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Construction and stability of regular multihorizon black holes in nonlinear electrodynamics

Regular black holes are characterized by the presence of an event horizon together with metric functions and curvature invariants that remain finite throughout spacetime. In this work, we construct three new static regular black hole solutions with a multihorizon structure within Einstein gravity coupled to nonlinear electrodynamics under the assumption of spherical symmetry. For each solution, we also present the corresponding nonlinear electrodynamics Hamiltonian.

The resulting metric functions give rise to a horizon structure whose evolution is determined by the electric charge q. The first solution exhibits up to four horizons for low values of the electric charge. As the charge increases, two of the inner horizons merge and disappear, while the remaining two eventually coincide in the extremal case. Therefore, the outer horizon is preserved throughout the evolution, as the root that initially corresponds to the outer horizon always remains the outermost horizon. The second solution exhibits a qualitatively different evolution. In this case, the two outermost horizons merge as the electric charge increases, producing an abrupt transition of the event horizon to the outermost inner horizon. That is, the root that initially corresponds to the event horizon loses its status as such. The third solution corresponds to the critical case of the second solution, in which this transition occurs smoothly rather than abruptly.

We investigate the stability of these solutions using three complementary approaches: Hamiltonian stability, quasinormal modes of a massless scalar field, and thermodynamic stability. We also examine the energy conditions. Our results show that the stability criteria are not equivalent: the second solution exhibits both Hamiltonian and scalar-mode instabilities, whereas the third is Hamiltonian-unstable but remains stable against scalar perturbations. The energy conditions are not a criterion for dynamical stability.

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