Entropy bound for a charged object from the Kerr-Newman black hole

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Abstract

We derive again the upper entropy bound for a charged object by employing thermodynamics of the Kerr-Newman black hole linearised with respect to its electric charge.

Recently, Bekenstein and Mayo [1] and Hod [2] have obtained an upper entropy bound for a charged object by requiring the validity of thermodynamics of the Reissner-Nordström black hole linearised with respect to its electric charge. They have found again the proposal of Zaslaskii [3] derived in another context. The proof takes into account the general existence of an electrostatic self-force acting on a point charge in a gravitational field [4, 5, 6] which has been exactly determined for the Schwarzschild black hole [7, 8, 9].

A question occurs immediately: what is the upper entropy bound for a charged object by requiring the validity of thermodynamics of the Kerr-Newman black hole linearised with respect to its electric charge ? It is possible to answer because the electrostatic self-force for a point charge on the symmetry axis of the Kerr black hole has been previously determined [10, 11]. The purpose of this work is to derive again the entropy bound in this situation according to the method initially due to Bekenstein [12] for a neutral object falling in a Schwarzschild black hole.

The Kerr black hole is characterized by the mass m and the angular momentum per unit mass a satisfying $m^2 > a^2$. In the coordinate system (t, r, θ, φ), the Kerr metric is

$$\begin{aligned} ds^2 &= \left(1 - \frac{2mr}{\Sigma}\right) dt^2 - \frac{\Sigma}{\triangle} dr^2 - \Sigma d\theta^2 + \frac{4amr\sin^2\theta}{\Sigma} dt d\varphi \\ &\quad - \sin^2\theta \left(r^2 + a^2 + \frac{2a^2 mr \sin^2\theta}{\Sigma}\right) d\varphi^2 \end{aligned} \tag{1}$$

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