V. A. Kuz'min. *Quarks and cosmology*. Unified Gauge Theories (UGT)[1,2] of strong, weak, and electromagnetic interactions have recently undergone considerable development. The gigantic scale on which all "low-energy" interactions ($10^{14}-10^{15}$ GeV) are unified means that the Universe at the early stages in its expansion—at $t \sim 10^{-34}$ sec and temperatures $T \sim 10^{14}$ GeV—was a natural "testing grounds" for the theory of the grand unification.

Study of the phase transitions[3-6] that take place in the UGTs as the Universe cools from its original singular state are of special interest from the cosmological standpoint. Critical phenomena in which the gauge-invariance group changes may strongly influence the evolution of the Universe. Their dynamics may determine the concentration of magnetic monopoles in the Universe[7,8,6] and the magnitude of its baryonic asymmetry.[9] Already in the minimal UGT based on the SU(5) group[1)] the phase-transition picture is quite varied, changing with the renormalized coupling constants of the original Lagrangian. The following variants of vacuum-symmetry evolution are possible:

1. The "standard" variant.[10] At a certain temperature T_1 during cooling of the Universe, the vacuum average first appears in the Φ field. The following phase transitions may occur in this case[2)]:

a) The system may go from the SU(5) symmetric-phase to the SU(3) ×SU(2) ×U(1) phase, either directly:

$$SU(5) \xrightarrow{T_1} SU(3) \times SU(2) \times U(1),$$

b) or through the intermediate SU(4) ×U(1) phase:

$$SU(5) \xrightarrow{T_1} SU(4) \times U(1) \xrightarrow{T_3} SU(3) \times SU(2) \times U(1).$$

c) Finally, even within the framework of the scheme considered here (when the Higgs 24-plot acquires the vacuum average before the quintet), we may have a nonstandard and extremely interesting variant of the development of the Universe in which domains with different gauge-invariance groups may exist simultaneously in different regions of space at a certain stage in the evolution of the Universe:[10]

$$SU(5) \xrightarrow{T_1} \left\{ \begin{matrix} SU(4) \times U(1) \\ SU(3) \times SU(2) \times U(1) \end{matrix} \quad \text{domains} \right\} \xrightarrow{T_3} SU(3) \times SU(2) \times U(1).$$

We note that, first of all, the domains with vacuums SU(4) ×U(1) and SU(3) ×SU(2) ×U(1) expand differently, i.e., the SU(4) ×U(1) domains expand more rapidly; secondly, no baryon excess forms in SU(4) ×U(1) domains, while the formation of the baryonic asymmetry proceeds as usual in SU(3) ×SU(2) ×U(1) domains.[9] This results in nonuniform distribution of matter in the Universe and perhaps eventually in the formation of galaxies and clusters of galaxies. Latent heat is released during the phase transitions; for instance the vanishing of domains with SU(4) ×U(1) symmetry may be accompanied by local explosions of certain regions of space. Therefore the existence of domains may also have resulted in thermal inhomogeneity of the Universe.

In this evolutionary scheme, the magnitude of the BAU (Baryonic Asymmetry of the Universe) generated in the minimal SU(5) is $\Delta \sim 10^{-14}$ ($\Delta = n_B/n_\gamma$, where n_B and n_γ are the baryon and photon concentrations, respectively), and the Higgs sector must expand to two quintets.[11]

2. The other, "unusual," variant was found by this author together with I. I. Tkachev and M. E. Shaposhnikov and consists of the following. In a certain ("natural") range of values of the coupling constants, the vacuum average appears first in the quintet as the system cools, and then in the 24-plet. In this case, the electrically weak $SU(2)_L$ group is ultrastrongly violated at $T \sim 10^{14}$ to 10^{15} GeV, i.e., the masses of the $W^\pm$, Z bosons and fermions are $\sim 10^{14}$ GeV, and BAU generation occurs in the SU(3) ×U(1) phase. Here the minimal SU(5) model predicts $n_B/n_\gamma \sim 10^{-7}$, which is quite satisfactory considering the dilution that follows.

As the temperature drops further, the $SU(2)_L$ group is restored, but it is violated again at $T \sim 100$ GeV (see Fig. 1). In this case the evolution of the symmetry group looks like this:

$$SU(5) \xrightarrow{T_1} SU(4) \xrightarrow{T_2} SU(3) \times U(1) \xrightarrow{T_3} SU(3) \times SU(2) \times U(1) \xrightarrow{T_{SW}} SU(3) \times U(1).$$

In any evolutionary variant, domains with different symmetry groups must vanish by time $T = 0$, otherwise the existence of the walls between domains would contradict observational data.[12] Therefore the baryonically symmetric cosmology with macroscopic matter and antimatter domains in the Universe, which arises on spontaneous violation of *CP* parity (BAU of the opposite

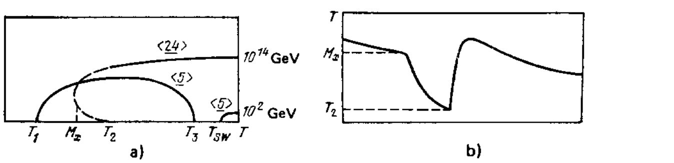

FIG. 1. a) Schematic temperature dependence of vacuum averages of 24 and 5 fields; b) schematic time dependence of temperature.

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1)I.e., the theory with two representations of the Higgs fields: a 24-plet Φ with a vacuum average $V \sim 10^{14}$ GeV and a quintet H with $v \sim 100$ GeV.

2)Before the appearance of the vacuum average in the H field.

sign is generated in domains with different *CP* parities[13]), can obtain only if the walls between domains vanish at a certain early stage in the evolution of the Universe.

The mechanism by which the *CP* walls vanish may be a phase transition[14] in which the complex vacuum average that ensures spontaneous violation of *CP* at high temperatures disappears. Then at all T (including $T = 0$), *CP* parity must be violated explicitly (this requirement is satisfied naturally in the Unified Gauge Theories). Depending on the relation between explicit and spontaneous *CP* violation in a theory with vanishing *CP* walls at low temperatures, we arrive either at an island structure of the Universe with domains of matter and antimatter or at inhomogeneities in the distribution of matter in the Universe.[14]

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