WHAT IS THE SIGNIFICANCE OF THE CONSERVATION OF ELECTRIC CHARGE Q?

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Conservation of electric charge Q is a universal law in the sense that it should be conserved in any interaction, known or yet unknown. However Q should not be considered as a simple number but as the half sum of two irreducible quantities BAL= A-L (A is the baryonic number and L is the leptonic number) and total flavour TF. Conservation of electric charge implies obviously conservation of Q (considered as a simple number) but also BAL and TF. We verify that electromagnetism and strong interaction which conserve Q, A and L and all individual flavours conserve obviously BAL and TF; likely weak interaction which conserves Q, A and L conserves also BAL and TF. However conservation of BAL does not imply necessarily conservation of A and L. In effect $\Delta BAL=0$ has another solution $\Delta A=\Delta L=\pm 1$ which points to a possible solution to explain how a material and neutral universe could arise evolving from A=0 L=0 Q=0 state to A>0 Q=0 state through a process which would conserve BAL and TF without conserving separately A and L.

Key-words: Conservation of Q related to conservation of BAL and TF; asymmetry of material and neutral Universe.

1. Introduction

Conservation laws are the backbone of physics. They determine what can or *cannot* occur. Some of them are universal in the sense that it is believed that any possible process has to fulfil them without exception. From the fundamental point of view, these conservation laws are either motional (the conservation of energy, of linear momentum, of angular momentum is deeply related to space-time symmetries and thus must be valid for all known or yet unknown interactions) or material (the conservation of electric charge Q is also believed to be always valid since electric charge has dynamical roles being the source of electromagnetism but conservation of Q is not related to space-time symmetries). No one has observed any process violating any of these rules.

However, we remark that the above conservation laws are only necessary conditions and not at all sufficient conditions. A hypothetical process which obeys only these conditions is thus not necessarily a process which can really take place in nature. So in classical physics, a process which occurs in nature has to obey an *additional* condition: the conservation of matter in the form of the conservation of mass. For microscopic processes electric charge Q has another interesting property: it always comes in units. Conservation of Q is then a simple counting relation. Again conservation of Q is not sufficient to be sure that a hypothetical reaction which fulfils it is really possible. In fact to explain why certain nuclear reactions and particle reactions are observed and why other reactions are *not* observed physicists introduced progressively other quantum numbers such as baryon number A, lepton number L or individual flavours like strangeness, charm …which come also in units. The concept of baryon number A is an extension of the concept of mass number (number of protons plus neutrons) in nuclear reactions. Now we know that matter is formed by quarks (constituents of hadrons which are particles sensitive to strong interaction) and leptons (electrons, muons, taus and corresponding neutrinos which are particles insensitive to strong interaction). A quark is defined by A=1/3 L=0 and a lepton is defined by A=0 L=1. A baryon (A=1) is formed by three quarks whatever their flavour is. Different kinds of quarks are distinct by different flavours (upness, downess, strangeness, charm, beauty/bottom and truth/topness). And by analogy different kinds of leptons are distinct by different leptonic flavours [1].

Physics is essentially an experimental science. Theories have to be confronted as closely as possible with experiments and observation which suggest patterns and rules. Conservation laws in microscopic processes were deduced empirically from innumerable observed reactions and from innumerable not observed reactions where all universal conservation laws were clearly satisfied. Apparently all observed reactions do satisfy

conservation of A and conservation of L. And one always fails to observe a reaction which violates either A or L. It is thus tempting to consider conservation of A and conservation of L on the same footing as conservation of Q. On the contrary other conservation laws such as *conservation of individual flavours (upness, downess, strangeness, charm ...) are not universal* in the sense that they are not valid in all interactions namely we know they are strictly conserved in electromagnetism and strong interaction but not in weak interaction. We note also that parity is conserved in electromagnetism and strong interaction but is not conserved in weak interaction.

At present, all observed microscopic processes can be understood within electromagnetism, strong interaction and weak interaction which are the three interactions of the Standard Model. These interactions always conserve baryonic number A, leptonic number L and electric charge Q. Microscopically it means that a quark remains a quark and a lepton remains a lepton after the exchange of messengers: photons for electromagnetism, W and Z for weak interaction and gluons for strong interaction. The exchange of photon, gluon or Z (they are all electrically neutral) does not modify the flavour and the charge of the particle while the exchange of W (charged particles) modifies the flavour and the charge of the particle. Gravitation is completely negligible at microscopic level. Experimentally, there is no known actually observed microscopic process which violates any of these numbers (A, L and Q). Despite gigantic efforts one has also always failed to observe indisputably a hypothetical microscopic process revealing either the violation of baryonic number A (no evidence of proton decay. Any unambiguous detection of proton decay would prove that there must exist an interaction which violates baryon number with or without violation of lepton number) or L (no evidence of neutrinoless double beta decay). Any unambiguous detection of neutrinoless double beta decay would signify that there exists a process (governed by weak interaction) which *violates L with ΔL=2 but conserves A*. While no one seriously doubts the validity of conservation of electric charge Q there is a priori no sound theoretical reason to require conservation of A and L in *any circumstance*. Conservation of A and L is considered to be only empirical rules. That is the reason why physicists search so eagerly to put into evidence a possible microscopic process violating A or/and L. Such a process which must conserve Q if found would clearly indicate that an interaction beyond the Standard Model exists and more importantly would indicate how A or/and L could be violated. An interesting question would then be: is conservation of Q independent of conservation of A or/and L? In other words, are Q, A and L completely independent simple numbers or are they intimately connected so that violation of A or L can have consequences on conservation of Q? Does

conservation of Q signify only conservation of the number Q (as number A or L) or conservation of Q has other implications on A or/and L and on other numbers? Fascinatingly in contrast with the total absence of experimental evidence of violation of A or/and L in microscopic scale we do know that our Universe is *material and neutral.* This simple *observational* fact is curiously indeed a huge Rosetta stone of the existence of an interaction which did conserve Q and did not conserve A at the microscopic level. We emphasize that interactions of the Standard Model do conserve Q, A and L at the microscopic level and consequently should also conserve them at the macroscopic level. The enigma is then: if initially our Universe had no matter and no antimatter particles why and how then our present Universe contains now essentially only matter particles? This statement implies immediately that there must exist in the past an interaction permitting to evolve from A=0 Q=0 Universe to A>0 Q=0 Universe. We emphasize also that conservation of Q is clearly an empirical observational fact and not just a simply theoretical assumption **[2]**.

Observation that our Universe is material and neutral excluded symmetric universe first suggested by Dirac (it would contain one-half matter particles and one-half antimatter particles; one-half stars one-half antistars; one-half galaxies one-half antigalaxies). The fundamental problem is then to find out a possible logical path permitting to evolve from A=0 Q=0 initial state to A>0 Q=0 final state (our present Universe). The Standard Model cannot provide a mechanism to do it since none of its interactions can change A. It is necessary to go beyond the Standard Model.

In 1967 an original possible solution to get out of this impasse was pointed out by Sakharov **[3]** in his pioneer work 'Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe'. CP violation was discovered in 1964 while there was and there still is no experimental evidence of particle interactions where the baryon number is violated. All observed particle reactions have equal baryon number and equal lepton number before and after. To date CP violation has been observed only in the decays of K mesons and B mesons. We emphasize that mesons are neutral matter particles (A=0 L=0) and are neither matter particles nor antimatter particles **[4]**. The two conjugate channels have not the same probability of occurrence (CP violation) but there is no violation of A. We must realize that violation of A is a *necessary condition*. So however important is the violation of CP *without* violation of A, an interaction responsible of this violation could not be at the origin of the asymmetry of our Universe. Any possible interaction should have the capability to induce baryon violation at the microscopic level. Nevertheless obviously CP violation by itself is and remains a fundamental phenomenon to be studied and elucidated. Sakharov introduced the

innovative idea of an interaction which would conserve only the *combination of A and L* (instead of conserving separately A and L). Subsequently Sakharov's work inspired many theoretical approaches based on GUT (Grand Unified Theories) **[6]** and Non-GUT theories **[7]** in particular those based on electroweak theory **[8]**. Models based on supersymmetry provided also interesting baryogenesis scenarios **[9]**. However we do not know if these scenarios would give rise to a material and electrically neutral Universe, namely to a Universe containing the same number of protons and electrons (inescapable observational constraints).

2. Conservation of matter in the form of conservation of mass in classical physics and chemistry

Classical physics is based on one side upon these four universal conservation laws and on the other side on the principle of matter conservation. In classical physics matter and mass are often confused. Conservation of matter means that any piece of matter revealed by its mass present in the reactants should be present in the products. In other words matter (mass) cannot be created nor destroyed. Chemistry (governed by electromagnetism) provides a spectacular illustration of the principle of conservation of matter: Balanced chemical equations basically and axiomatically express the conservation of matter: The number of atoms of a particular species in the reactants is equal to the number of those atoms in the products. Conservation of mass is then its direct corollary if one assumes that a specific atom has a defined mass whatever its combination with other atoms is. This is the Lavoisier's law stating that in a chemical reaction, matter revealed and represented by mass cannot be created nor destroyed, but can only be changed from one form to another. We point out that conservation laws in chemical equations deal only with positive integer numbers, the numbers of atoms of a particular species being necessarily a positive number. It is a simple counting rule: the sum of positive numbers in the reactants is equal to the sum of positive numbers in the products. This counting rule genuinely expresses the conservation of matter in chemical reactions although what is experimentally accessible is mass (very precise measurements with a balance). It turned out that in fact mass is only one form of energy ($E=mc^2$ after Einstein) and what is strictly conserved is energy and not mass. But generally the *Q-value* of a reaction is very tiny relative to masses, so in chemistry mass conservation is considered to be valid and is experimentally verified to a great accuracy even if strictly speaking mass is not conserved. The non conservation of mass $\Delta m/m$ is in a chemical reaction typically of the order of 10^{-10}, not detectable by weighing. In classical physics and in chemistry, conservation of mass reflects conservation of matter while in reality matter and mass are two completely different

concepts [4]. Matter particles are characterized by A>0 or/and L>0, antimatter particles are on the contrary characterized by A<0 or/and L<0. Particles with A=0 and L=0 are matter neutral particles. A particle and its antiparticle have the same mass which is ≥ 0. We note that all phenomena observed in classical physics could be understood within two interactions: electromagnetism and gravitation which have both infinite ranges.

3. Conservation of matter in the form of conservation of A and L in nuclear physics and particle physics

Stability of nuclei and existence of beta radioactivity cannot be explained within electromagnetism and gravitation. They require two interactions unknown in classical physics: strong interaction to explain stability of nuclei and weak interaction to account for radioactivity. These interactions must obviously fulfil all universal conservation laws namely conservation of linear momentum, angular momentum, energy and electric charge. But manifestly it is not sufficient to account for nuclear reactions or particle reactions since many reactions (for example p + n $\rightarrow$ p + n + n) that do conserve all these laws manifestly do not occur in nature. We point out that the existence of the above hypothetical process would mean that an additional material neutral particle is created thus matter is not conserved. To account for these experimental facts it is assumed that interactions between particles obey additional conservation laws which are not revealed through the behaviour of macroscopic objects. Particles are indeed characterized by several additional quantum numbers other than Q such as baryon number A, lepton number L, individual flavours such as upness, downess, strangeness …. Conservation of the number of protons Z and the number of neutrons N in nuclear reactions involving only protons and neutrons is directly similar to conservation of atoms in chemical reactions. It is equivalent to the conservation of Q and the mass number A=Z+N. Conservation of mass number clearly expresses conservation of the number of nucleons which are matter particles sensitive to strong interaction. Later to explain processes involving strange particles physicists introduced the concept of baryon number which extends the concept of mass number to all baryons including nucleons. Baryons (A=1) are formed by three quarks with A=1/3 whatever flavours are. There are six kinds of quarks: u, d, s, c, b and t. They differ from each other in mass and in flavours. Leptonic matter particles are similarly characterized by leptonic number L. There are six kinds of leptons (L=1): e, ν_e, μ, ν_μ, τ and ν_τ. They differ also from each other in mass and in flavours. And to account for antimatter particles an antibaryon is defined by A=-1 and an antiquark by A=-1/3. Leptonic antimatter particles are characterized by L=-1. The concept of antiparticles [4, 5, 10] doubles the number

of existing particles, each matter particle having a distinct corresponding antimatter particle. A particle and its antiparticle have opposite charge, opposite charge distributions and currents, opposite A, L and flavours and more generally their algebraic properties are all opposite. We deduce immediately that a truly neutral particle (TNP) which is defined as a particle identical with its antiparticle should have all its algebraic properties known or yet unknown equal to 0 [4, 5, 10]. This extension is very similar to the extension of the notion of positive numbers to negative numbers. Quarks can not be observed in isolation and possess fractional A and Q while all observed particles have integer A, L and flavours. Conservation of A deals with conservation of matter particles sensitive to strong interaction and conservation of L deals with conservation of matter particles insensitive to strong interaction. If A and L are both conserved then matter number M defined as M=A+L is also conserved.

A, L and flavours were unknown in classical physics. The reason may be simply that it is only at the level of individual particles that these quantum numbers take their sense and can be determined with certainty. A macroscopic object is indeed composed of a multitude of atoms and virtually the knowledge of the exact composition of this object allows us to know its A, L and flavours. Conservation of mass is in fact the consequence of conservation of atoms which implies in turn conservation of A, L and flavours. Since only matter is at work, A and L of a macroscopic object are great positive numbers.

4. Have A and L always to be conserved?

Conservation of A and L is indeed intimately connected to the principle of conservation of matter. This principle is apparently verified without any exception in all observed microscopic processes. One could however raise legitimately the following question: is it possible that this principle is not always valid? The concept of Q is connected to a field and is well known in classical physics. Q is the source of a field thus should be absolutely conserved while conservation of A and L is only an empirical fact and there is no evidence that A, L or individual flavours are the source of a field. Q is thus believed to be more fundamental than A and L. We know that individual flavours are not conserved in weak interaction but are absolutely conserved in electromagnetism and strong interaction. Similarly, it is possible that A or/and L are not conserved in a yet unknown novel interaction even if A and L are absolutely conserved in all known interactions. We point out that conservation of A and L (positive numbers for matter particles, negative numbers for antimatter particles, 0 for matter neutral particles) means indeed conservation of matter (classical physics, chemical reactions are in fact particular cases of conservation of A and L which take only positive

values. But we should emphasize that there is no evidence of any violation of A or L in microscopic level since all dedicated experiments to pop out violation of L (through neutrinoless double beta decay) or violation of A (through proton decay), despite gigantic efforts, are up to now negative. Paradoxically, it is the very existence of our material (A is a great positive number) and nevertheless electrically neutral Universe which requires the existence of an interaction violating A but conserving Q, if we assume that at the beginning, there were no matter particles and no antimatter particles in the universe leading to A=0 and L=0 and also evidently Q=0. We can verify over and over again that all microscopic processes so far observed experimentally (which thus take place in nature), do conserve A and L together with Q. They are governed by electromagnetism, strong interaction or weak interaction. In addition electromagnetism and strong interaction conserve strictly also individual flavours while weak interaction conserves only A, L and Q.

5. Apparent violation of conservation laws: misinterpretation or genuine fact

Physics is essentially an experimental and/or observational science. Theory must stand or fall with indisputable experiment or observation. Predictions of theories have to be consistent with experimental and/or observational facts. If a theory says that a process is impossible and if this process is univocally observed then the theory is false or incomplete in its present form. Observation of a process predicted by a theory would on the contrary strongly support its validity. The case of non observation of a predicted process is more subtle: maybe this process does not occur in nature or maybe there are other not yet known conditions to be fulfilled, maybe sensitivity is not sufficient, maybe experimental set up is not appropriate …One has also to be careful with false positive signal and avoid to misinterpret spurious signals or to take statistical fluctuation as true signal.

When there is apparently contradiction between experiments and/or observation and conservation laws, it is important to scrutinize the situation: it may reveal a misinterpretation (wrong scenario) or it may point to a genuine violation meaning that the examined conservation law is in reality not universal but valid for certain interactions and not for others interactions.

Alpha decay is governed by strong interaction and its spectrum is discrete so it was at first thought that beta spectrum should be also discrete. Experiments show indeed clearly that beta spectrum is continuous and does not present a peak at maximum energy. It was not possible to interpret alpha decay and beta decay with the same mechanism. The necessity to save universal conservation laws (energy, angular momentum) prompted Pauli to invent the

neutrino, a new neutral particle which turns out to be the neutral partner of the electron. Both of them are members of lepton family. The correctness of Pauli postulate was verified subsequently again and again.

Beta decay is governed by weak interaction. It was well known that parity is conserved in electromagnetism and strong interaction (many experiments show that) so it was tempting to consider that parity conservation is also universal thus valid also in weak interaction. (θ τ) puzzle led Lee and Yang [11] to point out the necessity of testing if parity conservation is also valid in weak interaction. It turns out that indeed parity is maximally violated in weak interaction [12]. Fall of parity in weak interaction shows that we have to be careful about conservation law: a conservation law valid in an interaction is not necessarily valid in another interaction. We remark also that individual flavours (for example strangeness) which are conserved in electromagnetism and strong interaction (and also in weak interaction through neutral current) are also not conserved in weak interaction through charged current.

6. Conservation of Q without conservation of A or/and L

All reactions observed to now do conserve Q, A and L without exception. This could be considered to be a logical consequence of the validity of A, L and Q conservation of electromagnetism, strong interaction or weak interaction which govern these reactions. Conversely if a microscopic process, clearly observed without ambiguity, does violate A or/and L then it should signify that a new interaction is at work. To go beyond the Standard Model, since conservation of Q is considered to be sacred, the only way is to write theoretically equations conserving strictly Q but nevertheless violating A or L. At first view, neutrinoless double beta decay would be a very powerful means to demonstrate that L would be violated (ΔL=2) without violating Q: a peak at maximum energy would be an undeniable signature of violation of L and would signify that the neutrino and the antineutrino are the same particle. There is up to now no evidence of such peak. (The only claimed positive evidence of the ββ0ν decay peak came from Klapdor-Kleingrothaus et al [13,14,15] but the correctness of their claim was seriously questioned [16,17,18]). In 1930s, the question of identity or difference [19] between neutron and antineutron or neutrino and antineutrino was raised. The case of neutron was immediately solved by Racah [20] because neutron has a non zero magnetic moment. Originally search of neutrinoless double beta decay was precisely proposed by Furry [21] to know if neutrino is or is not identical with antineutrino. Evidence of this process implies that neutrino and antineutrino are the same particle. Absence of this

process (taking implicitly conservation of parity for granted for this process) means on the contrary that neutrino and antineutrino are different. The latter statement was no more valid after the fall of parity, absence of this process might be due to the fact that the neutrino has no mass. Identity of neutrino and antineutrino is only a necessary condition but is no more a sufficient condition for the occurrence of neutrinoless double beta decay. Non zero mass neutrino is an additional necessary condition. It is clear that the neutrino as any other particle has to be either identical with or different from its antiparticle. Since the neutrino has at least one algebraic property different from zero, neutrino cannot be identical with antineutrino. Neutrinoless double beta decay cannot then occur whatever the mass of neutrino is. Persistent absence of evidence of this process despite more and more improved sensitivity reflects indeed evidence of absence of this process. We remark that the decay of neutron into $\overline{p} + \overline{e} + \nu$ channel would mean that neutron and antineutron are the same particle. This channel is naturally strictly forbidden since we know that neutron and antineutron are different. No evidence of this hypothetical process is naturally interpreted as evidence of non existence of this process and not as insufficiency of sensitivity to detect a process which occurs in nature. Search for neutrinoless double beta decay or search for the decay of neutron into $\overline{p} + \overline{e} + \nu$ channel with greater and greater sensitivity are very strict tests verifying that any difference in algebraic property of a neutral particle is sufficient to state that it is different from its own antiparticle. Any process implying Majorana nature for neutron and neutrino cannot occur in nature. There would be incoherence that should be explained if neutrinoless double beta decay or neutron decay into $\overline{p} + \overline{e} + \nu$ channel events are univocally detected or if one assumes that absence of evidence is only due to insufficiency of sensitivity.

One has to account for *coherently* all experimental results with the *same* assumption. One has to explain beta decay, beta beta decay and all observed experiments involving neutrino with either Dirac neutrino (neutrino and antineutrino are different) or Majorana neutrino (neutrino and antineutrino are the same particle). Curiously Klapdor-Kleingrothaus et al [13,14,15] did not mention, discuss and explain the apparent contradiction between the Majorana character of the neutrino (in the sense that there is no difference between neutrino and antineutrino except the helicity deduced from their interpretation) and the Dirac character of the neutrino (neutrino and antineutrino are different in particular they have opposite L values), necessary to explain all other clearly observed reactions, where the neutrino is explicitly involved. We pointed out that the fact that neutrino and antineutrino are distinct particles is sufficient to forbid neutrinoless double decay. In hindsight this absence could be

also understood as an inevitable consequence of conservation laws of weak interaction which governs both beta decay and beta beta decay. $\beta\nu$ decay and $\beta\beta 2\nu$ decay which do conserve A and L are on the contrary clearly observed whenever sensitivity is sufficient. Our arguments in favour of the interpretation that the absence of neutrinoless double beta decay events reveals in fact the absence of this process were discussed at length [1,2,4,5,10,22].

Proton decay, if it exists, cannot be governed by interactions of Standard Model. There is so far no evidence of any hypothetical channel of proton decay. We have then to conclude that there is not yet evidence of microscopic process allowing the proton to decay via an interaction conserving Q without conserving A or/and L. The only experimental clue of such interaction remains our material and neutral Universe. And we have to imagine a microscopic process which would allow to evolve from a A=0, L=0 and Q=0 state to a A>0 Q=0 state. Our material and neutral universe should be the outcome of a great number of microscopic processes which did conserve Q and did not conserve simultaneously A and L.

7. Instability (stability) from experimental point of view

We can only prove experimentally that a nucleus (a particle) is unstable by observing its decay (through any channel) while it is not possible to prove experimentally that a nucleus (particle) is absolutely stable since the time of observation should be infinite while any time of observation however long is necessarily finite. Practically, we isolate a great number N of given nuclei (particles) and we try to count during a counting time T the number n of nuclei (particles) which decay. If n is clearly different from zero it means that the nuclei (particles) are unstable and it is easy to deduce from n, N and T the mean lifetime τ of the nucleus (particle). If the detector is ideal with an efficiency of 1 then n is also the number of observed events.(In fact we have to take into account the efficiency ε of real detector, the number of observed events is then εn)

$n = N (1 - e^{-T/\tau})$

If $T \ll \tau$ then $n = NT/\tau$

To be significant, the identification of examined decay should be unequivocal and the determination of n without ambiguity (signals should be well above background which could hide signals) and NT should be significantly greater than τ. If τ is a very great number (great meanlife, then we have to have NT sufficiently great. We cannot decide, when there is no evidence of decay, that the nucleus (particle) is truly stable or it is indeed unstable but with a lifetime too long to allow the observation of its decay. We can only hope that by increasing

NT its decay will become observable. This ambiguity could only be lifted (in favour of unstablity) if the decay turns out to be unambiguously observed. Otherwise, the ambiguity always remains. From the strictly point of view of experiments, we can say with certainty that a given nucleus (particle) is unstable if we observe at least one unequivocal decay, but we can never say that a nucleus (particle) is absolutely stable even if again and again, there is no evidence of its decay. It is always possible to postulate that indeed $\tau \gg$NT so that decay has no chance to be detected.

When one speaks of stable nuclei, the word stable often does not mean stable in the absolute sense but only means that their half-life of a nucleus is greater than the age of the earth, i.e. ; $t_{1/2} > 10^9$ years. Indeed, many of them have been experimentally proved to be unstable with great half-lives. (for example, ^{209}Bi has a half-live of $1.9 \ 10^{19}$ y against alpha-decay [23] (via strong interaction), ^{82}Se has a half-live of $8.3 \ 10^{19}$ y against double-beta decay (via second-order weak interaction).

8. Instability deduced from theory and conservation laws

However it is possible to deduce what particle is unstable (stable) from properties of a given particle and lighter particles together with conservation laws. It is a universal principle that every particle decays into lighter particles, unless prevented from doing so by some conservation law. Physics is ruled by conservation laws which determine what *cannot occur*. And there is a prejudice that conversely, any process which does not contradict these laws is permitted and does indeed take place and thus could be observed provided appropriate conditions. Conservation laws of energy, of linear momentum and of angular momentum which are kinematical are related to space-time symmetries, are *universal* in the sense that they are valid for *all* kinds of interactions, known or yet unknown. We deduce immediately particles with zero mass are stable otherwise there would be non conservation of energy. More generally the decay of a particle to a set of particles is potentially possible only if their total mass is less than the particle under consideration. On the contrary, conservation laws of electric charge Q or other quantum numbers such as baryon number A, lepton number L or different kinds of flavours are material conservation laws. Q having a dynamical role, conservation of Q is believed to be very fundamental and should be universal and always be valid as motional conservation laws. The electron is thus stable since it is the lightest charged particle. The stability of the proton is more debatable even if there is so far no evidence of its decay which should respect the conservation of Q and in the same time violates baryon number A. A could be violated because so far A is not known to have the same dynamical

role as Q. We should realize that any decay should be governed by a fundamental interaction, so it must respect all conservation laws of the corresponding interaction. Since all known interactions of the Standard Model conserve strictly A, proton decay, if it exists should be governed by an *yet unknown interaction with strict conservation of Q but permitting nevertheless the violation of A*. This new interaction could have been at the origin of our observed asymmetric universe which is a matter universe and not a matter and antimatter universe. We remark that material conservation laws are specific to each kind of interaction (for example weak interaction does not conserve individual flavours while strong interaction and electromagnetism do conserve them). It is conceivable that a new interaction conserving Q but violating A exists in order to explain our material universe.

9. Conservation of A and L replaced by conservation of a combination of A and L

Sakharov **[3]** suggested a possible interesting way to conserve Q without conserving separately A and L. He proposed to replace the two conservation laws A and L by one sole conservation law of a quantity defined by the combination of A and L namely (3A-L) supposing that quarks and leptons are on the same footing. He evaluated in this framework the lifetime of the proton which turned out to be very large, more than 10^{50} years. This opened the path to examine the conservation of *other* combined baryon and lepton number. The problem is then to find out and to justify what combination would lead to a possible solution to the enigma of the asymmetry of our Universe since conservation of A and L are no more *separately* required. ΔA could thus be different from zero and we emphasize it is a *necessary* condition for any possible interaction leading to a matter-antimatter asymmetric universe. Sakharov tried to explain the most fascinating aspect of our universe: it is material but overlooked the second aspect of our universe which is apparently natural: it is electrically neutral. Indeed these two aspects are inseparable and are the most salient observational features of our universe which is composed of baryons (protons, neutrons) and leptons (electrons, neutrinos). More specifically the positive charge of protons is balanced by the negative charge of electrons. The immediate consequence is the strict equality between the number of protons and the number of electrons **[24, 25]**. The riddle is thus how to evolve from A=0, L=0 and Q=0 universe to A>0 and Q=0 universe via elementary processes with the outcome that at last the number of protons should be equal to the number of electrons. We remark that a process which could create a pair of proton electron (antiproton and antielectron) would satisfy this strict equality. We see then immediately that the conserved 'combined' quantity should be indeed A-L: from A=0, L=0 and Q=0 state (no proton, no

electron) we can go to A=1, L=1 and Q=0 state (one proton, one electron) where the charge of proton is balanced by the charge of electron. We remark that the conservation of 'combined' quantity proposed by Sakharov could not create a material and neutral universe as observed experimentally.

10. Q is not a simple number it is indeed intimately related to A, L and flavours

Electromagnetism depends solely on the value of electric charge Q, but Q is not a simple algebraic number such as A, L or strangeness …it is indeed intimately related to these additive quantum numbers.

In 1961 Gell-Mann proposed the eightfold way model to classify strange hadrons (only strange hadrons were known at that time) into octet of baryons, octet of mesons, decuplet of baryons. All members of a supermultiplet have the same baryon number, spin and parity. In this classification isospin (the third component of isospin I_3) plays a fundamental role. Each particle in the supermultiplet can be represented 'by a point on a coordinate system where one axis represents the quantum number I_3, and the other axis the strangeness. In such a coordinate system our pion-kaon-eta octet yields a symmetrical hexagonal pattern, with one particle at each vertex and two particles at the centre' **[26]**. Many predictions were later verified experimentally in particular members of a multiplet with the same strangeness have approximately the same mass. The most dramatic clue in favour of the correctness of this model was the discovery of Ω^-.

Indeed the eightfold way model lies basically on the Gell-Mann and Nishijima formula in the following form:

$$Q = I_3 + \frac{A + S}{2} \qquad (1)$$

For any hadron, Q is simply related to I_3 and the hypercharge HY= A + S

$$Q = I_3 + \frac{HY}{2} \qquad (2)$$

We underscore that HY is the sum of baryon number which characterize matter particles sensitive to strong interaction and strangeness which is a flavour number. The discovery of other quarks led to redefine HY as

$$HY = A + S + C + B + T \qquad (3)$$

Indeed $I_3 = \frac{U + D}{2} \qquad (4)$

U being the upness and D being the downess U and D are also flavour numbers as S, C, B and T. We can then write Gell-Mann and Nishijima formula in the following form:

$$Q = \frac{A}{2} + \frac{THF}{2} \qquad (5)$$

With the total hadronic flavour THF= D + U + S + C + B +T   (6)

THF is the sum of six hadronic flavours.

This equivalent formula considers all flavours in the same footing. This form is symmetric with respect to flavours. It separates the role of A and flavours. Q is clearly defined by two independent and irreducible quantities. However hadrons are not the only charged particles. Indeed the similarity between the three families of quarks and the three families of leptons allow to assign in analogy with hadron flavours, six lepton flavours D_l, U_l, S_l, C_l, B_l and T_l to e^-, ν_e, μ^-, ν_μ, τ^- and ν_τ.

By analogy, we define the total leptonic flavour TLF as the sum of six leptonic flavours.

THF= D_l + U_l + S_l + C_l+ B_l +T_l (7)

We obtain then a formula for Q valid for leptons, in close analogy with Eq. (5)

$$Q = -\frac{L}{2} + \frac{TLF}{2} \qquad (8)$$

And more generally for any particle (hadrons, leptons, messengers)

$$Q = \frac{A}{2} - \frac{L}{2} + \frac{THF}{2} + \frac{TLF}{2} \qquad (9)$$

or

$$Q = \frac{BAL}{2} + \frac{TF}{2} \qquad (10)$$

with BAL= A-L and TF=THF+TLF

where A is the baryon number, L is the lepton number, THF is the total hadronic flavour, TLF is the total leptonic flavour and TF the total flavour. Baryon number A characterizes matter particles sensitive to strong interaction and lepton number L characterizes matter particles insensitive to strong interaction. It is then natural to group them together into BAL as we group flavours terms into TF. We note that flavour numbers of quarks (baryonic matter) are either positive or negative. BAL is defined as baryon number minus lepton number (or baryon plus antilepton number). BAL is positive for baryonic matter particles sensitive to strong interaction and negative for leptonic matter particles insensitive to strong interaction. Any elementary or composite particle should be defined by these two numbers and not just by the algebraic value of Q which is equal to the half sum of these two independent and irreducible quantities. BAL is reduced to A for hadronic particles, to (-L) for leptons and to 0 for

messengers (γ, W, Z and gluons). Due to this relation, conservation of Q means not only conservation of the number Q but also conservation of two *irreducible* and linearly independent quantities BAL and TF. Each particle is characterized by BAL and TF which together define the value Q. Because of this particular structure of Q, it is evidently necessary that the value of Q is conserved but it is not sufficient. To be complete conservation of electric charge should be understood as conservation of BAL and TF or any of them together with Q considered as a simple number. Indeed conservation of any two of Q, BAL and TF implies automatically the conservation of the third quantity. This complex structure of electric charge could explain why certain processes conserving algebraic value of Q are possible and observed while other processes conserving also apparently Q are never observed and seem to be forbidden.

Conservation of BAL means $\Delta A = \Delta L$ and conservation of TF means $\Delta THF = -\Delta TLF$

One solution could be $\Delta A = \Delta L = 0$ which requires that A and L are separately conserved.

Similarly one solution for $\Delta TF = 0$ is $\Delta THF = -\Delta TLF = 0$

Obviously if each individual flavour is conserved then $\Delta THF = -\Delta TLF = 0$

It is precisely the case for strong interaction and electromagnetism (and also weak interaction through neutral current via the exchange of Z). But THF could remain constant even if some hadronic flavours change (purely hadronic mode) or TLF could remain constant even if some leptonic flavours change (purely leptonic mode). Another interesting case is the case where $\Delta THF = -\Delta TLF = \pm 2$ where change of THF is compensated by the change of TLF (semi-leptonic mode)

Strong interaction and electromagnetism require that A, L and all individual flavours are conserved while Weak Interaction requires only the conservation of A, L and TF. We emphasize that BAL and TF are automatically conserved in all observed reactions and in all reactions which can occur in nature if electric charge is conserved. We point out that Q depends on BAL and not on M=A+L.

11. Conjecture of a novel interaction MC conserving BAL, TF and Q but violating A and L. Possible tests

We point out that conservation of BAL has a solution other than $\Delta A = \Delta L = 0$, namely $\Delta A = \Delta L = \pm 1$ which is astonishingly the very condition required for the creation of a pair of proton electron or a pair of antiproton antielectron. It allows also the creation of a pair of neutron neutrino or antineutron antineutrino.

We could conjecture a novel interaction called Matter Creation (MC) defined by matter creation charge Q_{MC} = BAL and a true neutral messenger Z*(BAL=0, TF=0). Z* could give birth to a baryon lepton pair (or an antibaryon antilepton pair). MC conserves BAL, TF and Q but does not conserve A and L separately while interactions of the Standard Model conserves BAL, TF and Q but conserves also separately A and L. While materialization (through interactions of the Standard Model) creates a matter particle and its antimatter particle mattergenesis through MC creates a pair of matter particles (baryon lepton) or a pair of antimatter particles (antibaryon antilepton). Baryogenesis and leptogenesis are the two faces of the same mechanism mattergenesis.

The general formula

$$Q = \frac{BAL}{2} + \frac{TF}{2} \qquad (10)$$

has very strict implications. Any possible reaction which conserves Q has to fulfil the condition $\Delta A = \Delta L = 0$ or $\Delta A = \Delta L = \pm 1$ (and possibly other integers). We see immediately that neutrinoless double beta decay cannot occur. This hypothetical process could be indeed considered as a very stringent test of our formula. We can thus predict that all future experiments on neutrinoless double beta decay would only give negative results (one could only determine lower limits of half-life whatever the sensitivity is). If it turns out that neutrinoless double beta decay events are *univocally observed* then there would be incompatibility and it would be necessary to find out the reason. More generally unequivocal observation of any process with $\Delta A \neq \Delta L$ would invalidate our formula. MC would allow the disintegration of proton into channels verifying $\Delta A = \Delta L \neq 0$ but would not allow channels implying $\Delta A \neq \Delta L$. Despite gigantic efforts to find out proton decay there is so far no univocal signal. Observation of proton decay if unambiguous should be confronted with our prediction. Z* if it exists is certainly heavier than Z^0 (91 GeV). But it is not necessary that it is as heavy as X bosons in GUTs (10^{15} GeV) and the energy needed to create Z* might be attainable now or in the future in accelerator experiments. The best way to try to create Z* would be to use electron antielectron or proton antiproton collisions. Z* if created would be revealed by the creation of a triquark (uud) and an electron. The signature would be either the detection of an electron together with three jets of quarks (uud) or an electron and a proton.

MC force would permit the creation of either a baryon lepton pair or an antibaryon antilepton pair ($\Delta A = \Delta L = \pm 1$ and $\Delta THF = -\Delta TLF = \pm 1$). The addition of MC force has the advantage to provide a plain and natural explanation of our neutral matter universe, without

losing any feature explainable by the Standard Model. It does not require the existence of an anti-Universe rendering this concept superfluous. We remark also that the creation of our Universe was an historical event. Our model would explain why our Universe could be material and neutral but could not account for the precise value of the excess of matter particles over antimatter particles which should be considered as incidental. We developed a tossing model to explain why asymmetry was necessarily obtained but the value of the asymmetry was incidental **[2]**.

12. Conclusion

Physics is essentially an experimental and observational science. Predictions of any theory have to be confronted with experiments and observations. Conservation laws are the backbone of physics. All observed processes should conserve all *universal laws* and also specific laws associated to the interaction which governs the observed process. Conservation of electric charge Q considered as an algebraic number is believed to be an universal law (dynamical role in electromagnetism; no experimental counterexample) while conservation of baryon number and lepton number is suspected to be not universal because A or L seem not to be source of a field even if there is so far no experimental unequivocal example of either A or L violation in microscopic processes. There is thus no theoretical reason to consider the conservation of these two quantities as universal. In addition there is also observational reason to doubt the universal validity of conservation of A and L. In effect if conservation of A and conservation of L are separately absolute there would be no means to create from pure energy (A=0, L=0, Q=0) our Universe which is known to be material and neutral. Indeed the very existence of our material and neutral universe requires a process violating baryon number but conserving strictly Q. This process should have existed since our universe exists (if our universe was born from an initial state without matter particles and without antimatter particles).

By generalizing the Gell-Mann and Nishijima formula, we obtained a general formula relating Q to other quantities such as baryon number A, lepton number L and flavours. Q should not be considered as a simple number but as the half sum of two irreducible quantities BAL= A-L and total flavour TF. Conservation of electric charge implies obviously conservation of Q (considered as a simple number) but indeed also BAL and TF. All known conservation laws associated to electromagnetism, strong interaction and weak interaction which all conserve A and L correspond to the solution $\Delta A=\Delta L=0$. But $\Delta BAL=0$ has another solution $\Delta A=\Delta L=\pm 1$ which points to a possible solution to explain how a

material and neutral universe could evolve from A=0 L=0 Q=0 state to A>0 Q=0 state through a process which conserves BAL and TF without conserving separately A and L. Because of the structure of Q, conservation of electric charge which is universal requires in reality conservation of three numerical quantities Q, BAL and TF. Conservation of two of them implies automatically the conservation of the third quantity. This is the reason why it is sufficient to verify that A, L and Q are conserved in processes governed by weak interaction.

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