Entanglement Entropy of Two Black Holes and Entanglement Entropic Force

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We study the entanglement entropy, S_C, of a massless free scalar field on the outside region C of two black holes A and B whose radii are R_1 and R_2 and how it depends on the distance, $r(\gg R_1,R_2)$, between two black holes. If we can consider the entanglement entropy as thermodynamic entropy, we can see the entropic force acting on the two black holes from the r dependence of S_C. We develop the computational method based on that of Bombelli et al to obtain the r dependence of S_C of scalar fields whose Lagrangian is quadratic with respect to the scalar fields. First we study S_C in $d+1$ dimensional Minkowski spacetime. In this case the state of the massless free scalar field is the Minkowski vacuum state and we replace two black holes by two imaginary spheres, and we take the trace over the degrees of freedom residing in the imaginary spheres. We obtain the leading term of S_C with respect to $1/r$. The result is $S_C=S_A+S_B+\tfrac{1}{r^{2d-2}} G(R_1,R_2)$, where S_A and S_B are the entanglement entropy on the inside region of A and B, and $G(R_1,R_2) \leq 0$. We do not calculate $G(R_1,R_2)$ in detail, but we show how to calculate it. In the black hole case we use the method used in the Minkowski spacetime case with some modifications. We show that S_C can be expected to be the same form as that in the Minkowski spacetime case. But in the black hole case, S_A and S_B depend on r, so we do not fully obtain the r dependence of S_C. Finally we assume that the entanglement entropy can be regarded as thermodynamic entropy, and consider the entropic force acting on two black holes. We argue how to separate the entanglement entropic force from other force and how to cancel S_A and S_B whose r dependence are not obtained. Then we obtain the physical prediction which can be tested experimentally in principle.

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