Physical Review D - Particles, Fields, Gravitation and Cosmology 2015 vol.91 N10

Entropy of a self-gravitating electrically charged thin shell and the black hole limit

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Abstract

 A static self-gravitating electrically charged spherical thin shell embedded in a (3+1)-dimensional spacetime is used to study the thermodynamic and entropic properties of the corresponding spacetime. Inside the shell, the spacetime is flat, whereas outside it is a Reissner-Nordström spacetime, and this is enough to establish the energy density, the pressure, and the electric charge in the shell. Imposing that the shell is at a given local temperature and that the first law of thermodynamics holds on the shell one can find the integrability conditions for the temperature and for the thermodynamic electric potential, the thermodynamic equilibrium states, and the thermodynamic stability conditions. Through the integrability conditions and the first law of thermodynamics an expression for the shell's entropy can be calculated. It is found that the shell's entropy is generically a function of the shell's gravitational and Cauchy radii alone. A plethora of sets of temperature and electric potential equations of state can be given. One set of equations of state is related to the Hawking temperature and a precisely given electric potential. Then, as one pushes the shell to its own gravitational radius and the temperature is set precisely equal to the Hawking temperature, so that there is a finite quantum backreaction that does not destroy the shell, one finds that the entropy of the shell equals the Bekenstein-Hawking entropy for a black hole. The other set of equations of state is such that the temperature is essentially a power law in the inverse Arnowitt-Deser-Misner (ADM) mass and the electric potential is a power law in the electric charge and in the inverse ADM mass. In this case, the equations of thermodynamic stability are analyzed, resulting in certain allowed regions for the parameters entering the problem. Other sets of equations of state can be proposed. Whatever the initial equation of state for the temperature, as the shell radius approaches its own gravitational radius, the quantum backreaction imposes the Hawking temperature for the shell in this limit. Thus, when the shell's radius is sent to the shell's own gravitational radius the formalism developed allows one to find the precise form of the Bekenstein-Hawking entropy of the correlated black hole.

http://dx.doi.org/10.1103/PhysRevD.91.104027