CP violations: beyond field theory?

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Abstract

We investigate CP violations within the theoretical framework introduced in Refs. [1, 2, 3, 4, 5, 6]. In this framework, field theory shows up only as an approximate description. In particular, the breaking of the time reversal symmetry does not rely on a Kobayashi-Maskawa phase. We show how our approach allows to obtain the correct value of the CP asymmetry not only for the decays of K mesons, but also for the D mesons. In the case of B mesons, there is not yet a precise measurement, and our computation results in a prediction compatible with the current experimental bounds. Within the same theoretical framework, we also obtain the correct value of the baryon asymmetry.

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1 Introduction

CP violations are commonly considered part of the frontier of modern physics: on one side, their existence has been since long time experimentally confirmed on the K-mesons system; on the other side, current theoretical models predict their occurrence also in other meson systems, such as the B mesons, for which experimental data are however more questionable, and leave open the possibility of either a confirmation of the Standard Model predictions, or a confutation. There is then the intriguing case of the D mesons, for which the experimental data seem to fall out of the possible range of Standard Model predictions. Indeed, CP violations are often assumed to be a test of new physics, because, within the Standard Model, they are explained as the necessary consequence of imposing the most general possible mass matrix term in the three-families quark system. The most general expression is a complex 3×3 matrix, whose phases can all be re-absorbed into a redefinition of the phase of the quark wave-functions, except one, which survives, leading to a complex mixing that makes processes non-equivalent to their conjugates. Were quark families less than three, there would be no complex phase, and therefore no CP violation. On the other hand, with three families there is only one independent CP violation parameter, that highly constrains the magnitude of this phenomenon in its manifestation in the several meson systems. As long as only data concerning the K mesons system were considered, any possible discrepancy between theoretical explanation and experimental observation was excluded by the triviality of the situation, reduced to adjusting one parameter to one experiment. But now that, due to a better accuracy in experimental data, a second, independent system, the D mesons, is going to gain consideration, things are starting to become less trivial. Indeed, the discrepancy found in attempting to extend to the D system the explanation through the mass matrix phase, as constrained by the K decays, indicates that something in the whole construction does not fit completely. A possible way to gain a further, independent CP violation parameter, is to think at more quarks, or anyway at an enlarged matter sector, perhaps introduced via supersymmetry. This in principle could well be the case. However, from the pure theoretical point of view it remains the bad taste in the mouth of a solution obtained by enlarging the number of free parameters of the theory, in order to accommodate a larger number of experiments. In practice, the non completely satisfying attitude of fitting data with an appropriate parametrization, obtained through ad-hoc extensions of the model, rather than providing a general explanation of them. Apart from being questionable on pure ideological grounds, the attitude of looking for extensions of the model bears the risk of generating in turn also new problems. For instance, quite recently there have been hints of a possible resonance at around 125 GeV at LHC [7], suggesting the production of a neutral particle, possibly to be identified with the Higgs boson [1]. Almost at the same time, an analysis with the minimal supersymmetric extension of the Standard Model has indicated that such a value of the Higgs mass, although permitted, is also rather unnatural for some other aspects, because it would not lead to a natural explanation of some mass hierarchies [8]. This is just an example of what kind of complications arise. One could go on, and say of the further problems concerning Dark Matter, etc. One would say we are in a situation similar to the one complained by Kepler, when he criticized the Ptolemaic model and the

[1] See Ref. [6] for a discussion of this resonance.

technique of adding epicycles to epicycles, as a procedure that generated more problems than it solved.

In this note, we don't consider possible extensions of the Standard Model: we investigate CP violations within the theoretical framework introduced in [1, 2, 3, 4, 5, 6], which from many respects constitutes a somehow new approach "ab initio" to the topics covered by quantum field theory. In this approach, *all* of the physical aspects mentioned above, the origin of masses, the couplings, etc., are organized in a different theoretical scheme, that goes beyond field theory, no matter whether quantum and/or relativistic, supersymmetric or not. We refer the reader to [3, 2, 4, 5, 6] for more detail on the whole construction, and just summarize here some key aspects. In this approach, ordinary quantum field theory shows up as an effective approximation of a description of phenomena in terms of volumes of occupation (entropy) in the phase space of all possible geometries of the universe, identified through their energy content and distribution along space, that can be of any finite dimension. This universe possesses a natural ordering given by the inclusion of sets, where the sets are the configurations describing an energy distribution along space. This is of course only a partial order. A total order is obtained if one introduces classes of configurations: each class is the set of all the configurations corresponding to a certain total amount of energy, each one in principle describing a whole universe. These classes possess therefore an ordering inherited by the one of the configurations, where now the inclusion operation exactly corresponds to the ordering of the values of total energy along the natural numbers. Each of these classes, in principles sets of geometries, represents the physical universe with a given total energy: at any fixed amount of total energy the *physical universe* is given by the *superposition* of <u>*all*</u> *the configurations* corresponding to that total amount of energy. The total energy plays therefore the role of time coordinate. The time ordering is here a logical ordering in the space of classes of configurations, labelled by the amount of total energy. Each class corresponds therefore to the universe at a given time. At any time, three dimensional space arises only as the dimensionality of the universe which occurs in the highest number of configurations. Both the quantum uncertainty on the observables, and the bound on the speed of light leading to Einstein's relativity, arise in the approximation of looking at the universe from the three-dimensional perspective. In this scenario there is by construction no symmetry under time reversal. Indeed, one can show that, at any time, the staple of configurations gives rise to an observable universe in which all symmetries are broken. However, the time coordinate is something deeply different from the space coordinates. Strictly speaking, there is no "space-time": the concept of "space-time" arises only as an approximation, part of an effective description of the fundamental scenario in terms of evolving quantum fields in a three-dimensional space. The breaking of the time reversal symmetry is therefore something conceptually different from the breaking of space parity. Nevertheless, in the approximation of relativistic quantum field theory, the general non-time reversal invariance of the overall evolution of the universe reflects, in the microscopic description of physics, in the breaking of the CP symmetry. On the other hand, the parameter of this symmetry breaking cannot be referred to a deep, intrinsic property of a possible mass matrix of elementary particles, which is in any case just an effective parametrization, only valid in a certain approximation of the fundamental description of physics. In other words, although for practical purposes it is convenient to end up with a description in terms of elementary particles and fields with dynamics determined by the entries of a Lagrangian, the parameters of the effective action are only effective quantities determined time by time, and must be "updated" during the time evolution of the universe. In this perspective, there is therefore no "CP violation phase", and it is not a matter of having enough particles, and therefore matrix entries, to allow for a sufficient number of independent parameters to fit with all possible CP violating decays. Owing to the deep difference between space and time, apparently unified only within an approximated relativistic description, we must expect that, whereas the breaking of space parity (P-breaking) reflects in the form of the terms of the effective action (lack of right-handed interaction terms in the weak interactions), the breaking of CP is not well represented in the effective action.

2 Time reversal asymmetry in the phase space of particles

Once said that in this scenario there is no symmetry under time reversal at the scale of the evolution of the universe, we must see how this reflects also at the microscopic level of the interactions of elementary particles. In order to understand where the CP violation comes from, we must first say that in this scenario the classical part of the geometry of the universe corresponds to a compact space-time, in which the space extends up to the horizon set by the age of the universe $\mathcal{T}$. The masses of the elementary particles behave like ground momenta, the ground energy excitations, of such a compact space. The very basic energy excitation is related to the inverse of the age of the universe $\mathcal{T}$, and corresponds to the square root of the so-called cosmological constant: $\Lambda \sim 1/\mathcal{T}^2$. More in general, an elementary particle of mass m "feels" a space-time of length $\mathcal{T}' \sim 1/m$. Different particles "live" on different proper scales of the space-time. In some sense, this is a kind of generalization of the fact that fermions live on a square-root space-time as compared to bosons, although in the case of masses this fact concerns only the scale, not the geometric properties, of space [2]. In this formulation, masses and couplings measure the weight in the phase space, respectively of particles and fields, and of the processes and interactions related to them. Consequently, the decay amplitudes, or, in general, the interaction amplitudes, correspond to the volumes occupied by the corresponding processes in the appropriate phase space. We must therefore expect that also the amount of violation of time reversal in the weak decays does correspond to an asymmetry in the volume of the phase space for a decay process and its CP-mirror, which reflects the general lack of time-reversal symmetry of the theory at the macroscopic level. Moreover, since time and space parities are symmetries of space-time, we expect that the size of the time-reversal asymmetry should be related to the amount of available volume in the four-dimensional energy-momentum space [3].

[2]It turns out that the elementary masses scale as appropriate roots of the inverse of the age of the universe, $m_i \sim 1/\mathcal{T}^{a_i}$. A similar behaviour show elementary couplings, and, although in a more involved way, also the masses of composite particles, which turn out to depend too on a time scale. This fact not only allows to explain certain deviations in the spectra of quasars [4], and provides the right scaling behaviour to bypass cosmological constraints such as the nucleosynthesis bound [4], but bears also interesting consequences for the interpretation of certain aspects of the evolutionary biology [9].

[3]In our scenario the amplitude of a decay is related to the volume of a coset of symmetry groups. Not all these groups correspond to symmetries, and related volumes, of the physical space. For instance, the symmetry associated to the strong coupling does not: the size of the coupling is related to the volumes of an

In the usual interpretation of the experimental observations, the fact that a certain type of produced particles decay partly into their "natural" channel, and partly in the CP-conjugate channel, is interpreted as due to the oscillation of the initial state from its original configuration to its CP-conjugate, so on back and forth. Weak decays cannot in fact "directly" violate the CP symmetry, a particle cannot decay into an anti-particle; in order to do that, it must before "oscillate" into its anti-particle, and then, as an anti-particle, decay into an anti-particle state. In case of perfect CP-symmetry the amount of decay products belonging to the two CP-conjugate channels would be statistically the same. Instead of that, one observes a slight asymmetry. I am repeating this well known fact because I want to stress that what is physically observed is not the oscillation of the initial state in itself, but the presence in the decay products of states belonging to both the CP-conjugate channels. What any theoretical scenario must be able to explain are therefore not the details of the oscillation in itself, including the very idea of oscillation, which are related to a specific theoretical scheme, but the phenomenology of production of both types of states as end-products, in the right proportion. In our case, we are going to compare the volumes of the two processes, namely the decay into matter and into anti-matter, without bothering about whether this occurs as a direct transition or as an intermediate one, possible through an oscillation of the initial state. Let us consider a generic meson decay. As far as we can factorize the phase space of the single quarks of which the meson is composed, we can concentrate on the quark effectively involved in the decay. This simplification is not valid in the case of mesons with mass very different from the one of the constituent quarks. As discussed in Ref. [4], this occurs for mesons containing quarks with "bare" mass lower or close to the neutron mass, and they will be discussed case by case. In any case, the initial particle occupies a certain volume in the phase space, which, when restricted, via factorization, to the process and the particle under consideration, can be considered to be measured in units of its mass. In the four-space $dE\, d^3p$ the initial particle at rest occupies therefore a volume of size $1 = \left(\frac{m_i}{m_i}\right)^4$. The final particle, the one popping out as decay product, occupies in this space a volume $\left(\frac{m_f}{m_i}\right)^4$. The amplitude of the decay is proportional to the volume of the phase space left free, namely

$$N \propto \left[1 - \left(\frac{m_f}{m_i} \right)^4 \right] . \tag{2.1}$$

Let us consider now the decay into the CP-conjugate of the final state. In order to understand the behaviour in this case we must go back to the early interpretation of anti-matter as negative energy matter. In order to compute the variation in the phase space volume due to time reversal, consider that producing an anti-particle is like creating a "hole" at the place of a particle. Therefore, the volume of the produced particle will not have to be subtracted, but added, to the initial volume:

$$\overline{N} \;\propto\; \left[1 + \left(\frac{m_f}{m_i} \right)^4 \right] . \tag{2.2}$$

internal symmetry. The amplitudes of the weak decays are somewhat mixed, because part of the amplitude depends on the amount of available volume in the four-dimensional energy-momentum space.

The fact that for the decay into the conjugate state the phase space increases should not surprise, because, in the "proper frame" of the final state the time is going backwards, as effectively does an anti-particle when interpreted as a particle in a reflected time arrow. In this time flow, the universe shrinks instead of expanding, so that, once measured in the proper scale of the final particle, the relative volume of this process is larger as compared to the first case: it "weights more", is oversized as compared to the typical scale of the universe. Once normalized to the sum of the two amplitudes, the CP-asymmetry will therefore be of order:

$$\mathcal{A}_{CP} \sim -\left(\frac{m_f}{m_i}\right)^4 . \tag{2.3}$$

How does it happen that, despite this sign of the asymmetry, also at the microscopic level the world progresses in the "right" time direction, and more matter is produced than anti-matter? The key lies in a subtlety of the phase space volumes of quarks. In this scenario, more interacting (and therefore also more charged) particles weight more than less-interacting ones. The electron is heavier than the neutrino, and so on for the leptons of the other families. The up quark would be expected to be heavier than the down quark, because, keeping fixed all the other parameters, it has a larger absolute value of the electric charge. In the case of quarks, however, this hierarchy is true for the heavy quarks, not for those of the first family, the true "up" and "down" quark, the ones out of which stable matter is made. As discussed in [4], if one chooses by convention the sign of the electric charge so that the upper partner of an $SU(2)$ doublet of the weak symmetry is the one positively charged and the one that occupies the larger volume in the phase space, the mechanism of anomaly cancellation as it acts in this theoretical framework requires that the up and down quarks of the first family have flipped electric charge, so that the one that occupies the larger volume in the phase space, and therefore is also the heavier one, is the one which is negatively charged (the d quark), whereas the quark u is lighter. This means that, from the point of view of the phase space, the quark u behaves like a $\bar{d}$, and the d like a $\bar{u}$. Consequence of this exchange of volumes in the phase space is that the CP-asymmetry has opposite sign in the decays to the quarks of the first family. For instance, in the $K \to \pi$ decays the asymmetry is given by:

$$\mathcal{A}_{CP}^{(K)} \sim \left(\frac{m_f}{m_i}\right)^4 . \tag{2.4}$$

Since a process like this one is more frequent than those involving mesons formed with more massive quarks, and it is the principal one leading to the production of particles entirely made of the constituents of stable matter, it follows that all in all matter is indeed produced more frequently than anti-matter.

If, instead of starting with a neutral meson, in our chain of arguments we start with its conjugate, we obtain exactly the same result, 2.3 and 2.4: this is because the volume occupied in the phase space by the CP-conjugate of the initial state is the same, m_i^4, and all the other signs remain the same as before: the proportion of the probabilities of decaying into certain states versus that of decaying into their CP conjugates is the same for the neutral meson and the anti-meson. This is quite correct, because in these arguments we are not inspecting the details of a possible oscillation invoked in order to explain the decay of particles into anti-particles forbidden at the tree level in the ordinary field theory description. What concerns us is the fact that, no matter of whether an oscillation occurs or not, what one observes is the decay of a certain percentage into a channel, and the decay of another percentage into the conjugate channel.

3 CP violation in meson decays

Let us now test our approach on concrete examples. The first case in which historically CP violations have shown up is in the neutral K-mesons system. The K meson is composed by an s and an (anti-) d quark, and mostly decays into pions (one pion plus leptons, or also into more pions at once). The masses of the quarks involved in the transition that characterizes the process, namely $s \to d$, are much lower than the masses of the corresponding mesons, K and π. This means that strong corrections are at work. Indeed, as discussed in Ref. [4], these masses are "attracted" by the "stable" mass scale of the universe, which roughly corresponds to the neutron mass. In order to derive them from the mass of the bare quark components, in Ref. [4] they were treated as perturbations around the neutron mass scale. In the specific case of the computation of the phase space volumes in the purpose of deriving the size of the CP violation effect, we can keep into account these effects by using in the expression 2.4 m_K instead of m_s for m_i and, for m_f, m_π instead of m_d. The possible presence of other pions as decay products does not affect this computation, because, owing to the factorization properties of the phase space, here m_i and m_f stay for the mass of the initial and the final meson involved in the quark decay; in first approximation, the contribution to the phase space volumes of other particles produced in the decay can be neglected, they can be treated as "spectators". Inserting the values of $m_{K_0} \sim 497,6\,\mathrm{MeV}$ and $m_\pi =\sim 134,98\,\mathrm{MeV}$ we obtain:

$$\mathcal{A}_{CP}^{(K)} \sim 5,4 \times 10^{-3} \,, \tag{3.1}$$

to be compared with the experimental results [10]:

$$A_L = \frac{\Gamma(K_L^0 \to \pi^- \ell^+ \nu) - \Gamma(K_L^0 \to \pi^+ \ell^- \nu)}{\Gamma(K_L^0 \to \pi^- \ell^+ \nu) + \Gamma(K_L^0 \to \pi^+ \ell^- \nu)} = (3,32 \pm 0,06) \times 10^{-3} \,. \tag{3.2}$$

and

$$A_T = \frac{\Gamma(\bar{K}^0 \to K^0) - \Gamma(K^0 \to \bar{K}^0)}{\Gamma(\bar{K}_L^0 \to K^0) + \Gamma(K^0 \to \bar{K}^0)} = (6,6 \pm 1,3 \pm 1,0) \times 10^{-3} \,. \tag{3.3}$$

In the case of the D mesons, we have a transition $c \to s$ for the decay $D \to K\pi$, where as before the pion can be treated as spectator. In this case, the mass of the charm quark is slightly above that of the neutron, and we should expect it to be less affected by strong corrections. Indeed, the D mass is not so different from the mass of the c quark. If we insert in 2.3 as initial mass the quark c mass ($\sim 1,3$ GeV), and as final mass the K meson mass (~ 498 MeV), we obtain:

$$-\left(\frac{m_K}{m_c}\right)^4 \sim -2,2\,\% \,. \tag{3.4}$$

If instead we use the D meson mass ($1864,9$ MeV) we obtain:

$$-\left(\frac{m_K}{m_D}\right)^4 \sim -0,508\,\% \,. \tag{3.5}$$

With an "average" mass, $\langle m \rangle = (m_D + m_c)/2$, we would have:

$$-\left(\frac{m_K}{\langle m \rangle}\right)^4 \sim -0,9\,\%\,. \tag{3.6}$$

The experimental asymmetry, as reported by [11], is around $(-0,832 \pm 0,033)\%$.

A third system in which CP violations possibly play an important role is the one of the B mesons. In this case, experimental data are more involved, and, due to the difficulty in tagging the single channels, they are only given as inclusive rates. In order to give a rough estimate of the order of magnitude of the effect we expect in our theoretical framework, we may consider an average within a range starting from the decay $B \to J/\psi$, based on a transition $b \to c$, and therefore expected to be of order $-(m_c/m_b)^4 \sim -7,6 \times 10^{-3}$, passing through the channel $B \to K$, for which we better consider the K mass instead of that of the quark s, $-(m_K/m_b)^4 \sim -(498\,\mathrm{MeV}/4400\,\mathrm{MeV})^4 \sim -1,7 \times 10^{-4}$, to arrive to the semileptonic decay $B \to \ell \ldots$, which gives an almost negligible asymmetry (for instance, for the $B \to \mu$ decay, we have $-(106\,\mathrm{MeV}/4400\,\mathrm{MeV})^4 \sim -3,4 \times 10^{-7}$). The experiments report values around -5×10^{-4}, but with an error larger than the absolute value ($\pm 0,0056$), allowing the result being compatible with zero [10].

Considering the amount of uncertainty in our computations, essentially due to the difficulty of estimating the contribution of the correction to the mass scales around the GeV scale, the agreement with the experimental results, also given with a large amount of uncertainty, is anyway remarkable. It is interesting that, in our framework, we can not only predict with a reasonable accuracy the absolute values of the asymmetries, but also account for their sign.

4 CP violation in neutron decays: the baryon asymmetry

In our scenario there is a priori no no-go condition preventing the occurrence of baryon number violating decays. Similarly to what happens for the condition of three-dimensionality of space-time, also a situation in which there is no baryon number violating vertex, like in the Standard Model, is here recovered only statistically, being the baryon number violating process very rare in the phase space. If we consider a neutron beta decay into proton plus electron and neutrino we find that its phase space volume is much much larger than that of the CP-conjugate, baryon number violating decay channel:

$$A_{CP} = \frac{m_p^4}{m_n^4} \sim 0,995\,. \tag{4.1}$$

As one can expect, also in our scenario baryons can be produced out of non-baryonic states through baryon-antibaryon pair production, followed by asymmetric decay, with preference for one of the two CP-conjugate states. Indeed, in the universe one observes a baryon to photon ratio η [12],

$$\eta = \frac{n_B}{n_\gamma} = (5,5 \pm 0,5) \times 10^{-10}\,, \tag{4.2}$$

which can be interpreted as the result of the progressive annihilation of proton against anti-protons during the phase of cooling down of the universe, namely, before the average temperature of photons fell down below the mass-threshold for the proton-antiproton pair production, $T_\gamma < 2m_p$ [4]. In this interpretation, the present value of n_B/n_γ should be what remains of the asymmetry $(n_B - n_{\bar{B}})/n_\gamma$. The Kobayashi-Maskawa mechanism doesn't allow to account for such a high value of the asymmetry as the one which is observed. In our case, the size of CP violation effect depends on time (the age of the universe), and at earlier times it was stronger due to the fact that masses were (relatively) closer to each other. Namely, the absolute value of the difference of masses was larger, because all of them were closer to the Planck scale. But the ratio of mass differences to their absolute value was lower. Therefore, from expressions 2.3 and 2.4 one can see that the amount of CP violation was higher. However, also the evolution of the universe occurs in a different way. There is certainly a cooling down, but this is driven by the temperature of the universe as a black hole (see [2]), with temperature $T \sim 1/\mathcal{T}$. The energy densities of matter and radiation are always of the same order, $\rho_{m,r} \sim 1/\mathcal{T}^2$, therefore there is no phase in which there is a sea of photons predominantly with an energy higher than that of matter: the mean energies of photons and matter scale almost in the same way along the history of the universe [4]. In our scenario, the photon abundance, or equivalently the baryon asymmetry, does not come from the pre-history of the universe, but reflects instead a "stationary condition", as we now explain. Let us consider the neutron beta-decay. According to 4.1 one would think that from neutrons only protons are produced, and almost no anti-protons. However, the process of proton (or antiproton) production through neutron decay doesn't go on till the complete disappearance of the neutrons. The reason is that the decay products of the neutron, namely the proton, the electron, and the neutrino, are all end-products, which cannot further decay because they are already the particles of minimal mass, at the end of the decay chain. They can instead easily recombine to reproduce the neutron, so that, apart from some unstable isotopes, neutron and proton are found in nature basically in equal number. Owing to this "equilibrium" condition, with good approximation we may think that all the protons existing in the universe come from neutron decays, and that the baryon asymmetry should be computed from the properties of the neutron decay. However, expression 4.1 is of no help in deriving the amount of protons (antiprotons) effectively produced, and says nothing about the number of photons one eventually produces as the result of proton-antiproton annihilation. In order to derive the CP asymmetry in the neutron/proton system through an analysis of the volumes of the phase space we must take into account the fact that, unlike the decays considered in the previous section, here we have a process at equilibrium. That means, there is no net change in the volume of the phase space. One starts with a neutron/proton system and ends up again with a neutron/proton system. There is nevertheless a transition, involving the passage from up to down quarks and vice-versa, but this has to be treated as a fluctuation. It can be viewed as a sort of oscillation of the system p, n, e, ν:

$$(p, n, e, \nu) \leftrightarrow (\bar{p}, \bar{n}, e^+, \bar{\nu}) \, . \tag{4.3}$$

Consider the transition neutron-proton. There are three quarks involved, namely (u, d, d), which go into (u, u, d). It would seem that, as net change, we just have the decay $d \to u$.

[4]For an introduction see for instance [13].

However from the point of view of the phase space this is not so simple. Owing to the fact that, unlike the mesons, neutron and proton are made of three quarks, and therefore are $SU(3)$ singlets in which the colour symmetry mixes up degrees of freedom of all the three quarks, in the transition from neutron to proton all the three quarks are involved, in something like: $u \to d$, $d \to u$, $d \to u$ [5]. During this transition one physically generates a fluctuation in the volume of the phase space corresponding to a mass fluctuation of order $\Delta m = 3\Delta m_{d\to u}$. For what matters the CP violation the volume of the neutron does not count, and the only asymmetry in the phase space is given by the transition $0 \to 0 \pm \Delta m$, where Δm is measured in units of the neutron mass. In order to take into account the renormalization due to the strong corrections, for $\Delta m_{d\to u}$ we don't take the bare quark mass difference, but the neutron-proton mass difference. The so computed CP asymmetry should correspond to one-half of the expression 4.2, because for any pair of proton/antiproton which annihilate one produces two photons [6], and we can in first approximation neglect the photons produced by electron-positron and neutrino-antineutrino annihilation (the latter obtained through the intermediate production of a neutral boson), because in general of much lower energy. We obtain therefore:

$$\left[\frac{3(m_n - m_p)}{m_n}\right]^4 = \frac{n_B - n_{\bar{B}}}{2\, n_\gamma}\,. \tag{4.4}$$

Inserting the current mass values, we obtain:

$$\left[\frac{3(m_n - m_p)}{m_n}\right]^4 = 2,87 \times 10^{-10}\,, \tag{4.5}$$

and therefore:

$$\eta_{\text{predicted}} \sim 5,74 \times 10^{-10}\,. \tag{4.6}$$

Notice that this computation does not rely on the details of the various (virtual) channels, because, like in the CP violating decays, it considers only the net fluctuation between initial and final state. Therefore, the value we obtain in this way in principle accounts for the contribution of all the various virtual channels through which this transition may be thought to occur. This value is a ratio of two mass scales which have almost the same time-dependence. Therefore, it has almost no time-dependence, and we expect it to approximately correspond to the value 4.2, derived in Ref. [12] from nucleosynthesis constraints.

The analysis we have presented in this work strongly suggests that the mechanism of CP violation could well be a signal not simply of "new physics" in the usual sense this term is intended, but of a new approach to the whole construction of the physics of elementary particles. The approach we propose does, as it should, well reproduce the properties which are already well computed within the traditional field theory framework the Standard Model is based on, but allows to look through a new perspective at all the aspects concerning

[5] Mesons are instead of type $q\bar{q}$, for which $SU(3)$ singlets are built up diagonally.

[6] Pair annihilation produces a double photon due to momentum conservation (there cannot be a photon with zero momentum).

in general the mass sector (see Ref. [4] for a detailed derivation of all the masses of the elementary particles), and in particular CP violations, including the photon abundance and baryon asymmetry. Within this approach, also the strong CP problem looks different. Since the CP violating mechanism is related to the amount of "free" phase space made available at the net of the mass difference between initial and final state, strong interactions are not expected to give rise to CP violation: they don't in fact give rise to mass differences, because they are not a broken symmetry, but a confining symmetry. This symmetry is not observed as an interaction between free particles, not because it is too heavily broken, but because it is too strong. According to the discussion of [4] and [6] about the origin of mass differences, different quark colour states have the same mass because, owing to confinement, different quark colours occupy the same volume of phase space. In this scenario, configurations corresponding to a description of quarks through Lagrangians containing strong CP violating terms occupy a very small volume in the phase space of all the configurations. They are not perceived as giving rise to different states, but as quantum fluctuations of the dominant configuration of the universe.

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