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Derivation of a Kubo-like formula for charge and spin transport

We study the linear response of a gapped periodic quantum system to a small electric field, modelled by a potential εX_j, $\varepsilon \ll 1$, by measuring the conductivity σ_{ij} of a current operator in the form $J_i = \mathrm{i}[H_0, SX_i]$, where H_0 is the Hamiltonian of the unperturbed system and S is an operator acting on the internal degrees of freedom only (e.g. on spins). This is of relevance for 2-dimensional quantum (spin) Hall systems, where S is the identity operator (resp. S is the third component of the spin operator). The expected current is computed in a non-equilibrium almost-stationary state, defined via space-adiabatic perturbation theory. When S is a conserved quantity, i.e. $[H_0, S] = 0$, we recover a generalized Kubo formula for the conductivity, and consequently its quantization in appropriate units. When instead $[H_0, S] \neq 0$, we show that further correction terms appear in the Kubo-like formula for σ_{ij}.