Annihilation-free 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 hypothesise that photons, rather than being absorbed, are captured by particles, conserving their integrity while remaining undetected. Therefrom, an annihilation-free chemical model of leptons, hadrons and gauge bosons is conjectured by introducing concealed photons. Our model conserves and reorganises *indestructible* coloured subparticles across subatomic reactions. 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.
Composite models; Beyond Standard Model; Weak interaction asymmetry; Matter-antimatter asymmetry; Subatomic chemistry.

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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 (SM) [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 π^0, π^+, π^-, made of one quark and one antiquark, are hadrons by definition, yet naturally decay into leptons or gauge bosons, as in $\pi^+ \to \mu^+ + \nu_\mu$ or $\pi^0 \to 2\gamma$, where μ^+, ν_μ and γ 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 $W^+ \to \mu^+ + \nu_\mu$ or $Z^0 \to 3g$. 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 rules, such as the conservation of leptonic or baryonic quantum numbers.

Leptons and hadrons can be further categorised 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 may therefore require the development of an entirely new physics beyond the Standard Model [5].

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 [6] 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 [7-15] have been built. More recently, the substructure of subatomic particles has been compared to that of molecules [14] (even if the model still relied on annihilation ultimately), and $e/6$ charges [15] and *indestructible subparticles* [16] have been envisaged. To validate and possibly decide among these models, additional constraints are needed.

Now, what could be the reason for the decay of particles into other particle kinds (leptons, hadrons, gauge bosons)? Why would all particles involve e and $\hbar$? And why would they all satisfy conservation laws and symmetries of the Standard Model? These observations are actually remarkable, and particle physics should account for them by somehow unifying all leptons, hadrons and gauge bosons. Following the principle of parsimony, one economical way to unify all particles is to presuppose the existence of some underlying subparticles common to all subatomic particles. For instance, since some particles annihilate into photons or are created from photons alone, photons could possibly be composed of the same subparticles that form leptons and hadrons. Thus, the prospect that a compositeness model could satisfy an annihilation-free subatomic chemical scheme conserving *indestructible* subparticles across reactions [16], following the assertion 'nothing is lost, nothing is created, everything is transformed', would constitute an elegant solution to the aforementioned questions. Hence, would it be it possible to conjecture for every subatomic particle a unique composition of subparticles that would fit all subatomic reactions, so that these subparticles would be conserved and reorganised across all subatomic reactions? And at which conditions would such an annihilation-free chemical theory be possible? And what would be its properties?

In this speculative study, we question the possible existence of an annihilation-free chemistry lying at the level of subatomic particles. We propose a chemical model 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 next show that the introduction of concealed photons allows 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 reorganised across reactions. The conservation laws observed in particle physics are satisfied in our model, and its 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 worldview 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 (of note, theories that cannot be hypothetically constructed but are empirically discovered instead, such as the Periodic Table, were highly regarded and called 'principle theories' by Einstein [17]). We feel our theory should be appraised for its own merits with regard to agreement with observed phenomena, mathematical coherence, elegance, and its original qualitative and quantitative predictions, rather than assessed with respect to criteria specific to Quantum Field Theory (QFT) [18]. 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. The relation to QFT is considered in the Discussion.

Taken together, the compositeness model and subatomic reactions constitute a coherent chemical model of subatomic particles and provide natural interpretations of many physical phenomena. In our model, strong interaction colours are true charges rather than quantum states, and particles of higher generations correspond to excited states. Therein also, heavy particles can be created from radiation. Strikingly, while the weak interaction asymmetry was not introduced from the start, clues hinting at this asymmetry (emergence of the leptonic quantum number, composition of neutrinos, the asymmetry under charge conjugation) naturally emerged from the requirement that Sparks be conserved across subatomic reactions. In agreement with a recent observation [3], a fundamental asymmetry is also predicted between antimatter and matter: antimatter particles are found to be more complex than their corresponding matter particles, suggesting a possible explanation for antimatter scarcity (see the Discussion). Altogether, our theory unifies all subatomic particles into a single chemical scheme, possibly 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 $\overline{\nu}_e$ or absorb an electronic neutrino ν_e. Taken together, the observed transformations:

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

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

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

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

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

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 hypothesise 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 [19] that often involve additional photons or particles like π^0 or $\overline{\nu}\nu$, which presumably amount to whole photons. The boson Z^0 for example decays [19] into e^-e^+ with probability p = 3.363 (±0.004) %, but alternatively into $e^-e^+\gamma$ ($p < 5\times10^{-4}$) or $e^-e^+\gamma\gamma$ ($p < 7\times10^{-6}$), suggesting Z^0 might occasionally carry photons. Denoting γ^* the concealed photon, reactions (r2-r4) could be modified to:

$$(e^- + \gamma^*) + e^+ \rightarrow 3\gamma, \tag{r2'}$$

$$(Atom + \gamma^*) + \gamma \rightarrow Atom + e^- + e^+, \tag{r3'}$$

$$n + \gamma^* \rightarrow p^+ + e^- + \overline{\nu}_e, \tag{r4'}$$

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 observation that highly energetic particles are capable of producing heavy particles [20]. 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 [21] could well indicate that overlooked photons take part in the reaction (see the Discussion).

3. Introduction of coloured subparticles

Herein is conjectured the existence of six kinds of subparticles that we call *sparks* and denote ξ, possessing electric charge $\pm e/6$ (see Appendix A) and a true specific colour charge: *green*, *blue* or *red* — not merely a quantum state (*existence of sparks hypothesis*). Although leptons and some bosons are colourless, their constituents could possess strong interaction colour charges to account for the presence of colour within quarks, provided their colour charges cancel. Neutrons for instance are made of charged particles (quarks) but remain electrically neutral overall because their electric charges cancel. Similarly, strong interaction colour 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 colourless triples. Hence, the aforementioned colourless 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 [22].

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

$$p^+ \to n + e^+ + \nu_e, \tag{r6}$$

$$\mu^- \to e^- + \overline{\nu}_e + \nu_\mu, \tag{r7}$$

$$\pi^0 \to 2\gamma, \tag{r8}$$

$$\pi^+ \to \mu^+ + \nu_\mu, \tag{r9}$$

$$\pi^- \to \mu^- + \overline{\nu}_\mu, \tag{r10}$$

where μ^- is the muon and $\overline{\nu}_\mu$ 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:

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

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. [23]) is corroborated by the fact for instance that the muonic Compton wavelength is much smaller than that of the electron. Noteworthy, it is compatible with the observation that neutrinos oscillate between different generations (electronic, muonic, tauic neutrinos) [24]. 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 $e^-\,\overline{\nu}_e$, $\mu^-\,\overline{\nu}_\mu$, $\tau^-\,\overline{\nu}_\tau$ and e^-e^+, $\mu^-\mu^+$, $\tau^-\tau^+$) with equal probabilities [19]. 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:

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

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

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

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

$$p^+ + 2\gamma^* \rightarrow n + e^+ + \nu_e, \tag{r6'}$$

$$\mu^- + \gamma^* \rightarrow e^- + \overline{\nu}_e + \nu_\mu, \tag{r7'}$$

$$\pi^- \rightarrow (\mu^- + \gamma^*) + \overline{\nu}_\mu, \tag{r10'}$$

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 (~2.2×10^{-6}s). Similarly, β^+ 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'), (r4') with (r5), 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 was not introduced from the start, but rather 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 Ξ, displaying the number of instances n_ξ of every kind of sparks $\xi_{\text{colour}}{}^{\text{charge}}$. This arrangement allows reading the colour 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).

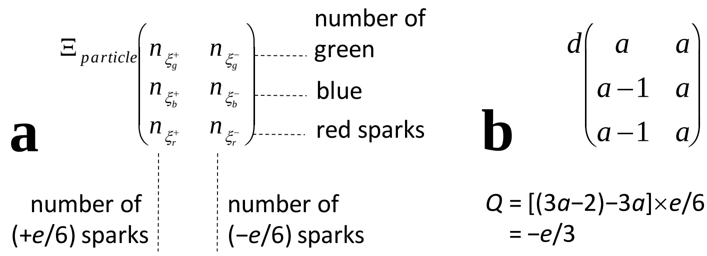

Figure 1. Ξ–matrix representation. a. Particles are represented by Ξ–matrices displaying the number of instances of every kind of sparks ξ. The rows indicate their number of green, blue and red sparks. The first (respectively second) column indicates their number of $+e/6$ (respectively $-e/6$) sparks. 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 colour is determined by identifying the row(s) with the most sparks, while electric charge can be read from the Ξ–matrix by summing first column, subtracting second column, and multiplying by $e/6$. **b**. The Ξ–matrix representing quark d_{green} for instance exhibits green colour charge and electric charge $Q = [a + (a–1) + (a–1) – 3a] \times e/6 = –e/3$.

As the photon is a neutral colourless particle, it must be composed of an equal number of all kinds of sparks. Setting $a = N_{photon}/6$ and $b = N_{lepton}/6$ 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), Ξ-matrices for these particles may be written:

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

so that they exhibit colourlessness and appropriate electric charges. Note that Ξ-matrices are subject to very strong constraints, since a Ξ-matrix used for representing a particular particle has to fit in every subatomic reaction involving it. Using Ξ-matrices, reaction (r1) would be represented as:

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

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 reorganised across the reaction. Pair production [20] also appears to be possible in our framework, since writing the reaction the other way round still satisfies the conservation of sparks. Now, reaction (r7') becomes:

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

It is apparent here that neutral colourless neutrinos and additional concealed photons are needed to balance the kinds and numbers of sparks on both sides of the reactions. 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. 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. Accordingly, weak interaction asymmetry is apparent within Ξ-matrices expressing the composition of neutrinos and antineutrinos.

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

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

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

One may notice that, in our representation, antimatter particles 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 a prediction of our model, and is compatible with the recent observation of a non-zero mass difference between matter and antimatter [3].

Interaction	Matter particles	Antimatter particles	Bosons
Electroweak	$\begin{matrix} e^- \\ \mu^- \\ \tau^- \end{matrix}\begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix}$ $\begin{matrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{matrix}\begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix}$	$\begin{matrix} e^+ \\ \mu^+ \\ \tau^+ \end{matrix}\begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix}$ $\begin{matrix} \bar{\nu}_e \\ \bar{\nu}_\mu \\ \bar{\nu}_\tau \end{matrix}\begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix}$	$W^\pm\begin{pmatrix} 2a\pm1 & 2a\mp1 \\ 2a\pm1 & 2a\mp1 \\ 2a\pm1 & 2a\mp1 \end{pmatrix}$ $Z^0\begin{pmatrix} 2a & 2a \\ 2a & 2a \\ 2a & 2a \end{pmatrix}$ $\gamma\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$
Strong	$\begin{matrix} u \\ c \\ t \end{matrix}\begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix}$ $\begin{matrix} d \\ s \\ b \end{matrix}\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}$	$\begin{matrix} \bar{u} \\ \bar{c} \\ \bar{t} \end{matrix}\begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix}$ $\begin{matrix} \bar{d} \\ \bar{s} \\ \bar{b} \end{matrix}\begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix}$	$g_{g\bar{b}}\begin{pmatrix} a+1 & a \\ a-1 & a \\ a & a \end{pmatrix}$

Figure 2. Ξ–matrix representation of fundamental particles. Ξ–matrices enumerate the constituents of their corresponding particles, but do not account for their internal structure or other properties. The three gluons $g_{r\bar{r}}$, $g_{b\bar{b}}$, $g_{g\bar{g}}$ and photon for instance are different particles, even though they share the same Ξ–matrix. Strongly interacting particles with other colours or anticolours are obtained by rearranging the rows of their corresponding Ξ–matrices. Note that Ξ-matrices are subject to very strong constraints, since a Ξ-matrix used for representing a particular particle has to fit in every subatomic reaction involving it. Particles of different generations share the same Ξ–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, thus naturally suggesting why antimatter could be scarce in the universe.

The proposed Ξ-matrices for quarks and antiquarks can represent the corresponding subatomic reactions. For instance, Ξ-matrices for quarks and antiquarks satisfy π^0 decays (r8):

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

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

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

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

$$\pi^-:\ d\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix} + \bar{u}\begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix}$$

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

Recalling baryons are constituted of three quarks of three different colours, matrices for the *neutron* and *proton* can be obtained:

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

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

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

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

$$n\begin{pmatrix}3a-1 & 3a-1\\ 3a-1 & 3a-1\\ 3a-1 & 3a-1\end{pmatrix}+\gamma^*\begin{pmatrix}a & a\\ a & a\\ a & a\end{pmatrix}$$

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

$$p^+\begin{pmatrix}3a & 3a-2\\ 3a & 3a-2\\ 3a & 3a-2\end{pmatrix}+2\gamma^*\begin{pmatrix}a & a\\ a & a\\ a & a\end{pmatrix}$$

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

Ξ-matrices remarkably fit all reactions involving nucleons. Many such subatomic reactions are displayed in Figure 3. Ξ-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, Ξ-matrices representing gluons induce colour transformations to all quarks and antiquarks within the matrices themselves (Figure 3e). 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/Ψ-meson decay into two or three gluons, (iii) muonium decay into a pair of neutrinos:

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

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

$$J/\Psi:\ c\begin{pmatrix}a+1 & a-1\\ a & a-1\\ a & a-1\end{pmatrix}+\bar{c}\begin{pmatrix}a-1 & a+1\\ a & a+1\\ a & a+1\end{pmatrix}+\gamma^*\begin{pmatrix}a & a\\ a & a\\ a & a\end{pmatrix}$$

$$\longrightarrow g_{g\bar{b}}\begin{pmatrix}a+1 & a\\ a-1 & a\\ a & a\end{pmatrix}+g_{b\bar{r}}\begin{pmatrix}a & a\\ a+1 & a\\ a-1 & a\end{pmatrix}+g_{r\bar{g}}\begin{pmatrix}a-1 & a\\ a & a\\ a+1 & a\end{pmatrix},$$

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

$$\longrightarrow \bar{\nu}_e\begin{pmatrix}a-b & a-b\\ a-b & a-b\\ a-b & a-b\end{pmatrix}+\nu_e\begin{pmatrix}b & b\\ b & b\\ b & b\end{pmatrix}+\gamma^*\begin{pmatrix}a & a\\ a & a\\ a & a\end{pmatrix}.$$

Exotic particles, such as the recently observed tetraquark [25] and pentaquarks [26], are also naturally represented (Figure 3f).

(a)

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

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

(b)

$$\pi^0: u\begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix}+\bar{u}\begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix}\to\gamma\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}+\gamma\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$$

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

$$\pi^0: d\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}+\bar{d}\begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix}\to\gamma\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}+\gamma\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$$

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

(c)

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

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

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

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

$$n\begin{pmatrix} 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \\ 3a-1 & 3a-1 \end{pmatrix}+\nu_\mu\begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix}\to p^+\begin{pmatrix} 3a & 3a-2 \\ 3a & 3a-2 \\ 3a & 3a-2 \end{pmatrix}+\mu^-\begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix}$$

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

(d)

$$W^+\begin{pmatrix} 2a+1 & 2a-1 \\ 2a+1 & 2a-1 \\ 2a+1 & 2a-1 \end{pmatrix}\to e^+\begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix}+\nu_e\begin{pmatrix} b & b \\ b & b \\ b & b \end{pmatrix}$$

$$Z^0\begin{pmatrix} 2a & 2a \\ 2a & 2a \\ 2a & 2a \end{pmatrix}\to e^-\begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix}+e^+\begin{pmatrix} 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \\ 2a-b+1 & 2a-b-1 \end{pmatrix}$$

$$W^-\begin{pmatrix} 2a-1 & 2a+1 \\ 2a-1 & 2a+1 \\ 2a-1 & 2a+1 \end{pmatrix}\to e^-\begin{pmatrix} b-1 & b+1 \\ b-1 & b+1 \\ b-1 & b+1 \end{pmatrix}+\bar{\nu}_e\begin{pmatrix} a-b & a-b \\ a-b & a-b \\ a-b & a-b \end{pmatrix}+\gamma^*\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$$

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

$$u\begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix}+2\gamma^*\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}\to W^+\begin{pmatrix} 2a+1 & 2a-1 \\ 2a+1 & 2a-1 \\ 2a+1 & 2a-1 \end{pmatrix}+d\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}$$

$$\bar{u}\begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix}+2\gamma^*\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}\to W^-\begin{pmatrix} 2a-1 & 2a+1 \\ 2a-1 & 2a+1 \\ 2a-1 & 2a+1 \end{pmatrix}+\bar{d}\begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix}$$

(e)

$$g_{r\bar{g}}\begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix}+d_g\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}\to d_r\begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix}+\gamma^*\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$$

$$g_{r\bar{g}}\begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix}+\bar{u}_{\bar{r}}\begin{pmatrix} a & a+1 \\ a & a+1 \\ a-1 & a+1 \end{pmatrix}\to\bar{u}_{\bar{g}}\begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix}+\gamma^*\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$$

$$g_{r\bar{g}}\begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix}+u_g\begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix}\to u_r\begin{pmatrix} a & a-1 \\ a & a-1 \\ a+1 & a-1 \end{pmatrix}+\gamma^*\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$$

$$g_{r\bar{g}}\begin{pmatrix} a-1 & a \\ a & a \\ a+1 & a \end{pmatrix}+\bar{d}_{\bar{r}}\begin{pmatrix} a+1 & a \\ a+1 & a \\ a & a \end{pmatrix}\to\bar{d}_{\bar{g}}\begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix}+\gamma^*\begin{pmatrix} a & a \\ a & a \\ a & a \end{pmatrix}$$

(f)

$$d\begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix}+s\begin{pmatrix} a-1 & a \\ a & a \\ a-1 & a \end{pmatrix}+d\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}+s\begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix}+\bar{u}\begin{pmatrix} a & a+1 \\ a & a+1 \\ a-1 & a+1 \end{pmatrix}\equiv\Xi^{--}\begin{pmatrix} 5a-3 & 5a+1 \\ 5a-3 & 5a+1 \\ 5a-3 & 5a+1 \end{pmatrix}$$

$$d\begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix}+u\begin{pmatrix} a & a-1 \\ a+1 & a-1 \\ a & a-1 \end{pmatrix}+d\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}+u\begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix}+\bar{c}\begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix}\equiv\theta_C\begin{pmatrix} 5a-1 & 5a-1 \\ 5a-1 & 5a-1 \\ 5a-1 & 5a-1 \end{pmatrix}$$

$$u\begin{pmatrix} a+1 & a-1 \\ a & a-1 \\ a & a-1 \end{pmatrix}+u\begin{pmatrix} a & a-1 \\ a+1 & a-1 \\ a & a-1 \end{pmatrix}+d\begin{pmatrix} a-1 & a \\ a-1 & a \\ a & a \end{pmatrix}+d\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}+\bar{d}\begin{pmatrix} a & a \\ a+1 & a \\ a+1 & a \end{pmatrix}\equiv N^+\begin{pmatrix} 5a & 5a-2 \\ 5a & 5a-2 \\ 5a & 5a-2 \end{pmatrix}$$

$$c\begin{pmatrix} a & a-1 \\ a+1 & a-1 \\ a & a-1 \end{pmatrix}+\bar{c}\begin{pmatrix} a & a+1 \\ a-1 & a+1 \\ a & a+1 \end{pmatrix}+d\begin{pmatrix} a & a \\ a-1 & a \\ a-1 & a \end{pmatrix}+\bar{u}\begin{pmatrix} a-1 & a+1 \\ a & a+1 \\ a & a+1 \end{pmatrix}\equiv Z^-\begin{pmatrix} 4a-1 & 4a+1 \\ 4a-1 & 4a+1 \\ 4a-1 & 4a+1 \end{pmatrix}$$

Figure 3. Ξ–matrix representation of subatomic reactions. All leptons, gauge bosons, quarks, pions and nucleons appearing in the reactions are replaced by their Ξ–matrix, as defined in Figure 2, γ^* 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 colour charges, but also involves neutral colourless 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. Reactions that are shown here involve: **(a)** leptons, **(b)** pions, **(c)** nucleons, **(d)** weak interaction bosons, **(e)** gluons, **(f)** observed pentaquarks and tetraquark. Some exotic reactions, such as the decay of Z^0 into three gluons, have been included.

5. 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. Other conserved properties are specific to the world of particles and constitute the conservation laws of the Standard Model [1]. These include the conservations of baryon number, lepton number, muon lepton number, tau lepton number, strangeness, charm, bottomness, topness, and isospin. The Standard Model further exhibits specific symmetries and symmetry violations. Contrary to all other interactions, 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 colourless particles constituted of three quarks and noticing that in our model Ξ-matrices for quarks are composed of one supplementary spark that defines their colour (Figure 2), it can be seen from Figure 3 that quarks must either be assembled in triples or bound to a single antiquark (which contains two supplementary sparks) in order to form colourless particles. Thus, baryons can take part in reactions in three different ways in our model:

$$q_g q_b q_r + X \longrightarrow q_g q_b q_r + X, \tag{C1}$$

$$\bar{q}_{\bar{g}} \bar{q}_{\bar{b}} \bar{q}_{\bar{r}} + X \longrightarrow \bar{q}_{\bar{g}} \bar{q}_{\bar{b}} \bar{q}_{\bar{r}} + X, \tag{C2}$$

$$q_g q_b q_r + \bar{q}_{\bar{g}} \bar{q}_{\bar{b}} \bar{q}_{\bar{r}} + X \leftrightarrow q_g \bar{q}_{\bar{g}} + q_b \bar{q}_{\bar{b}} + q_r \bar{q}_{\bar{r}} + X, \tag{C3}$$

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 Ξ-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 [22], 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 [23]. It is 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.

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 sparks, defined as the conservation of the kinds and numbers of 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’):

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

and see how it develops upon charge conjugation and parity:

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

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

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

then becomes:

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

Hence, reaction (r7’) is symmetric upon CP transformation. Let us now consider reaction (*r*9):

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

which upon CP transformation turns into:

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

instead of the expected:

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

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. Hence our theory predicts CP violation for pion decay, which could be tested with increased precision. 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.*

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

with crossing symmetries:

$$n + \nu_e \to p^+ + e^-,$$
$$n + e^+ \to p^+ + \bar{\nu}_e.$$

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.

6. A quantitative prediction: the determination of electron mass

Even if the previous qualitative predictions are important and original, some quantitative predictions would certainly reinforce our faith in the model. Hence, we proceeded to create a relativistic electrodynamical model of the electron using sparks as building blocks [22]. Here, we present only a succinct description of the model, as a detailed mathematical demonstration is provided in Ref. 22.

Schrödinger noticed within the Dirac equation itself a rapid oscillatory trembling motion, the Zitterbewegung (zbw), exhibiting microcurrents arising at light velocity c. Surprisingly, the electron seemed to follow a helical trajectory of radius $\lambda\!\!\!^{-}_c$, the reduced Compton wavelength, surrounding the average travel direction (Figure 4a).

Since sparks are subject to both the strong and electromagnetic interactions, with the former dominating at short distances [1], groups of three sparks could presumably assemble beforehand to form composite colourless particles, thereafter called *triolets*, bearing charge

$+e/6$, $-e/6$, $+e/2$ or $-e/2$ (Figure 4b). Henceforth, we suppose the electron is exclusively composed of triolets, which travel at light velocity, and being colourless, are submitted to electromagnetic and centrifugal forces only.

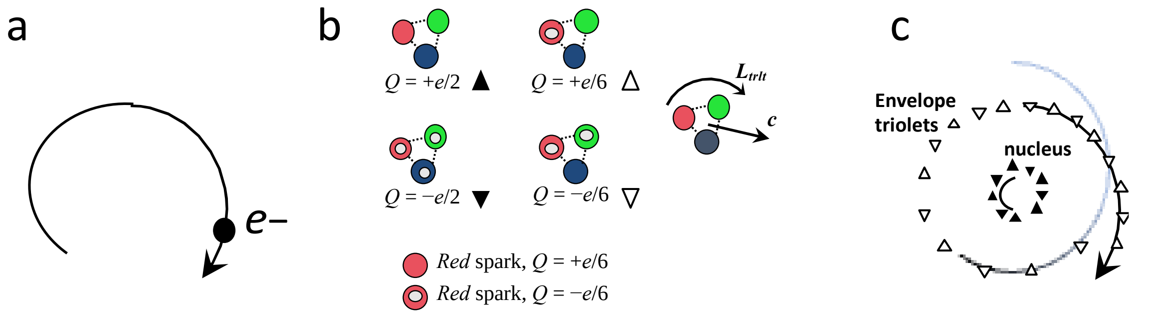

Figure 4. Triolets and the helical trajectory. a. In Schrödinger's Zitterbewegung model derived from Dirac's equation, the wavefunction associated to the electron seems to revolve at light velocity along a helical trajectory of radius $\lambda\!\!\!^{-}_c$, the reduced Compton wavelength, surrounding the average travel direction. Quantum mechanics does not specify which forces could cause the electron, which is assumed to be point-like, to follow such a peculiar helical trajectory. **b**. Triolets are colourless particles composed of three sparks, each bearing electric charge $\pm e/6$ and a specific strong interaction colour charge, and bear electric charge $\pm e/6$ or $\pm e/2$ depending on their combination of sparks. Thereafter, triolets will be represented as upward or downward, filled or hollow triangles depending on their electric charge, as depicted here. **c**. In our model, the electron is composed of triolets forming a nucleus and an envelope. It is conceivable that, in the absence of perturbation, the nucleus of the moving electron attracts envelope triolets and maintains them bound, thus explaining their helical trajectory. Conversely, envelope triolets would revolve at light velocity on an orbit of radius $\lambda\!\!\!^{-}_c$ around the nucleus, exhibiting the Zitterbewegung microcurrents, and guide the nucleus, sensing the electromagnetic fields generated by the envelopes of other particles.

Considering the electron as a particle of a certain extension composed of revolving charged subparticles, the triolets, thereby exhibiting magnetic moment and intrinsic angular momentum (its spin) sensed by other particles, and 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 without invoking Poincaré stresses, and satisfy the Virial theorem. We constructed an electrodynamical model of the electron at rest, in which predominantly intertwined positive and negative triolets formed coherent loops (making Poincaré stresses superfluous), exhibiting microcurrents, and providing interpretations of measured observables and fundamental constants. The classical and anomalous magnetic moments could be produced respectively by two different *components* of the electron, namely a negatively charged *envelope* and a neutrally charged *nucleus*, also responsible for the electron's wave-like and corpuscular behaviours respectively. The peculiar helical trajectory of the electron predicted by the *zbw* model could be naturally apprehended by considering that *zbw* describes the dynamics of envelope triolets, which would be attracted by the nucleus (Figure 4c). Moreover, we regard electron mass as being a manifestation of the total electromagnetic cohesion energy E of the particle, as Lorentz hypothesized, through Einstein's formula $m=E/c^2$ (the latter interpretation of the mass is naturally suggested by the observation that the muon possesses a mass ~206.77 times bigger than that of the electron, while its Compton wavelength is ~206.77 times smaller, as would be the case for a mass of electromagnetic origin, presenting a potential proportional to inverse distance).

Electromagnetic forces acting on any particular envelope triolet would presumably depend on its surrounding triolets, organizing the envelope into a complex structure, where triolets could revolve at various radii, not necessarily be uniformly distributed along the orbits, and even experience periodical fluctuations. To facilitate calculations however, we chose to make approximations and consider triolets at radial equilibrium rotating in the same direction on four coplanar circular orbits of different radii depending on their charge (Figure 5). In the model, positive and negative nucleus triolets are intertwined to maintain their cohesion, and could rotate along two close yet separate orbits due to the charged envelope, causing a similar arrangement in the envelope. In addition, we considered the electron as a bound system whose inner potentials depend on position coordinates only, not velocities, and thus verify the Virial theorem: for inverse square law electromagnetic interactions, total internal kinetic energy T and potential energy U should respectively amount to $+mc^2$ and $-2mc^2$, resulting in total internal energy $E=T+U=-mc^2$ corresponding to electron mass, the minus sign being indicative of a bound system.

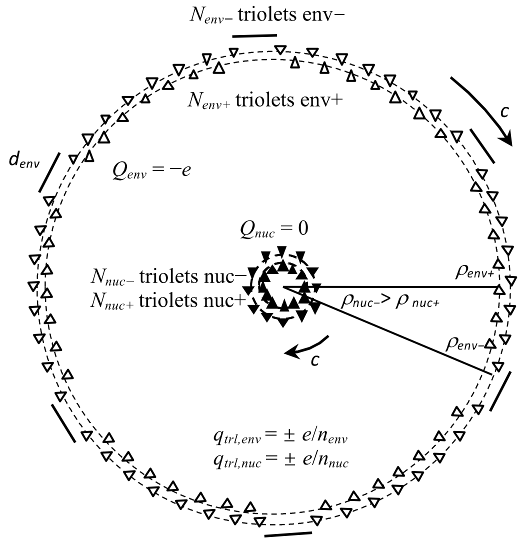

Figure 5. Model of the electron at rest. In our simplified model, triolets rotate at light velocity in the same direction along four different coplanar circular orbits depending on their electric charge, constituting an envelope and nucleus. Negative triolets are more numerous at the envelope, while the nucleus is neutrally charged. Due to the charged envelope, nucleus triolets are separated into two close orbits depending on their charge that would be responsible for the anomalous magnetic moment. Envelope triolets similarly revolve on separated orbits whose radii are close to the reduced Compton wavelength. Possible triolet configurations (triolet kinds and numbers, angular distributions, orbital radii) must fulfil constraints expressing radial stability and the measured values of charge, spin, magnetic moments, and mass. Due to consecutive negative triolets, intertwined envelope triolets assemble into stretches separated by a distance d_{env}.

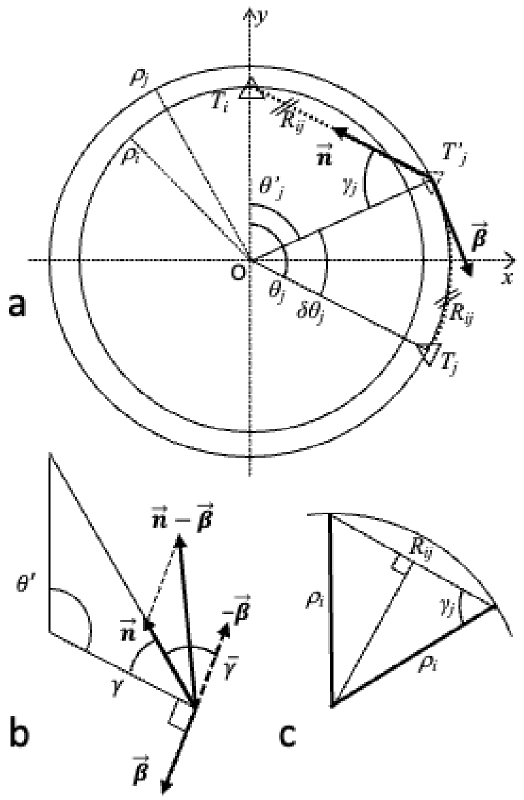

Figure 6. Geometric diagrams. a. The influence of electromagnetic fields due to triolet T_j onto T_i: let triolets T_i and T_j belong to the same component (envelope or nucleus). Triolet T_j rotates at light velocity along circular orbit of radius ρ_j and arrives at angle θ_j at time t, but was at position T_j' at angle θ_j' and retarded time t' when it emitted electromagnetic fields that reached triolet T_i revolving along coplanar circular orbit of radius ρ_i and arriving at angle 0 (vertical y axis) at time t. The retarded electromagnetic fields can be expressed using Liénard-Wichert potentials. This figure applies to all envelope and nucleus triolets. **b**. Diagram showing vectors and angles involved in the demonstration of the expressions of electromagnetic fields and potentials. **c.** Diagram depicting the case ρ_j=ρ_i.

Specifically, the system was built upon the measured values of charge, magnetic moments, spin and kinetic energy, and was validated by showing that cohesion could be satisfied, and electron mass recovered [22]. As triolets are electrically charged and travel at light velocity, we used Liénard-Wichert potentials from relativistic electrodynamics to express the radial components of electric field $\boldsymbol{E_{ij\perp}}$ and magnetic field $\boldsymbol{B_{ij}}$ emitted by triolet T_j of charge q_j at retarded time t', radius ρ_j and retarded angle θ'_j, and sensed at distance R_{ij} — electromagnetic fields travelling at light velocity in vacuum — by triolet T_i at radius ρ_i (Figure 6). From known electrodynamical expressions for these fields, using cylindrical unit vectors and coordinates, we deduced:

$$\boldsymbol{E_{ij\perp}} = \frac{q_j \sin\gamma_j}{4\pi\varepsilon_0 R_{ij}\rho_i\left(1+\sin\gamma_j\right)^2}\hat{\boldsymbol{\rho}} \qquad (\mathrm{e.}\,4)$$

$$\boldsymbol{B_{ij}} = \frac{-q_j}{4\pi\varepsilon_0 c R_{ij}\rho_j\left(1+\sin\gamma_j\right)^2}\hat{\boldsymbol{z}} \qquad (\mathrm{e.}\,5)$$

where R_{ij} and γ_j are defined by:

$$R_{ij}^2 = \rho_i^2 + \rho_j^2 - 2\rho_i\rho_j\cos\theta_j' \tag{e.6}$$

$$\sin\gamma_j = \frac{\rho_i}{R_{ij}}\sin\theta_j' \tag{e.7}$$

Note that these fields depend on position coordinates only, not velocities, thereby justifying the use of the Virial theorem. We then derived expressions for the net radial Lorentz force $\boldsymbol{F}_{ij\perp}$ due to triolet T_j exerted on triolet T_i and for the centrifugal force $F_{ctfg,i}$ experienced by triolet T_i:

$$\boldsymbol{F}_{ij\perp} = \frac{q_i q_j}{4\pi\varepsilon_0 R_{ij}\left(1+\sin\gamma_j\right)^2}\left[\frac{\sin\gamma_j}{\rho_i} + \frac{1}{\rho_j}\right]\hat{\boldsymbol{\rho}} \tag{e.8}$$

$$\vec{\boldsymbol{F}}_{ctfg,i} = \frac{\hbar c}{b_i\rho_i^2}\hat{\boldsymbol{\rho}} \tag{e.9}$$

where b_i stands for constants b_{env} or b_{nuc}. In the electron at rest, assuming triolets remained at radial equilibrium, the centrifugal force should compensate the net radial component of the Lorentz force exerted by other triolets. Neglecting the small contribution of the envelope onto the nucleus and vice-versa, and expressing equilibrium for triolet i along the radial direction and rearranging, we obtained for the envelope and nucleus:

$$\frac{1}{\alpha} \simeq \frac{b_{env}}{n_{env}^2}\sum_{j\in env}^{N_{env}-1}\frac{\rho_i^2\,\mathrm{sgn}(j)}{R_{ij}(1+\sin\gamma_j)^2}\left(\frac{\sin\gamma_j}{\rho_i}+\frac{1}{\rho_j}\right) \tag{e.10}$$

$$\frac{1}{\alpha} \simeq \frac{b_{nuc}}{n_{nuc}^2}\sum_{j\in nuc}^{N_{nuc}-1}\frac{\rho_i^2\,\mathrm{sgn}(j)}{R_{ij}(1+\sin\gamma_j)^2}\left(\frac{\sin\gamma_j}{\rho_i}+\frac{1}{\rho_j}\right) \tag{e.11}$$

where sgn(j) is the sign of charge of triolet T_j and α the fine-structure constant, which is found to be related to the ratio between the net radial electromagnetic force and the centrifugal force experienced by any single triolet inside the electron. We assumed positive and negative triolets were intertwined and uniformly distributed along the orbits except — as negative triolets are more numerous at the envelope — consecutive negative envelope triolets, which presumably repel to produce stretches of alternatively charged triolets separated by empty space (Figure 5). The potential energy due to the interactions between the nucleus and envelope being negligible [22], the total potential energy of our system is: $U_{tot} \simeq U_{env}+U_{nuc}$, where U_{env} and U_{nuc} are respectively the envelope and nucleus potential energies, which were evaluated to:

$$U_{env} \simeq \frac{2\alpha mc^2}{n_{env}^2}\sum_{i\in env}^{N_{env}}\sum_{j\neq i}^{N_{env}-1}\frac{\mathrm{sgn}(i\cdot j)}{H_{ij}\left(1+\sin\gamma_j\right)} \tag{e.13}$$

$$U_{nuc} \simeq \frac{2\alpha mc^2}{n_{nuc}^2}\sum_{i\in nuc}^{N_{nuc}}\sum_{j\neq i}^{N_{nuc}-1}\frac{\mathrm{sgn}(i\cdot j)}{H_{ij}\left(1+\sin\gamma_j\right)} \tag{e.14}$$

where $H_{ij}=R_{ij}/ƛ_C$. Assuming $\eta_{env+}\simeq\eta_{env-}$ and $\eta_{nuc+}\simeq\eta_{nuc-}$, we could derive equation (e.13) and $U_{env} = -mc^2$ from (e.10), and (e.14) and $U_{nuc} = -mc^2$ from (e.11). Thus, electron mass is derived effectively from substructure stability.

The problem then reduced to determining adequate triolet configurations, i.e. sets of values for $\{n_{env}, n_{nuc}, N_{env+}, N_{env-}, N_{nuc}, b_{env}, b_{nuc}, \eta_{env+}, \eta_{env-}, \eta_{nuc+}, \eta_{nuc-}, d_{env}\}$, that verified radial equilibrium conditions for every triolet and correctly predicted the total energy. In our model, the numbers of triolets in the envelope and nucleus are the adjusting parameters, but the same numbers (N_{env}=126 and N_{nuc}=18) were found to account both for substructure stability and electron mass. Our model therefore implements Lorentz' hypothesis, which advocates the electromagnetic origin of mass, from an objective crite@rion, even if satisfaction of the criterion itself ultimately relies on two parameters: the numbers of triolets in the envelope and nucleus. Noteworthy, these parameters are not arbitrary, but instead are constrained by radial equilibrium conditions that fix their values in our model.

Envelope triolets could fluctuate radially or otherwise in time, possibly constituting a periodic wave that would revolve at light velocity. This system has not been investigated here, but is of interest because this periodic wave could correspond to the wave associated to the electron, first imagined by de Broglie and later represented by wavefunction $|\psi>$ in quantum mechanics.

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. Altogether, our study establishes that deterministic electrodynamical models of subatomic particles can be constructed beneath the Compton scale.

7. Discussion — Qualitative predictions

The remarkable thing about the model is that every subatomic particle can be represented by a unique Ξ-matrix that fits in all subatomic reactions. Our model does not merely account for the conservation of electric and colour charges, but also involves neutral colourless 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. 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 colour charge and leptonic quantum number were not merely conserved separately, but entangled rather. This entanglement, present within the structure of Ξ-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 [27], 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. Ξ-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.

Symmetry violations with respect to charge, parity and time associated to the weak interaction notoriously astonished Pauli, Feynman and other physicists at the time [28]. In agreement with these observations, weak interaction reactions are found to be asymmetric with respect to charge conjugation in our model. Hence, our description captures a property of nature that was not introduced from the start. Indeed, we find it remarkable that only weak interaction reactions require one additional photon upon charge conjugation. Thus, it is possible that symmetry violations arise because of that 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. The asymmetries could actually be borne by that additional photon, and the weak interaction itself would not need to be asymmetric anymore. Interestingly, CP invariance fails for pion decay (r9, r10') in our model because of the additional concealed photon. 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. Hence, crossing symmetry is not satisfied in our scheme. Further investigations are needed to verify the consistency of the modified reactions with respect to spin, and helicity.

Interestingly, in our model, strong interaction colours appear as true charges rather than quantum states in the matrices, and anti-colours do not exist *per se*, but are constituted of the two other colours. 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 anti-leptons are found to contain many more sparks than charged leptons (three times as much in the 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-colours are constituted by the two other colours could be the primordial asymmetry responsible for antimatter scarcity. To our knowledge, this proposition is novel and different from previous possible explanations. Moreover, it is 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, accounting for antimatter scarcity in our model does not require the existence of a force outside the Standard Model.

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 (~6.6×10^{12}) in a muonium state ($\mu^+ e^-$) than on its own [30]? According to our model [22], 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 $\lambda\!\!\!^{-}_\mu$, 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 [21]. The fact that these observations, performed in various environments photon-wise, exhibited important discrepancies could indicate that overlooked photons take part in the reaction.

There is also another argument that is often seen as being unscientific, although several prominent physicists, such as Einstein, Dirac or Gell-Mann, considered it to be important, namely that mathematical beauty somehow captures the beauty of Nature, as most confirmed physical theories are also mathematically beautiful. In his book, Wilczek defines beauty as *symmetry*, *simplicity*, and *productivity* (i.e., "getting out more than you put in"), and considers that beauty is a scientific criterion of practical importance [31]. During a seminar, Gell-Mann recalls how one of his theories, which was beautiful but seemed to be invalidated by seven different experiments, turned out to be correct eventually [32]. Einstein considered that the 'inner perfection' of a mathematical theory constituted a natural criterion with which to assess theories [33]. We invoke this argument here because we feel our theory is beautiful, simple and productive, as it makes use of matrix addition to unite all subatomic particles and their interactions into a single chemical framework, which conserves subparticles, satisfies all conservation laws and most symmetries of the Standard Model, provides novel possible insights to many observations, and allows making predictions (e.g., electron mass). Specifically, we find the theory beautiful as the matrices for quarks astonishingly associate in couples and triples to generate matrices for mesons and nucleons that exhibit the correct charges and fits the reactions; simple and coherent as the mathematics only involve additions of matrices; and productive as, most remarkably, the requirement of conserving sparks across reactions made key features of weak interaction asymmetry emerge naturally.

Finally, how does our theory compare to QFT? Couldn't the virtual photons of QFT actually be real photons that would be detached and immediately reattached to particles, in agreement with our concealed photons hypothesis? Wouldn't this view make our theory compatible with the predictions of QFT? Of note, in our theory, particles are not excited states of underlying quantum fields as in QFT, but rather are composed of numerous subparticles whose coordinated undulation would possibly generate the quantum fields [29]. Thus, we do not regard our theory as being a substitute for the SM, but rather see it as an interpretation of the SM in terms of underlying subparticles, as our model is found to be compatible with most of its laws and symmetries. The differences rather lie in the *interpretation* of phenomena (radiation, strong interaction colours, virtual and concealed photons, quantum fields, etc.). Even if our theory turns out to be invalid eventually, it could still present some true insights, as Bohr's model of the atom did. Do currently accepted quantum theories propose a possible explanation for matter-antimatter asymmetry or predict electron mass? No, they do not, so why reject a consistent theory that provides possible explanations, until it is experimentally invalidated or reunited? Even if our speculative theory disagrees with the current worldview, and even if it is not demonstrated but empirically discovered instead (as a 'principle theory', such as defined by Einstein [17]), shouldn't a concurrent theory fitting all phenomena within an elegant framework be tolerated and shared among physicists, as its agreement with observations is remarkable and as it offers novel insights to key issues in particle physics?

8. Conclusions

In this study, we have 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, providing a putative underlying structure to subatomic reactions, and possibly suggesting the existence of a second chemistry lying at the level of subatomic particles.

All conservation laws and most symmetries of particle physics are found to be satisfied in our model. Conservation of the leptonic quantum number for instance naturally emerges from the representation. Remarkably, the asymmetry related to the weak interaction is also apparent, and could be seen as a prediction of the theory. Our model provides new insight for symmetry violations, even if several issues regarding the symmetries still need to be addressed. Of note, our study introduces a putative additional conservation law, viz., *the conservation of sparks*.

Our collection of just six kinds of subparticles allows to reconstruct all subatomic particles involved in all physical phenomena. Importantly, no consistent chemical theory could be created until we conjectured that colours were true charges rather than quantum states, or until we assumed that higher-generation particles were excites states of the original particles (for instance, making the muon contain more sparks than the electron prevented the construction of a coherent model). 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 [22].

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 and elegance with which Ξ-matrices fit subatomic decays and annihilations could possibly reflect the existence of a *subatomic chemistry*, and reveal 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 colour charge *green*, *blue* or *red*. This makes up 2×3 elementary subparticles, which we chose to call *Sparks* and denote ξ.

Appendix B. Constraints on the number of sparks

Let $N_{particle(s)}$ denote the number of sparks composing the considered particles. Our conjectures regarding leptons may be mathematically expressed as the system of equations:

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

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

$$\mu^- \rightarrow e^- + \overline{\nu}_e + \nu_\mu. \tag{r7}$$

Reaction (r7) is not coherent with our scheme, since $N_{e^-} = N_{\mu^-}$ (e1), if we exclude the solution $N_{neutrino} = N_{antineutrino} = 0$. Therefore, we may conjecture that the muon can either already bear a concealed photon or encounter a new photon:

$$\mu^- + \gamma^* \rightarrow e^- + \overline{\nu}_e + \nu_\mu, \tag{r7'}$$

thus yielding:

$$N_{photon} = N_{neutrino} + N_{antineutrino}. \tag{e4}$$

Moreover, since $N_u = N_d$ (e3) and thus $N_{proton} = N_{neutron}$, reactions involving neutrons and neutrinos:

$$n + \nu_\mu \rightarrow p^+ + \mu^-, \tag{r11}$$

$$n + \nu_e \rightarrow p^+ + e^-, \tag{r12}$$

imply:

$$N_{lepton} = N_{neutrino}. \tag{e5}$$

Now, we also have:

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

$$(e^- + \gamma^*) + e^+ \rightarrow 3\gamma, \tag{r2'}$$

$$(Atom + \gamma^*) + \gamma \rightarrow Atom + e^- + e^+, \tag{r3'}$$

implying:

$$2N_{photon} = N_{lepton} + N_{antilepton}. \tag{e6}$$

Taken together, equations (e4-e6) constitute the system of equations (e2) and also yield:

$$N_{antilepton} = N_{photon} + N_{antineutrino}, \tag{e7}$$

$$N_{photon} = N_{lepton} + N_{antineutrino}. \tag{e8}$$

Rearranging equation (e6) using (e5) gives:

$$2N_{photon} = N_{antilepton} + N_{neutrino}. \tag{e9}$$

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

$$\pi^0 \rightarrow 2\gamma, \tag{r8}$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu, \tag{r9}$$

$$\pi^- \rightarrow \mu^- + \overline{\nu}_\mu. \tag{r10}$$

As the π^0, constituted of a quark and an antiquark, decays into two photons (r8), we set:

$$N_{quark} + N_{antiquark} = 2N_{photon}, \tag{e10}$$

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

$$\pi^- \rightarrow \mu^- + \overline{\nu}_\mu + \gamma^*, \tag{r10'}$$

while reaction (r9) needs not be modified, since the number of sparks on either side of the reaction amounts to $2N_{photon}$, from (e9) and (e10). Reaction (r10') indicates that, in our model, the negative pion produces a muon already carrying a concealed photon. It can be noticed that concealed photons only appear as products of reactions or in long-lifetime decays involving the weak interaction.

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

Author Contributions

SA conceived the study, formed the hypotheses, and constructed the model. PR reorganised ideas. PR helped SA write the manuscript. Conceptualization, SA; formal analysis, SA; investigation, SA; writing—original draft preparation, SA; writing—review and editing, PR. All authors have read and agreed to the present version of the manuscript.

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Conflicts of Interest.

The authors declare no conflict of interest.

References

1. D. J. Griffiths, Introduction to Elementary Particles, 2nd revised edition, Wiley-VCH, 2008.
2. S. F. Novaes, 1999. Standard model: An introduction, Proceedings of the 10th Jorge Andre Swieca Summer School: Particles and Fields, C99-01-31, Sao Paulo, arXiv:0001283v1.
3. R. Aaij et al. (LHCb Collaboration), 2021. Observation of the mass difference between neutral charm-meson eigenstates, Phys. Rev. Lett. 127 (2021), 111801.
4. L. Canetti, M. Drewes, M. Shaposhnikov, Matter and antimatter in the universe, New J. Phys. 14 (2012), 095012.
5. X.C. Vidal et al., 2018. Beyond the Standard Model Physics at the HL-LHC and HE-LHC, arXiv:1812.07831.
6. P. Langacker, Grand unified theories and proton decay, Phys. Reports **72** (1981), 185-385.
7. J. C. Pati, A. Salam, J. Strathdee, Are quarks composites? Phys. Lett. B **59** (1975), 265–268.
8. M. A. Shupe, A composite model of leptons and quarks, Phys. Lett. B **86** (1979), 87–92.
9. H. Harari, A schematic model of quarks and leptons, Phys. Lett. B **86** (1979), 93–96.
10. H. Terezawa, Subquark model of leptons and quarks, Phys. Review D **22** (1980), 184–199.
11. H. Harari, N. Seiberg, A dynamic theory for the rishon model, Phys. Lett. B **98** (1981), 269–273.
12. U. Baur, H. Fritzsch, H. Faissner, Composite weak bosons and their radiative decays, Phys. Lett. B **135** (1984), 313–318.
13. S.-Z. Wang, 2011. Composite leptons and quarks from hexad preons, arXiv:1112.0181.
14. C. Heuson, 2003. A structural model of quarks and leptons, arXiv:hep-ph/9904493.
15. M. E. de Souza, The Higgs-like Bosons and quark compositeness, Frontiers in Sciences **3** (2013), 81-88.
16. C. S. Kalman, Why Quarks Cannot Be Fundamental Particles, Nucl. Phys. B (Proc. Suppl.) **142** (2005), 235-237.
17. J. Bub, Quantum Mechanics as a Principle Theory, Stud. Hist. Phil. Mod. Phys. 31 (1) (2000), 179-226.

18. M. Peskin, D. Schroeder, An introduction to Quantum Field Theory, Reading, Addison-Wesley, 1995.
19. S. Eidelman et al., Review of Particle Physics, Phys. Lett. B **592** (2004).
20. O. J. Pike, F. Mackenroth, E. G. Hill, S. J. Rose, A photon-photon collider in a vacuum hohlraum, Nature photonics **8** (2014), 434-436.
21. A. T. Yue et al., Improved determination of the neutron lifetime, Phys. Rev. Lett. **111** (2013), 222501.
22. S. Avner, F. Boillot, Electron mass predicted from substructure stability in electrodynamical model, Front. Phys. **8**, 213 (2020).
23. P. A. M. Dirac, An extensible model of the electron, Proc. of the Royal Society, London, Series A **268** (1962).
24. Y. Fakuda et al. (Super-Kamiokande collaboration), Evidence for Oscillation of Atmospheric Neutrinos, Phys. Rev. Lett. **81** (1998), 1562.
25. R. Aaij et al. (LHCb Collaboration), Observation of the Resonant Character of the $Z(4430)-$ State, Phys. Rev. Lett. **112** (2014), 222002.
26. R. Aaij et al. (LHCb Collaboration), Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda^0{}_b \rightarrow J/\psi K^- p$ Decays, Phys. Rev. Lett. **115** (2015), 072001.
27. R. Eisberg, R. Resnick, Quantum physics of atoms, molecules, solids, nuclei and particles, 2nd edition, John Wiley & Sons, 1985.
28. R. P. Hudson, 2001. Reversal of the Parity conservation law in nuclear physics, in Lide, D. R., A century of excellence in measurements, standards, and technology, NIST special publication 958, preprint at https://nvlpubs.nist.gov/nistpubs/sp958-lide/111-115.pdf.
29. S. Avner, Conceiving particles as undulating granular systems allows fundamentally realist interpretation of quantum mechanics. Entropy **23** (2021), 1338.
30. S. N. Gninenko, N. V. Krasnikov, V. A. Matveev, Invisible decay of muonium: Tests of the standard model and searches for new physics, Phys. Rev. D **87** (2013), 015016.
31. F. Wilczek, A Beautiful Question: Finding Nature's Deep Design; Penguin Press: New York, NY, USA, 2015. See also: Beauty is Physics' Secret Weapon, Nautilus 2016, available at: https://nautil.us/beauty-is-physics-secret-weapon-235755/ (accessed on 15th May 2023).
32. M. Gell-Mann, Beauty and Truth in Physics. TED Talk, 2007, available at: https://www.ted.com/talks/murray_gell_mann_beauty_truth_and_physics (accessed on 15th May 2023).
33. G. Holton, Constructing a Theory: Einstein's Model, The American Scholar **48**, 3 (1979), 309-340