The paper "VIOLATION OF CP INVARIANCE, C ASYMMETRY AND BARYON ASYMMETRY OF UNIVERSE."(A. D. Sakharov, 1967)

The paper [1] addresses the fundamental question of the asymmetry between matter and antimatter in our universe. The Dirac equation predicts the existence of antiparticles along with the corresponding particles. It has been verified experimentally that every known kind of particle has a corresponding antiparticle. The CPT Theorem guarantees that a particle and its antiparticle have exactly the same mass and lifetime, and opposite charge. Given this symmetry, it is puzzling that the universe does not have equal amounts of matter and antimatter. Indeed, there is no experimental evidence that there are any significant concentrations of antimatter in the observable universe.

There are two main interpretations for this disparity: either the universe began with a small preference for matter (total baryonic number of the universe different from zero), or the universe was originally perfectly symmetric, but somehow a set of phenomena contributed to a small imbalance in favor of matter over time. The second point of view is preferred, although there is no clear experimental evidence indicating either of them to be the correct one.

In his 1967 paper, Andrei Sakharov proposed a set of three necessary conditions that a baryon-generating interaction must satisfy to produce matter and antimatter at different rates. These conditions were inspired by the recent discoveries of the cosmic background radiation and CP-violation in the neutral kaon system. The three necessary "Sakharov conditions"are:

1) Baryon number B violation.
2) C-symmetry and CP-symmetry violation.
3) Interactions out of thermal equilibrium.

Baryon number violation is obviously a necessary condition to produce an excess of baryons over anti-baryons. But C-symmetry violation is also needed so that the interactions which produce more baryons than anti-baryons will not be counterbalanced by interactions which produce more anti-baryons than baryons. CP-symmetry violation is similarly required because otherwise equal numbers of left-handed baryons and right-handed anti-baryons would be produced, as well as equal numbers of left-handed anti-baryons and right-handed baryons. Finally, the interactions must be out of thermal equilibrium, since otherwise CPT symmetry would assure compensation between processes increasing and decreasing the baryon number.

Currently, there is no experimental evidence of particle interactions where the conservation of baryon number is broken perturbatively: this would appear to suggest that all observed particle reactions have equal baryon number before and after. Mathematically, the commutator of the baryon number quantum operator with the (perturbative) Standard Model hamiltonian is zero: $[\hat{\mathbf{B}}, \hat{\mathbf{H}}] = \hat{\mathbf{B}}\hat{\mathbf{H}} - \hat{\mathbf{H}}\hat{\mathbf{B}} = 0$. However, the Standard Model is known to violate the conservation of baryon number non-perturbatively: a global U(1) anomaly. Baryon number violation can also result from physics beyond the Standard Model (see supersymmetry and Grand Unification Theories).

The second condition - violation of CP-symmetry- was discovered in 1964 (direct CP-violation, that is violation of CP-symmetry in a decay process, was discovered later, in 1999). Due to CPT-symmetry, violation of CP-symmetry demands violation of time inversion symmetry, or T-symmetry.

In the out-of-equilibrium decay scenario, the last condition states that the rate of a reaction which generates baryon-asymmetry must be less than the rate of expansion of the universe. In this situation the particles and their corresponding antiparticles do not achieve thermal equilibrium due to rapid expansion decreasing the occurrence of pair-annihilation.

The work by Sakharov remained unnoticed for several years, and the key hypothesis of baryonic charge nonconservation, which is necessary for the generation of an asymmetry between baryons and antibaryons, was not accepted until the models of Grand Unification were put forward in 1974. After it was understood that nonconservation of baryons might be quite a natural and general phenomenon, the attitude to the possibility of a dynamical generation of baryon asymmetry of the universe changed drastically. Acceptance of Sakharov's ideas stimulated the flood of papers which remained unabated ever since.

[1] A. D. Sakharov JETP Lett.-USSR **5**,24 (1967).