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Phase transitions, anomalous baryon number violation and electroweak multiplet dark matter

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Our study presents a comprehensive analysis of baryon number violation during the electroweak phase transition (EWPT) within the framework of an extended scalar electroweak multiplet. We perform a topological classification of scalar multiplet's representation during the EWPT, identifying conditions under which monopole or sphaleron field solutions emerge, contingent upon whether their hypercharge is zero; which indicates that only monopole scalar multiplet can contribute to the dark matter relic density. We also conduct a systematic research of other formal aspects, like the construction of higher dimensional sphaleron matrix, computation of the sphaleron and monopole mass, and the analysis of boundary conditions for the field equation of motions. We then scrutinize the computation of sphaleron energy and monopole mass within the context of a multi-step EWPT, employing the SU(2) septuplet scalar extension to the Standard Model (SM) as a case of study. In the scenario of a single-step EWPT leading to a mixed phase, we find that the additional multiplet's contribution to the sphaleron energy is negligible, primarily due to the prevailing constraint imposed by the ρ parameter. Conversely, in a two-step EWPT scenario, the monopole mass can achieve significantly high values during the initial phase, thereby markedly constraining the monopole density and preserving the baryon asymmetry if the universe undergoes a first-order phase transition. In the two-step case, we delineate the relationship between the monopole mass and the parameters relevant to dark matter phenomenology.

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