of the electron. Noteworthy, this is also compatible with the observation that neutrinos oscillate between different generations (electronic, muonic, tauic neutrinos) [21]. These equations are also compatible for instance with the observation that pure leptonic decays of boson  $W^+$  (respectively  $W^-$  and  $Z^0$ ) produce  $e^+ \nu_e$ ,  $\mu^+ \nu_\mu$ , or  $\tau^+ \nu_\tau$  (respectively  $e^- \bar{\nu}_e$ ,  $\mu^- \bar{\nu}_\mu$ ,  $\tau^- \bar{\nu}_\tau$  and  $e^- e^+$ ,  $\mu^- \mu^+$ ,  $\tau^- \tau^+$ ) with equal probabilities [16]. Likewise, we had to conjecture that all quarks, irrespective of their charge or generation, contained the same number of sparks, and that so did all antiquarks:

$$\begin{cases} N_d = N_u = N_c = N_s = N_b = N_t \equiv N_{quark} \\ N_{\bar{d}} = N_{\bar{u}} = N_{\bar{c}} = N_{\bar{s}} = N_{\bar{b}} = N_{\bar{t}} \equiv N_{antiquark} \end{cases} \quad (e2)$$

In our model, we assumed the color of quarks resulted from the dominant color of their constitutive sparks. Finally, we found that relations:

$$\begin{cases} N_{lepton} = N_{neutrino} \\ N_{photon} = N_{neutrino} + N_{antineutrino} \\ 2N_{photon} = N_{lepton} + N_{antilepton} \end{cases} \quad (e3)$$

were necessary to maintain coherence (**Appendix B**). Equations (e1-3) implied that reactions (r6; r7; r10) were not consistent, and therefore needed to be adjusted to:

$$p^+ + 2\gamma^* \rightarrow n + e^+ + \nu_e \quad (r6')$$

$$\mu^- + \gamma^* \rightarrow e^- + \bar{\nu}_e + \nu_\mu \quad (r7')$$

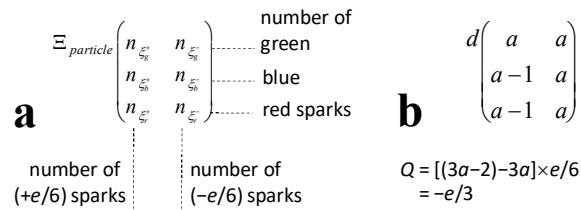
$$\pi^- \rightarrow (\mu^- + \gamma^*) + \bar{\nu}_\mu \quad (r10')$$

to form a consistent set of reactions. Reaction (r7') indicates that the muon either decays because it already bears a concealed photon or because it encounters a new photon. The latter situation is possible since muons are relatively long-lived particles ( $\sim 2.2 \times 10^{-6}$ s). Similarly,  $\beta^+$  emission (r6') is allowed in our model provided two photons are available, suggesting why it seldom occurs, and only inside nuclei.

Remarkably, the comparisons of reactions (r9) with (r10'), and (r4') with (r6'), reveal an asymmetry between weakly interacting particles and antiparticles, as charge conjugation involves an additional concealed photon in only one of the reactions. This asymmetry naturally emerges from the attempt of constructing a consistent annihilation-free chemical model, and is reminiscent of the asymmetry of the weak interaction with respect to charge, parity and time, as will be discussed below.

#### 4. Compositeness and chemical model

Henceforth, every subatomic particle will be represented by a matrix  $\Xi$ , displaying the number of instances  $n_\xi$  of every kind of sparks  $\xi_{\text{color}}^{\text{charge}}$ . This arrangement allows reading the color of a particle directly from the matrix by identifying the row with the highest number of sparks, and determining its electric charge by summing the first column, subtracting the second column, and multiplying the result by  $e/6$  (see Figure 1).



**Figure 1.  $\Xi$ -matrix representation.** **a.** Particles are represented by  $\Xi$ -matrices displaying the number of instances of every kind of sparks  $\xi$ . The rows indicate their number of green, blue and red sparks. The first (respectively second) column indicates their number of  $+e/6$  (respectively  $-e/6$ ) sparks. The top left value for instance stands for the number of instances of green,  $+e/6$  sparks  $\xi_g^+$  present in the considered particle. Particle color is determined by identifying the row(s) with the most sparks, while electric charge can be read from the  $\Xi$ -matrix by summing first column, subtracting second column, and multiplying by  $e/6$ . **b.** The  $\Xi$ -matrix representing quark  $d_{\text{green}}$  for instance exhibits green color charge and electric charge  $Q = [a + (a-1) + (a-1) - 3a] \times e/6 = -e/3$ .

$\Xi$ -matrices effectively provide an additional level of description in terms of sparks to subatomic particles, just as molecules are more detailed when their constitutive atoms are specified. The problem thus reduces to determining a *unique*  $\Xi$ -matrix for every subatomic particle so that sparks are conserved and rearranged across *all* subatomic reactions. As the photon is a neutral colorless particle, its  $\Xi$ -matrix

must be composed of an equal number of all kinds of sparks. Setting  $a = N_{\text{photon}}/6$  and  $b = N_{\text{lepton}}/6$  for generality, with  $b < a$  — which can be seen from reaction (r4') —, and reckoning that the photon, electron, neutrino, positron and anti-neutrino are respectively constituted of  $6a$ ,  $6b$ ,  $6b$ ,  $6(2a-b)$ , and  $6(a-b)$  sparks according to equations (e3),  $\Xi$ -matrices for these particles may be written:

$$\gamma \begin{pmatrix} a & a \\ a & a \end{pmatrix}, \quad e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix}, \quad \nu \begin{pmatrix} b & b \\ b & b \end{pmatrix}, \\ e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix}, \quad \bar{\nu} \begin{pmatrix} a-b & a-b \\ a-b & a-b \end{pmatrix},$$

so that they exhibit colorlessness and appropriate electric charges. Reaction (r1) is then represented by:

$$e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} \rightarrow \gamma \begin{pmatrix} a & a \\ a & a \end{pmatrix} + \gamma \begin{pmatrix} a & a \\ a & a \end{pmatrix}.$$

This representation is coherent because the sum of any kind of sparks on the left-hand side of the reaction (at any matrix position) is equal to the corresponding sum on its right-hand side. Thus, every spark is conserved and reorganized across the reaction. Pair production [16] also appears to be possible in our framework, since writing the reaction the other way round still satisfies the conservation of sparks. Reaction (r7') becomes:

$$\mu^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \end{pmatrix} \rightarrow e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_e \begin{pmatrix} a-b & a-b \\ a-b & a-b \end{pmatrix} + \nu_\mu \begin{pmatrix} b & b \\ b & b \end{pmatrix}.$$

It is apparent here that neutral colorless neutrinos and additional concealed photons are needed to balance the kinds and numbers of sparks on both sides of the reactions. Notice that the presence of  $+b$  (respectively  $-b$ ) indicates that the particle is a lepton (resp. an antilepton), thus naturally reflecting the conservation of the leptonic quantum number. Note further that  $\Xi$ -matrices are subject to very strong constraints, since a matrix used for representing a particular particle has to fit in every subatomic reaction involving it.

Now, can such a representation account for particles and reactions involving quarks? Before representing such reactions, we need to determine proper compositions for quarks and antiquarks in terms of sparks.  $\Xi$ -matrices for  $u$ ,  $d$ ,  $\bar{u}$ , and  $\bar{d}$  quarks have been conjectured by requiring that they simultaneously exhibit suitable color and electric charges, and satisfy reactions (r8; r9; r10') involving pions. Only green quarks and anti-green antiquarks are shown below:

$$u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \end{pmatrix}, \quad \bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \end{pmatrix}, \quad d \begin{pmatrix} a & a \\ a-1 & a \end{pmatrix}, \quad \bar{d} \begin{pmatrix} a & a \\ a+1 & a \end{pmatrix}.$$

Note that our matrices for quarks and antiquarks correctly exhibit electric charges, and green and anti-green colors. Likewise,  $\Xi$ -matrices are proposed for the weak interaction bosons so that they match reactions  $W^+ \rightarrow e^+ \nu_e$ ,  $W^- \rightarrow e^- \bar{\nu}_e$ ,  $Z^0 \rightarrow e^- e^+$ , and for gluons, ensuring they change the color of quarks. Importantly, particles of different generations share the same  $\Xi$ -matrix, as higher generation particles possess the same number of occurrences of every kind of sparks. Proposals of  $\Xi$ -matrices for all elementary particles are presented in **Figure 2**.



Interaction	Matter particles	Antimatter particles	Bosons
Electroweak	$e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix}$ $\nu_e \begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix}$	$e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix}$ $\bar{\nu}_e \begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix}$	$W^\pm \begin{pmatrix} 2a\pm 1 & 2a\mp 1 \\ 2a\pm 1 & 2a\mp 1 \\ 2a\pm 1 & 2a\mp 1 \end{pmatrix}$ $Z^0 \begin{pmatrix} 2a & 2a \\ 2a & 2a \\ 2a & 2a \end{pmatrix}$ $\gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$
Strong	$u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix}$ $d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}$	$\bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix}$ $\bar{d} \begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix}$	$g_{\bar{q}q} \begin{pmatrix} a+1 & a \\ a-1 & a \\ a & a \end{pmatrix}$

**Figure 2.  $\Xi$ -matrix representation of fundamental particles.**  $\Xi$ -matrices enumerate the constituents of their corresponding particles, but do not account for their internal structure or other properties. The three gluons  $g_{rr}$ ,  $g_{bb}$ ,  $g_{gg}$  and photon for instance are different particles, even though they share the same  $\Xi$ -matrix. Strongly interacting particles with other colors or anticolors are obtained by rearranging the rows of their corresponding  $\Xi$ -matrices. Particles of different generations share the same  $\Xi$ -matrix and their symbols are shown vertically. Higher generation particles could thus just be excited states of the original particle, as they possess the same number of sparks. Since  $a > b$ , antimatter particles are found to be more complex than matter particles in terms of their number of sparks.  $\Xi$ -matrices are subject to very strong constraints as a  $\Xi$ -matrix representing a particular particle has to fit in every subatomic reaction involving it.

Note that particular solution  $b = a/2$  would make the neutrino and anti-neutrino possess the same number of sparks, and the positron be an inverted electron with an attached photon, suggesting why they both would have the same mass. One may also notice that, in our representation, antiquarks and charged antileptons would require more sparks than their corresponding matter particles. The fact that antiparticles are more complex than matter particles in terms of their number of constitutive sparks was not introduced from the start, but rather is a direct consequence of reaction (r4'), which implies that  $N_{e^-} < N_\gamma$ , and of reaction (r1), which in turn requires that  $N_{e^-} < N_{e^+}$ . This fundamental asymmetry between matter and antimatter is therefore a prediction of our model, and it is compatible with the recent observation of a non-zero mass difference between matter and antimatter [3].

The proposed  $\Xi$ -matrices for quarks and antiquarks satisfy the corresponding subatomic reactions. For instance,  $\Xi$ -matrices for quarks and antiquarks satisfy  $\pi^0$  decays (r8):

$$\begin{aligned} \pi^0: & u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} + \bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} \rightarrow \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} + \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}, \\ \pi^0: & d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + \bar{d} \begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix} \rightarrow \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} + \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}. \end{aligned}$$

Reactions (r9) and (r10') may also be represented as:

$$\begin{aligned} \pi^+: & u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} + \bar{d} \begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix} \rightarrow \mu^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + \nu_\mu \begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix}, \\ \pi^-: & d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + \bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} \rightarrow \mu^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_\mu \begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}. \end{aligned}$$

Recalling baryons are constituted of three quarks of three different colors, matrices for the neutron and proton can be constructed:

$$d_g \begin{pmatrix} a & a \\ a-1 & a \end{pmatrix} + d_b \begin{pmatrix} a-1 & a \\ a & a \end{pmatrix} + u_r \begin{pmatrix} a & a-1 \\ a & a-1 \end{pmatrix} \equiv n \begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix},$$

$$d_g \begin{pmatrix} a & a \\ a-1 & a \end{pmatrix} + u_b \begin{pmatrix} a & a-1 \\ a+1 & a-1 \end{pmatrix} + u_r \begin{pmatrix} a & a-1 \\ a & a-1 \end{pmatrix} \equiv p^+ \begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix}.$$

Note that although  $\Xi$ -matrices for  $u$  and  $d$  quarks were originally defined to suit reactions (r8-r10') involving pions, they strikingly combine in triples to yield  $\Xi$ -matrices for the proton and neutron that exhibit colorlessness and their correct charges. Reactions involving nucleons (r5), (r4') and (r6') may then be represented thus:

$$n \begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix} + \nu_e \begin{pmatrix} b & b \\ b & b \end{pmatrix} \rightarrow p^+ \begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix} + e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix},$$

$$n \begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \end{pmatrix} \rightarrow p^+ \begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix} + e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_e \begin{pmatrix} a-b & a-b \\ a-b & a-b \end{pmatrix},$$

$$p^+ \begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix} + 2\gamma^* \begin{pmatrix} a & a \\ a & a \end{pmatrix} \rightarrow n \begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix} + e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + \nu_e \begin{pmatrix} b & b \\ b & b \end{pmatrix}.$$

These matrices remarkably fit all reactions involving nucleons. In **Figure 3** are displayed many such subatomic reactions. Thus,  $\Xi$ -matrices are found to fit all previously considered reactions involving leptons (**Figure 3a**), pions (**Figure 3b**), nucleons (**Figure 3c**), and weak interaction bosons (**Figure 3d**), conserving and rearranging occurrences of every kind of sparks at every matrix position. Likewise,  $\Xi$ -matrices representing gluons induce color transformations to all quarks and antiquarks within the matrices themselves (**Figure 3f**).

Exotic reactions, including weak and strong annihilations are also naturally represented in our scheme. This is the case of (i) decay of weak interaction boson  $Z^0$  into three strong interaction gluons, (ii)  $J/\Psi$ -meson decay into two or three gluons, or (iii) muonium decay into a pair of neutrinos:

$$Z^0 \begin{pmatrix} 2a & 2a \\ 2a & 2a \\ 2a & 2a \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \rightarrow g_{g\bar{b}} \begin{pmatrix} a+1 & a \\ a-1 & a \\ a & a \end{pmatrix} + g_{b\bar{r}} \begin{pmatrix} a & a \\ a+1 & a \\ a-1 & a \end{pmatrix} + g_{r\bar{g}} \begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix},$$

$$J/\Psi: c \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} + \bar{c} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} \rightarrow g_{g\bar{b}} \begin{pmatrix} a+1 & a \\ a-1 & a \\ a & a \end{pmatrix} + g_{b\bar{g}} \begin{pmatrix} a-1 & a \\ a+1 & a \\ a & a \end{pmatrix},$$

$$J/\Psi: c \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} + \bar{c} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \rightarrow g_{g\bar{b}} \begin{pmatrix} a+1 & a \\ a-1 & a \\ a & a \end{pmatrix} + g_{b\bar{r}} \begin{pmatrix} a & a \\ a+1 & a \\ a-1 & a \end{pmatrix} + g_{r\bar{g}} \begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix},$$

$$\mu^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} \rightarrow \bar{\nu}_e \begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix} + \nu_e \begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}.$$

Exotic particles, such as the recently observed tetraquark [22] and pentaquarks [23], are also naturally represented (**Figure 3e**).

$$\begin{aligned}
\text{(a)} \quad & \mu^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \rightarrow e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_e \begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix} + \nu_\mu \begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix} & e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} \rightarrow \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} + \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \\
\text{(b)} \quad & \pi^+ : u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} + \bar{d} \begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix} \rightarrow \mu^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + \nu_\mu \begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix} & \pi^0 : u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} + \bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} \rightarrow \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} + \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \\
& \pi^- : d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + \bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} \rightarrow \mu^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_\mu \begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} & \pi^0 : d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + \bar{d} \begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix} \rightarrow \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} + \gamma \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \\
\text{(c)} \quad & d_g \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + d_b \begin{pmatrix} a-1 & a \\ a & a \\ a & a \end{pmatrix} + u_r \begin{pmatrix} a & a-1 \\ a & a-1 \\ a+1 & a-1 \end{pmatrix} \equiv \eta \begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix} & \text{(d)} \quad W^+ \begin{pmatrix} 2a+1 & 2a-1 \\ 2a+1 & 2a-1 \\ 2a+1 & 2a-1 \end{pmatrix} \rightarrow e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + \nu_e \begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix} \\
& d_g \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + u_b \begin{pmatrix} a & a-1 \\ a+1 & a-1 \\ a & a-1 \end{pmatrix} + u_r \begin{pmatrix} a & a-1 \\ a & a-1 \\ a+1 & a-1 \end{pmatrix} \equiv p^+ \begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix} & W^- \begin{pmatrix} 2a-1 & 2a+1 \\ 2a-1 & 2a+1 \\ 2a-1 & 2a+1 \end{pmatrix} \rightarrow e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_e \begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \\
& n \begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix} + \nu_e \begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix} \rightarrow p^+ \begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix} + e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} & Z^0 \begin{pmatrix} 2a & 2a \\ 2a & 2a \\ 2a & 2a \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \rightarrow g_{gg}^- \begin{pmatrix} a+1 & a \\ a-1 & a \\ a & a \end{pmatrix} + g_{br}^- \begin{pmatrix} a & a \\ a+1 & a \\ a-1 & a \end{pmatrix} + g_{rg}^- \begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix} \\
& n \begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \rightarrow p^+ \begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix} + e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_e \begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix} & Z^0 \begin{pmatrix} 2a & 2a \\ 2a & 2a \\ 2a & 2a \end{pmatrix} \rightarrow e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} \\
& p^+ \begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix} + 2\gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \rightarrow n \begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix} + e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + \nu_e \begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix} & u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} + 2\gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \rightarrow W^+ \begin{pmatrix} 2a+1 & 2a-1 \\ 2a+1 & 2a-1 \\ 2a+1 & 2a-1 \end{pmatrix} + d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} \\
\text{(e)} \quad & d \begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix} + s \begin{pmatrix} a-1 & a \\ a & a \\ a-1 & a \end{pmatrix} + d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + s \begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix} + \bar{u} \begin{pmatrix} a & a+1 \\ a & a+1 \\ a-1 & a+1 \end{pmatrix} \equiv \Xi^{--} \begin{pmatrix} 5a-3 & 5a+1 \\ 5a-3 & 5a+1 \\ 5a-3 & 5a+1 \end{pmatrix} & \text{(f)} \quad g_{rg}^- \begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix} + d_g \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} \rightarrow d_r \begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \\
& d \begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix} + u \begin{pmatrix} a & a-1 \\ a+1 & a-1 \\ a & a-1 \end{pmatrix} + d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} + \bar{c} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} \equiv \theta_c \begin{pmatrix} 5a-1 & 5a-1 \\ 5a-1 & 5a-1 \\ 5a-1 & 5a-1 \end{pmatrix} & g_{rg}^- \begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix} + u_g \begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix} \rightarrow u_r \begin{pmatrix} a & a-1 \\ a & a-1 \\ a+1 & a-1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix} \\
& c \begin{pmatrix} a & a-1 \\ a+1 & a-1 \\ a & a-1 \end{pmatrix} + \bar{c} \begin{pmatrix} a & a+1 \\ a-1 & a+1 \\ a & a+1 \end{pmatrix} + d \begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + \bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} \equiv Z^- \begin{pmatrix} 4a-1 & 4a+1 \\ 4a-1 & 4a+1 \\ 4a-1 & 4a+1 \end{pmatrix} & g_{rg}^- \begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix} + \bar{u}_r \begin{pmatrix} a & a+1 \\ a & a+1 \\ a-1 & a+1 \end{pmatrix} \rightarrow \bar{u}_g \begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}
\end{aligned}$$

**Figure 3.  $\Xi$ -matrix representation of subatomic reactions.** All leptons, gauge bosons, quarks, pions and nucleons appearing in the reactions are replaced by their  $\Xi$ -matrix, as defined in **Figure 2**,  $\gamma^*$  denoting a single concealed photon. It can be verified that the number of occurrences of every kind of sparks (at every matrix position) is conserved on both sides of the reactions. Our model does not merely account for conservation of electric and color charges, but also involves neutral colorless neutrinos and photons to balance the occurrences of sparks within reactions. Note that the presence of  $+b$  (respectively  $-b$ ) indicates that the particle is a lepton (resp. an antilepton), thus naturally reflecting the conservation of the leptonic quantum number. Weak interaction asymmetry naturally emerges from the reactions, as the presence of concealed photons is asymmetrical with respect to charge conjugation. Reactions that are shown here involve: **(a)** leptons, **(b)** pions, **(c)** nucleons, **(d)** weak interaction bosons, **(e)** observed pentaquarks and tetraquark, **(f)** gluons. Some exotic reactions, such as the decay of  $Z^0$  into three gluons, have been included.

## 5. Qualitative and quantitative predictions — Discussion

The remarkable thing about the model is that every particle can be represented by a unique  $\Xi$ -matrix that fits in all subatomic reactions. Our model does not merely account for the conservation of electric and color charges, but also involves neutral colorless neutrinos and photons to balance the occurrences of sparks within reactions. It is significant that all conservation laws observed in particle physics (*i.e.* baryon number, lepton number, muon lepton number, tau lepton number, strangeness, charm, bottomness, topness, isospin) [1] popped up naturally in our model (**Appendix C**). For instance, the presence of  $+b$  (respectively  $-b$ ) within a matrix indicates that the corresponding particle is a lepton (resp. an antilepton), thus reflecting the conservation of the leptonic quantum number. It is as if the electric charge, strong interaction color charge and leptonic quantum number were not merely conserved separately but entangled rather. This entanglement, present within the structure of  $\Xi$ -matrices themselves, is reminiscent of previous discoveries of physical properties, which historically led to the discovery of real particles, such as the atoms, photons, and quarks [24], and thus suggests that sparks could constitute real particles. The key point is that we didn't try to map the conservation laws, but rather attempted to define a compositeness model of subatomic particles that would ensure that sparks are conserved across reactions.  $\Xi$ -matrices possibly fit subatomic reactions because of the satisfaction of conservation laws and symmetries, but it might also be the other way round, *i.e.* the symmetries would arise because of the existence of sparks.

Notice that concealed photons only appear as products of reactions or in long-lifetime decays involving the weak interaction. Symmetry violations with respect to charge, parity and time associated to the weak interaction notoriously astonished Pauli, Feynman and other physicists at the time [25]. In agreement with these observations, weak interaction reactions are found to be asymmetric with respect to charge conjugation and parity in our model (**Appendix C**). Indeed, we find remarkable that only weak interaction reactions require one additional photon upon charge conjugation. Thus, symmetry violations could arise because of the additional concealed photon. Weak interaction reactions could be asymmetric with respect to (i) charge conjugation, because a concealed photon would exist in one case and not in the other, (ii) parity, because the additional photon would capture a spin value of 1, (iii) time reversal, possibly because a supplementary photon would need to be added to the reverse reaction. Interestingly, CP invariance fails for pion decay ( $\pi^0 \rightarrow \gamma \gamma$ ) in our model because of the additional concealed photon (**Appendix C**). It is unclear whether that additional photon could be related to time reversal, so that CPT invariance remains satisfied. Note that the predicted CP violation for pion decay is reminiscent of the observed CP violation in reactions involving neutral Kaons [24], which correspond to excited pions in our model. Another symmetry in the Standard Model is *crossing symmetry* [1], which refers to the fact that particles on one side of a reaction can be transformed into their corresponding antiparticles on the other side. Such transformed reactions are not complete in our model, as concealed photons are missing to balance the number of sparks (**Appendix C**). Hence, crossing symmetry is not verified in our scheme. Further investigations are needed to verify the consistency of the modified reactions with respect to intrinsic parity, spin, and helicity.

Interestingly, in our model, strong interaction colors appear as true charges rather than quantum states in the matrices, and anti-colors do not exist *per se*, but are constituted of the two other colors. This causes antiquarks to require more sparks than their corresponding quarks (**Figure 2**). Indeed, in our model, antiquarks possess four more sparks than quarks do, and charged antileptons are found to contain many more sparks than charged leptons (three times as much in particular case  $b = a/2$ ). This fundamental asymmetry between matter and antimatter is predicted by our model, and is compatible with its recent experimental observation [3]. Formation of matter and antimatter could thus be respectively selected and hindered with regard to their complexity in terms of their number of sparks, as particles made of a greater number of subparticles could be less likely to assemble, or more unstable. Hence, the fact that anti-colors are constituted by the two other colors could be the primordial asymmetry responsible for antimatter scarcity. To our knowledge, this proposition is novel and compatible with most conclusions presented in Ref. 4, specifically that antimatter scarcity is general to the entire universe, and that antimatter was more common in the early universe, which exhibited higher temperature. Notably, it does not require the existence of a force outside the Standard Model.

Even if the above qualitative predictions are important and original, quantitative predictions would certainly reinforce our model. Hence, we proceeded to create a relativistic electrodynamical model of the *electron* using sparks as building blocks [19]. The observables of the electron have long been measured with great precision, but their signification have remained unclear. Supposing natural interpretations of its observables (spin, Compton wavelength, classical and anomalous magnetic moments), we showed that our model could capture their values, exhibit cohesion and stability without invoking Poincaré stresses, and satisfy the Virial theorem. Specifically, the concept of sparks proved fruitful as electron mass and muon mass were derived directly from the stability of their substructure defined in terms of sparks. This prediction is important, as it implements Lorentz' hypothesis, which advocates the electromagnetic origin of mass, and as electron mass had not previously been derived from an objective criterion to our knowledge. This derivation constitutes a quantitative estimate of a detectable effect, viz. the electron mass, which is directly founded on the existence of the spark model under consideration. Thus, the act of postulating the existence of a subatomic chemical theory eventually led to the construction of a coherent electron model, which illustrated the possibility of creating causal and objectively realist models of particles beneath the Compton scale. As suggested in the discussion of Ref. 19, the very complexity of the electron model could be compatible with a causal, objective, local, fundamentally realist, albeit contextual and unpredictable, interpretation of quantum mechanics [26].

Furthermore, our theory can also provide novel interpretations to yet undecided issues in particle physics. For instance, why would the antimuon be so much more stable ( $\sim 6.6 \times 10^{12}$ ) in a muonium state ( $\mu^+ e^-$ ) than on its own [27]? According to our model [19], the electron would have its sparks dispersed over a region of radius  $\lambda_c$ , the reduced Compton wavelength. This is much bigger than that of the antimuon, whose expected radius is roughly  $\lambda_\mu$ , the reduced muonic Compton wavelength, according to the same model. Recalling that in the present chemical model, antimuon decay requires

the presence of an incoming photon (analogue of  $r7'$ ), it is plausible that the electron cloud (made of numerous sparks) shields the antimuon from incoming photons, thus preventing it from decaying.

Experiments could help verify the existence of a subatomic chemistry: for instance, a reduction in the mean lifetime of free neutrons and muons bombarded with photons of various energies would suggest that interacting photons are required for neutron and muon decay, in support of the existence of overlooked photons in the reactions ( $r4'$ ;  $r7'$ ), and of the existence of a subatomic chemistry indirectly. Indeed, this could be the phenomenon at the basis of the discrepancies (of the order of four standard deviations) observed in recent measurements of free neutron lifetime [18]. The fact that these observations, performed in various environments photon-wise, exhibited important discrepancies could well indicate that overlooked photons take part in the reaction.

## 6. Conclusions

In this study, we developed a chemical theory of subatomic particles based on two main hypotheses: the existence of concealed photons and the existence of sparks. In this framework, subatomic particles are constituted of instances of just six kinds of subparticles (the sparks), which are conserved across subatomic reactions, thus suggesting the existence of a second chemistry lying at the level of subatomic particles.

All conservation laws of particle physics are satisfied in our model, and charge conjugation and parity symmetry violations related to the weak interaction are also apparent. Our model provides new insight for these conservation laws and symmetry violations, even if several issues regarding the symmetries still need to be addressed. Importantly, our study introduces an additional conservation law, *i.e. the conservation of matter*, in the sense that the underlying subparticles are conserved and reorganized across subatomic reactions.

Our collection of just six kinds of subparticles allows to reconstruct all subatomic particles involved in phenomena of particle physics. Noteworthy, no consistent chemical theory could be created until we conjectured that colors were true charges rather than quantum states, or until we assumed that higher-generation particles were excited states of the original particles. These are still undecided questions in particle physics, and the fact that our constrained model requires their satisfaction could suggest their validity. Our model has far reaching implications in physics, as it also suggests that (i) heavy particles can be created from radiation by rearranging sparks, (ii) overlooked photons are involved in alternative decay modes, (iii) weak interaction asymmetry is related to concealed photons, and (iv) antimatter scarcity could stem from the complexity of antimatter particles. Notably, sparks could prove to be a fruitful hypothesis as they enabled the creation of a causal and objectively realist electron model, whose mass is predicted from the stability of its substructure [19].

Our model could be seen as a possible interpretation of the Standard Model in terms of sparks. Although sparks might possess absolute charges smaller than  $(\pm e/6)$  and other chemical models be constructed from different hypotheses — even though we could not develop any other successful model, and had difficulties making the present model become consistent —, the accuracy with which

$\Xi$ -matrices fit subatomic decays and annihilations could allegedly reflect the existence of a *subatomic chemistry*, revealing the underlying unity of all particles.

### Appendix A. Intuitive argument hinting at the electric charges of sparks

Ordinary matter is made of quarks, not antiquarks, that take on two discrete values of electric charge:  $+2e/3$  and  $-e/3$ . Interestingly, considering charges  $+e/2$ ,  $-e/2$  and  $+e/6$  may form such values:  $e/2+e/6 = +2e/3$  and  $-e/2+e/6 = -e/3$ . Antiquarks, on the other hand, seem to involve only  $(-e/6)$  charges:  $e/2-e/6 = +e/3$  and  $-e/2-e/6 = -2e/3$ . Thus, rather intuitively, we chose to define elementary subparticles bearing electric charges  $+e/6$  and  $-e/6$  and a definite strong interaction color charge *green*, *blue* or *red*. This makes up  $2 \times 3$  elementary subparticles, which we chose to call *Sparks* and denote  $\xi$ .

### Appendix B. Constraints on the number of sparks

Letting  $N_{particle(s)}$  denote the number of sparks composing the considered particles, we assume:

$$\begin{cases} N_{lepton} \equiv N_{e^-} = N_{\mu^-} = N_{\tau^-} \\ N_{neutrino} \equiv N_{\nu_e} = N_{\nu_\mu} = N_{\nu_\tau} \\ N_{antilepton} \equiv N_{e^+} = N_{\mu^+} = N_{\tau^+} \\ N_{antineutrino} \equiv N_{\bar{\nu}_e} = N_{\bar{\nu}_\mu} = N_{\bar{\nu}_\tau} \end{cases} \quad (e1)$$

Let us now consider the number of sparks in muon decay:

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu. \quad (r7)$$

Reaction (r7) obviously cannot be satisfied, since  $N_{e^-} = N_{\mu^-}$  (e1), if we exclude the solution  $N_{neutrino} = N_{antineutrino} = 0$ . We thus conjecture that the muon must either already bear a concealed photon or encounter a new photon:

$$\mu^- + \gamma^* \rightarrow e^- + \bar{\nu}_e + \nu_\mu, \quad (r7')$$

thus yielding:

$$N_{photon} = N_{neutrino} + N_{antineutrino}. \quad (e4)$$

Moreover, since  $N_u = N_d$  (e2) and thus  $N_{proton} = N_{neutron}$ , reactions involving neutrons and neutrinos:

$$n + \nu_\mu \rightarrow p^+ + \mu^-, \quad (r11)$$

$$n + \nu_e \rightarrow p^+ + e^-, \quad (r12)$$

imply:

$$N_{lepton} = N_{neutrino}. \quad (e5)$$

Now, we also have:

$$e^- + e^+ \rightarrow 2\gamma, \quad (r1)$$

$$(e^- + \gamma^*) + e^+ \rightarrow 3\gamma, \quad (r2')$$

$$(Atom + \gamma^*) + \gamma \rightarrow Atom + e^- + e^+, \quad (r3')$$

implying:

$$2N_{\text{photon}} = N_{\text{lepton}} + N_{\text{antilepton}}. \quad (\text{e6})$$

Taken together, equations (e4-e6) constitute the system of equations (e3) and also yield:

$$N_{\text{antilepton}} = N_{\text{photon}} + N_{\text{antineutrino}}, \quad (\text{e7})$$

$$N_{\text{photon}} = N_{\text{lepton}} + N_{\text{antineutrino}}. \quad (\text{e8})$$

Rearranging equation (e6) using (e5) gives:

$$2N_{\text{photon}} = N_{\text{antilepton}} + N_{\text{neutrino}}. \quad (\text{e9})$$

We may notice the asymmetry between particles and antiparticles by comparing equations (e8) and (e9). This can be illustrated by considering reactions involving pions:

$$\pi^0 \rightarrow 2\gamma, \quad (\text{r8})$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu, \quad (\text{r9})$$

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu. \quad (\text{r10})$$

Since the  $\pi^0$ , constituted of a quark and an antiquark, decays into two photons (r8), we have:

$$N_{\text{quark}} + N_{\text{antiquark}} = 2N_{\text{photon}}, \quad (\text{e10})$$

and the left-hand side of reaction (r10) must thus possess a number of sparks:  $N_{\pi^-} = N_{\text{quark}} + N_{\text{antiquark}} = 2N_{\text{photon}}$ , while its right-hand side, according to (e8), possesses a number of sparks of  $N_{\text{photon}}$ . Reaction (r10) should thus be corrected to:

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu + \gamma^*, \quad (\text{r10}')$$

while reaction (r9) needs not be modified, since the number of sparks on either side of the reaction amounts to  $2N_{\text{photon}}$ , from (e9) and (e10). Reaction (r10') predicts that, in our model, the negative pion produces a muon already carrying a concealed photon.

Likewise, reaction (r6) has been corrected to (r6'), by considering the number of sparks on both sides of the reaction.

### Appendix C. Conservation laws and symmetries

Conservation of energy, momentum, angular momentum and charge are always verified in physics, and related to symmetries inherent to space and time through Noether's theorem [1]. Other conserved properties are specific to the world of particles and constitute the conservation laws of the Standard Model. These include the conservations of baryon number, lepton number, muon lepton number, tau lepton number, strangeness, charm, bottomness, topness, and isospin [1]. The Standard Model further exhibits specific symmetries and symmetry violations. Contrary to all other interactions, the weak interaction is asymmetric with respect to parity (P), time reversal (T) and charge conjugation (C), while remaining invariant under mutual CPT transformation. Does our model correctly account for these observed conservation laws and symmetries?



Let us first consider the conservation of baryon number. Recalling that baryons are colorless particles constituted of three quarks and noticing that in our model  $\Xi$ -matrices for quarks are composed of one supplementary spark that defines their color (**Figure 2**), it can be seen from **Figure 3** that quarks must either be assembled in triples or bound to a single antiquark (which exhibits two supplementary sparks) in order to form colorless particles. Thus, baryons can take part in reactions in three different ways in our model:

$$q_g q_b q_r + X \rightarrow q_g q_b q_r + X, \quad (C1)$$

$$\bar{q}_g \bar{q}_b \bar{q}_r + X \rightarrow \bar{q}_g \bar{q}_b \bar{q}_r + X, \quad (C2)$$

$$q_g q_b q_r + \bar{q}_g \bar{q}_b \bar{q}_r + X \leftrightarrow q_g \bar{q}_g + q_b \bar{q}_b + q_r \bar{q}_r + X, \quad (C3)$$

where  $X$  stands for particles other than baryons. In (C1), the baryon number is positive and conserved. In (C2), the baryon number is negative and conserved. In (C3), the net baryon number on the left-hand side is zero because their sum cancels, while there are no baryons on the right-hand side. Hence, in either case, the baryon number is conserved in our model.

Similarly, as has already been noted, leptons involve a term  $(+b)$  in the  $\Xi$ -matrices of our model, and antileptons a term  $(-b)$ . The terms  $(+b)$  and  $(-b)$  are always found in equal numbers on both sides of the reactions, so that the net lepton number is conserved across reactions in our model.

In our electron model [19], the muon was regarded as a tiny electron, exhibiting the same exact structure, only at a much smaller scale. This is in agreement with Dirac's assumption that the muon could be an excited state of the electron [20]. It is therefore conceivable that the scale of the envelope and nucleus defines the excitation state. Those scales could be conserved across subatomic reactions, providing a possible explanation for the existence of reactions such as:

$$\mu^- + \nu_e \rightarrow e^- + \nu_\mu,$$

where the charges are redistributed among the various excitation states of the particles involved. Thus, the conservation of the muonic lepton number could be interpreted in our model as the conservation of a leptonic excitation state. This is also true of the conservation of the tauic lepton number, which would be regarded as yet another possible excitation state of the electron or muon. Quarks come in three flavors just as leptons do, and their flavors could also be interpreted as different quark excitation states. Thus, strangeness conservation for instance could be regarded as the quark analogue of the muonic lepton number conservation. It would in effect correspond to the scale of the quark nucleus and envelope, and would presumably also be conserved across reactions. The same is true of the other internal quantum numbers related to flavors, *i.e.* charm, bottomness and topness. Finally, isospin is a property of subatomic particles that can be defined by the Gell Mann-Nishijima relation:  $I_3 = Q/e - (S+B)/2$ , where  $I_3$  is isospin projection,  $B$  the baryon number,  $S$  the strangeness,  $Q$  the charge of the considered particle and  $e$  the elementary charge. As the quantum numbers on the right-hand side of this relation are all conserved across subatomic reactions according to the previous conservation laws, isospin is naturally conserved too.

Recall further that all internal quantum numbers (Baryon number, lepton number, muon lepton number, tau lepton number, strangeness, charm, bottomness, topness, isospin) of antiparticles

are opposite to those of the particles, while mass, energy, momentum, or spin remain unaffected. Noteworthy, upon charge conjugation, some inversions can be observed within the matrices themselves: quark matrices are changed into antiquark matrices, reversing baryons and the net baryon number; ( $b$ )'s also turn to  $(-b)$ 's, reversing the net lepton number.

Thus, our model verifies the known conservation laws of the Standard Model. But it also goes one step further, as it proposes a new conservation law, viz. the conservation of matter, defined as the conservation of the kinds and numbers of the subparticles composing all particles across subatomic reactions.

The Standard Model also exhibits some remarkable symmetry violations. Are these also observed here? We already noted that, in our model, subatomic reactions involved one additional photon under charge conjugation, *e.g.* between (r9) and (r10'). Let us see how these symmetry violations apply to our model. Consider reaction (r7'):

$$\mu^- + \gamma^* \rightarrow e^- + \bar{\nu}_e + \nu_\mu,$$

and see how it develops upon charge conjugation and parity:

$$\mu^+ + \gamma^* \rightarrow e^+ + \nu_e + \bar{\nu}_\mu,$$

The mutual CP transformation (charge + parity transformations) is also verified at the level of  $\Xi$ -matrices, since:

$$\mu^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \end{pmatrix} \rightarrow e^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_e \begin{pmatrix} a-b & a-b \\ a-b & a-b \end{pmatrix} + \nu_\mu \begin{pmatrix} b & b \\ b & b \end{pmatrix}.$$

becomes:

$$\mu^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \end{pmatrix} \rightarrow e^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + \nu_e \begin{pmatrix} b & b \\ b & b \end{pmatrix} + \bar{\nu}_\mu \begin{pmatrix} a-b & a-b \\ a-b & a-b \end{pmatrix}.$$

Hence, reaction (r7') is symmetric upon CP transformation. Let us now consider reaction (r9):

$$\pi^+: u \begin{pmatrix} a+1 & a-1 \\ a & a-1 \end{pmatrix} + \bar{d} \begin{pmatrix} a & a \\ a+1 & a \end{pmatrix} \rightarrow \mu^+ \begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix} + \nu_\mu \begin{pmatrix} b & b \\ b & b \end{pmatrix},$$

which upon CP transformation turns into:

$$\pi^-: d \begin{pmatrix} a & a \\ a-1 & a \end{pmatrix} + \bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \end{pmatrix} \rightarrow \mu^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_\mu \begin{pmatrix} a-b & a-b \\ a-b & a-b \end{pmatrix},$$

instead of the expected:

$$\pi^-: d \begin{pmatrix} a & a \\ a-1 & a \end{pmatrix} + \bar{u} \begin{pmatrix} a-1 & a+1 \\ a & a+1 \end{pmatrix} \rightarrow \mu^- \begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \end{pmatrix} + \bar{\nu}_\mu \begin{pmatrix} a-b & a-b \\ a-b & a-b \end{pmatrix} + \gamma^* \begin{pmatrix} a & a \\ a & a \end{pmatrix}.$$

Hence, CP invariance fails for pion decay in our model, as (r10') includes an additional concealed photon. Another transformation is still required to account for that supplementary photon. It is unclear whether this transformation could be related to time reversal, so that CPT invariance remains satisfied. Note that the predicted CP violation for pion decay is reminiscent of the observed CP violation in reactions involving neutral Kaons, which would correspond to excited pions in our model.

Yet another symmetry in the Standard Model is *crossing symmetry* [1], which refers to the fact that particles on one side of a reaction can be transformed into their corresponding antiparticles on the other side, as in e.g.

$$n \rightarrow p^+ + e^- + \bar{\nu}_e,$$

with crossing symmetries:

$$n + \nu_e \rightarrow p^+ + e^-,$$

$$n + e^+ \rightarrow p^+ + \bar{\nu}_e.$$

However, the first reaction is not complete in our model, as the concealed photon is missing. Hence, crossing symmetry is not verified in our scheme.

### Author Contributions

SA conceived the study, formed the hypotheses, and constructed the model. PR reorganized ideas. PR helped SA write the manuscript.

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### Conflicts of Interest

The authors declare no conflict of interest.

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