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Penrose process from BSW collisions

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The Penrose process uses the negative energy states of the ergosphere of a black hole to extract energy and deposit it at infinity. Originally, the process was realized in the decayment of one particle into two new particles. The BSW effect uses the properties of the event horizon to generate infinite center of mass energies in the collision of two incoming particles. In this work we determine the energetics of a Penrose process of two electrically charged particles suffering a BSW collision along the radial direction at the event horizon of an extremal Reissner-Nordström black hole. Specifically, several types of radial collisions can be considered, the most interesting one is between a critical particle, i.e., a particle that has its electric charge adjusted in a particular way to the other relevant parameters, and a usual particle, as it gives a divergent center of mass frame energy locally. A divergent center of mass frame energy at the point of collision is a favorable condition to extract energy from the black hole, but not sufficient, since, e.g., the product particles might go down the hole. To understand whether energy can be extracted or not in a Penrose process, we investigate in detail a collision between ingoing particles 1 and 2, from which particles 3 and 4 emerge, with the possibility that particle 3 can carry the energy extracted far out from the black hole horizon, i.e., there is a high Killing energy transported by particle 3. One finds that the mass, the energy, the electric charge, and the initial direction of motion of particle 3 can have different values, depending on the collision internal process itself. But, the different possible values of the parameters of the emitted particle 3 lie within some range, and moreover the energy of particle 3 can, in some cases, be arbitrarily high but not infinite, characterizing a super-Penrose process. It is also shown that particle 4 lives in its own electric ergosphere with negative energy states while it exists, i.e., before being engulfed by the event horizon, as it is required in a Penrose process. The full background for this collisional Penrose process is a d dimensional extremal Reissner-Nordström black hole spacetime with negative, zero, or positive cosmological constant, i.e., an asymptotically anti-de Sitter, flat, or de Sitter spacetime.

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