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Steady-state quantum thermodynamics with synthetic negative temperatures

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A bath with a negative temperature is a subject of intense debate in recent times. It raises fundamental questions not only on our understanding of negative temperature of a bath in connection with thermodynamics but also on the possibilities of constructing devices using such baths. In this work, we study steady-state quantum thermodynamics involving baths with negative temperatures. A bath with a negative temperature is created synthetically using two baths of positive temperatures and weakly coupling these with a qutrit system. These baths are then coupled to each other via a working system. At steady state, the laws of thermodynamics are analyzed. We find that whenever the temperatures of these synthetic baths are identical, there is no heat flow, which reaffirms the zeroth law. There is always a spontaneous heat flow for different temperatures. In particular, heat flows from a bath with a negative temperature to a bath with a positive temperature which, in turn, implies that a bath with a negative temperature is "hotter" than a bath with a positive temperature. This warrants an amendment in the Kelvin-Planck statement of the second law, as suggested in earlier studies. In all these processes, the overall entropy production is positive, as required by the Clausius statement of the second law. We construct continuous heat engines operating between positive and negative temperature baths. These engines yield maximum possible heat-to-work conversion efficiency, that is, unity. We also study the thermodynamic nature of heat from a bath with a negative temperature and find that it is thermodynamic work but with negative entropy.

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