Baryogenesis via the packaged entanglement states with C-symmetry breaking

Rongchao Ma
Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China

Baryogenesis, or the origin of matter-antimatter asymmetry of the universe, is one of the major unsolved problems in physical cosmology. Here we present a new interpretation to the baryogenesis based on the theory of packaged entanglement states in which the particles are indeterminate and hermaphroditic. A measurement or an external perturbation to these packaged entanglement states will cause the wave function to collapse and therefore break the system's C-symmetry. This process satisfies the Sakharov conditions. By further proposing an entanglement selection principle, we can give a self-consistent interpretation to the origin of matter-antimatter asymmetry produced in early universe. Thus, the collapse of packaged entanglement states with C-symmetry breaking could be or at lease contribute to the origin of matter-antimatter asymmetry.

I. Introduction.— Baryogenesis [1–6] usually refers to the physical process that caused the imbalance between baryons and anti-baryons produced after the Big Bang. The existing physical theories [7] predict that there should be equal amount of matter and antimatter created in early universe. However, the observations show that there is far more matter than antimatter in the present universe [8–11]. This means that our universe either started with more matter than antimatter, or started with equal amount of matter and antimatter but later became matter dominated due to some unknown physical laws. Most research works focused on the latter.[1] In 1967, Sakharov [12] proposed three necessary conditions for a physical process that can lead to the matter-antimatter asymmetry. Up to now a number of mechanisms were proposed to address the matter-antimatter asymmetry, such as Higgs field baryogenesis [13], electroweak baryogenesis [14, 15], leptogenesis [16, 17], Affleck-Dine baryogenesis [18], GUT (grand unified theory) baryogenesis [19, 20], Planck-scale baryogenesis [1], etc.

The present work is motivated by the early works in which we show that C-symmetry breaking occurs in the collapse of so-called packaged entanglement states.[21, 22] More specifically, particles can form the packaged entanglement states in which the particles are indeterminate and hermaphroditic. The packaged entanglement states are the eigenstates of charge conjugation operator C. In some of the packaged entanglement states, however, the total charge are not conserved after the wave function collapse. This phenomenon directly leads to the imbalance between particles and antiparticles, or particle-antiparticle asymmetry. Therefore, the collapse of packaged entanglement states with C-symmetry breaking may be responsible for the matter-antimatter asymmetry of our universe.

In this letter, we first show that the collapse of packaged entanglement states satisfies the Sakharov conditions. Next, we proposed an "entanglement selection principle" to explain why the particles created after the Big Bang are in the packaged entanglement states, but not in the separable states. Finally, we concluded that the collapse of packaged entanglement states is responsible for the baryogenesis and also discussed the characters of the baryogenesis mechanisms.

II. Packaged entanglement states and Sakharov conditions.— Any physical processes that can lead to the matter-antimatter asymmetry must satisfy certain necessary conditions. In 1967, Sakharov [12] proposed three necessary conditions for these physical processes: 1. Violation of baryon number B, 2. Violation of C-symmetry and CP-symmetry, 3. Thermal nonequilibrium. One can see that, to explain the observed matter-antimatter asymmetry in our universe, a possible way is to construct a theory that describes a physical process which can result in C-symmetry breaking.

Ref. [22] has shown that a M-particles system can forms a basis consisted with 2^M packaged entanglement states, i.e.,

$$
\begin{aligned}
\left|\Phi^{\pm}\right\rangle_1 &= \frac{1}{\sqrt{2}}\left(\left|P\right\rangle_1\left|P\right\rangle_2\left|P\right\rangle_3\cdots\left|P\right\rangle_{M-1}\left|P\right\rangle_M \pm \left|\bar{P}\right\rangle_1\left|\bar{P}\right\rangle_2\left|\bar{P}\right\rangle_3\cdots\left|\bar{P}\right\rangle_{M-1}\left|\bar{P}\right\rangle_M\right),\\
\left|\Phi^{\pm}\right\rangle_2 &= \frac{1}{\sqrt{2}}\left(\left|\bar{P}\right\rangle_1\left|P\right\rangle_2\left|P\right\rangle_3\cdots\left|P\right\rangle_{M-1}\left|P\right\rangle_M \pm \left|P\right\rangle_1\left|\bar{P}\right\rangle_2\left|\bar{P}\right\rangle_3\cdots\left|\bar{P}\right\rangle_{M-1}\left|\bar{P}\right\rangle_M\right),\\
\left|\Phi^{\pm}\right\rangle_3 &= \frac{1}{\sqrt{2}}\left(\left|P\right\rangle_1\left|\bar{P}\right\rangle_2\left|P\right\rangle_3\cdots\left|P\right\rangle_{M-1}\left|P\right\rangle_M \pm \left|\bar{P}\right\rangle_1\left|P\right\rangle_2\left|\bar{P}\right\rangle_3\cdots\left|\bar{P}\right\rangle_{M-1}\left|\bar{P}\right\rangle_M\right),\\
&\cdots\cdots\cdots,\\
\left|\Phi^{\pm}\right\rangle_{2^{M-1}} &= \frac{1}{\sqrt{2}}\left(\left|\bar{P}\right\rangle_1\left|\bar{P}\right\rangle_2\left|\bar{P}\right\rangle_3\cdots\left|\bar{P}\right\rangle_{M-1}\left|P\right\rangle_M \pm \left|P\right\rangle_1\left|P\right\rangle_2\left|P\right\rangle_3\cdots\left|P\right\rangle_{M-1}\left|\bar{P}\right\rangle_M\right).
\end{aligned}
\tag{1}
$$

All the packaged entanglement states in Eq.(1) are the eigenstates of charge conjugation operator C. Some of the packaged entanglement states have unequal number of Ps and $\bar{P}$s (see the first half or the second half combinations on the right side of in Eq.(1)). The C-symmetry does not hold in the collapse of these wave functions. Let us now choose $\left|\Phi^{+}\right\rangle_1$ to show that the collapse of these states satisfy the Sakharov conditions [12].

1. Violation of baryon number B. Currently, there is no direct experimental evidences [5] that show the violation baryon number B. However, this violation is obviously necessary to produce the matter-antimatter asymmetry, which can be described by the asymmetry parameter [23] $\eta_B = (n_B - n_{\bar{B}})/n_\gamma \simeq n_B/n_\gamma = (6.19 \pm 0.15) \times 10^{-10}$, where n_B, $n_{\bar{B}}$, and n_γ are the overall number density of baryons, anti-baryons, and cosmic background radiation photons, respectively. Let us now use the theory of packaged entanglement states to give a possible explanation to this fact.

Due to a measurement or some external perturbation, the packaged entanglement state $\left|\Phi^{+}\right\rangle_1$ will collapse into either the separable state $\left|\Theta\right\rangle_1 = \left|P\right\rangle_1\left|P\right\rangle_2\left|P\right\rangle_3\cdots\left|P\right\rangle_{M-1}\left|P\right\rangle_M$, or the separable state $\left|\bar{\Theta}\right\rangle_1 = \left|\bar{P}\right\rangle_1\left|\bar{P}\right\rangle_2\left|\bar{P}\right\rangle_3\cdots\left|\bar{P}\right\rangle_{M-1}\left|\bar{P}\right\rangle_M$.

In the separable state in $\left|\Theta\right\rangle_1$, the total electric charge (Q), baryon number (B), lepton number (L), isospin (I_3), charm (C), strangeness (S), topness (T), and bottomness (B') are the sums of that of each particles, respectively.[24] In the separable state $\left|\bar{\Theta}\right\rangle_1$, each particle conjugates to that in $\left|\Theta\right\rangle_1$. Therefore, the quantum numbers of $\left|\bar{\Theta}\right\rangle_1$ are negative, i.e., $-Q$, $-B$, $-L$, $-I_3$, $-C$, $-S$, $-T$, and $-B'$, respectively. However, the packaged entanglement state $\left|\Phi^{+}\right\rangle_1$ is a linear combination of $\left|\Theta\right\rangle_1$ and $\left|\bar{\Theta}\right\rangle_1$. Thus, all the quantum numbers Q, B, L, I_3, C, S, T, and B' are zeros.[21] This means that the collapse of $\left|\Phi^{+}\right\rangle_1$ not only violates the baryon number B, but also violates the other packaged quantum numbers, i.e., B, L, I_3, C, S, T, and B'.

2. Violation of C-symmetry and CP-symmetry. From above discussion we see that all the total packaged quantum numbers of $\left|\Phi^{+}\right\rangle_1$ are 0s, but those of $\left|\Theta\right\rangle_1$ are Q, B, L, I_3, C, S, T, B' respectively, and those of $\left|\bar{\Theta}\right\rangle_1$ are $-Q$, $-B$, $-L$, $-I_3$, $-C$, $-S$, $-T$, $-B'$ respectively.

A measurement or some external perturbation will cause the packaged entanglement state $\left|\Phi^{+}\right\rangle_1$ to collapse into either the separable state $\left|\Theta\right\rangle_1$, or the separable state $\left|\bar{\Theta}\right\rangle_1$. It doesn't matter how one applies the operators C, CP, or CPT to the separable state $\left|\Theta\right\rangle_1$ (or $\left|\bar{\Theta}\right\rangle_1$), he/she cannot send $\left|\Theta\right\rangle_1$ (or $\left|\bar{\Theta}\right\rangle_1$) back to the packaged entanglement state $\left|\Phi^{+}\right\rangle_1$. This means that the collapse of $\left|\Phi^{+}\right\rangle_1$ breaks C, CP, and CPT symmetry.[25, 26]

3. Thermal nonequilibrium. The particles in packaged entanglement state $\left|\Phi^{+}\right\rangle_1$ are indeterminate and hermaphroditic. But the particles in separable state $\left|\Theta\right\rangle_1$ (or $\left|\bar{\Theta}\right\rangle_1$) are determinate, i.e., they are either particles or antiparticles. A measurement or some external perturbation will cause the state $\left|\Phi^{+}\right\rangle_1$ to jump into the separable state $\left|\Theta\right\rangle_1$, or $\left|\bar{\Theta}\right\rangle_1$.

One can see that the packaged entanglement state $\left|\Phi^{+}\right\rangle_1$ is similar to an "unstable" state, but the separable states $\left|\Theta\right\rangle_1$, or $\left|\bar{\Theta}\right\rangle_1$ are similar to "stable" states. Therefore, the collapse of $\left|\Phi^{+}\right\rangle_1$ into $\left|\Theta\right\rangle_1$ (or $\left|\bar{\Theta}\right\rangle_1$) is an irreversible or a one way process. This physical process along with the expansion of universe assure the departure from thermal equilibrium.[5]

III. Entanglement selection principle.— We have shown that the collapse of packaged entanglement states with C-symmetry breaking satisfies the Sakharov conditions and therefore results in matter-antimatter asymmetry. But we still need to answer the question why the particles created in early universe are in the packaged entanglement states (in which the particles are indeterminate), but not in the separable states (in which the particles are determinate). This could be explained by the idea of universal selection from the universal Darwinism (generalized Darwinism) [27–29].

By applying the theory of Darwinism to the packaged entanglement state, we will show that: *the particles created in the separable states are short-lived due to the particle-antiparticle annihilation, but the particles created in the packaged entanglement states with C-symmetry breaking can be long-lived and survive until today.* Because the selection criteria used here is based on the packaged entanglement states, we shall call such a selection process as "entanglement selection" for the purpose of specifying its unique feature.

According to Dirac's theory [7], particles must be created in particle-antiparticle pairs. This condition can be satisfied by a separable state with equal amount of particles Ps and antiparticles $\bar{P}$s, i.e., $|\Theta\rangle = |P\rangle_1 |P\rangle_2 |P\rangle_3 \cdots |P\rangle_N |\bar{P}\rangle_1 |\bar{P}\rangle_2 |\bar{P}\rangle_3 \cdots |\bar{P}\rangle_N$. It can also be satisfied by the packaged entanglement states in Eq.(1) in which each particle in the first half conjugates to that in the second half (see the right side of Eq.(1)).

According to quantum mechanics, each state that satisfies the above particle-antiparticle pair condition is possible to occur. If a group of elementary particles are created in a separable state, say $|\Theta\rangle = |P\rangle_1 |P\rangle_2 |P\rangle_3 \cdots |P\rangle_N |\bar{P}\rangle_1 |\bar{P}\rangle_2 |\bar{P}\rangle_3 \cdots |\bar{P}\rangle_N$, then there should be equal amount of particles and antiparticles. In early universe, these particles and antiparticles should locate in a limited volume and they should annihilate each other. In this sense, the particles created in the separable state $|\Theta\rangle$ won't live long and will go back to radiation quickly. Afterwards, the radiation (or energy) creates a group of new particles again. This creation-annihilation process will continue and finally stop until the particles happen to be created in one of the packaged entanglement states, which collapse and break the C-symmetry. Finally, an unequal amount of particles and antiparticles is obtained according to Eq.(1). Finally, a small amount of antiparticles will annihilate an equal amount of particles. These short-lived particles pairs will go back to radiation again and start a new entanglement selection process. But the remnant particles that are not annihilated will survive.

The above entanglement selection principle also indicates that it is a random result that our universe is made of matter, but not anti-matter. More specifically, it depends on the initial condition at the moment of wave function collapse. For example, if the packaged entanglement state $|\Phi^+\rangle_1$ collapse and happened to roll into $|\Theta\rangle_1$, then an universe made of matter is created. However, if $|\Phi^+\rangle_1$ happened to roll into $|\bar{\Theta}\rangle_1$, then an anti-universe made of antimatter is created.

IV. Discussion.— We have studied the mechanism of baryogenesis based on the collapse of packaged entanglement states with C-symmetry breaking. In this section, we would like to further discussion its characters by comparing with other existing mechanisms of baryogenesis.

As mentioned before, the matter-antimatter asymmetry in the observable universe [8–11] could be interpreted in two ways: 1. the universe started with more matter than antimatter; 2. the universe started with equal amount of matter and antimatter but later became matter dominated due to some physical laws. The mechanism proposed in this work belongs to the second way. In fact, the baryon asymmetry is generated after the inflation. This is similar to the other existing theories of baryogenesis.

The baryogenesis theory proposed in this work used quantum mechanics to describe the mechanism that produced the matter-antimatter asymmetry. The main point is the collapse of wave function of the packaged entanglement states. However, the other baryogenesis theories [13, 14, 16, 18, 19] used quantum field theory and statistical mechanics to describe the mechanism of baryogenesis. The main points in these theories are the interactions between elementary particles.

Finally, we would like to mention that the baryogenesis based on packaged entanglement states may indicate the possibility of multiverse [30–32]. It at least does not rule out the possibility of multiverse. This is because the entanglement selection principle results in the random origin of the universe, which means that the structure and composition of a universe is not unique. This multiple origin indicates that there is no reason why the existence of universe is unique, but not multiple.

V. Conclusion.— In summary, the collapse of packaged entanglement states with C-symmetry breaking satisfies the Sakharov conditions, i.e., violation of baryon number B, violation of C-symmetry and CP-symmetry, and thermal nonequilibrium. An entanglement selection principle is proposed to explain why the particles and antiparticles created in early universe is in the packaged entanglement states. Combining the above two ideas, one can give a self-consistent explanation to the imbalance between baryons and anti-baryons produced in early universe.

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