Thermoelectric performance of topological boundary modes

S. Böhling[1,2], G. Engelhardt[2], G. Platero[3] and G. Schaller[1]

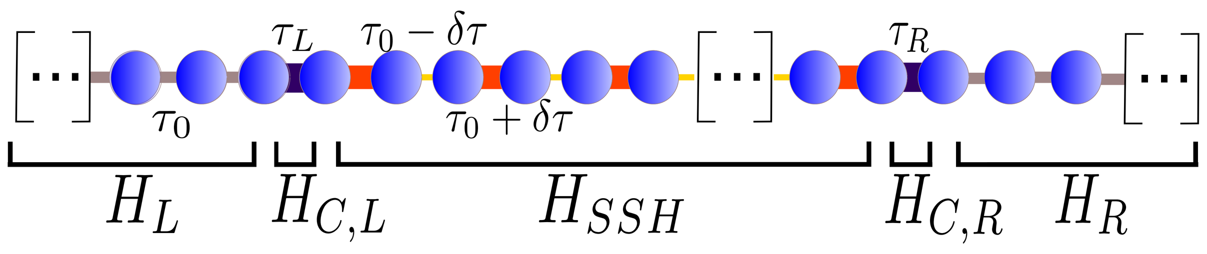
[1] Institut für Theoretische Physik, Technische Universität Berlin, 10623 Berlin, Germany
[2] Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany
[3] Beijing Computational Science Research Center, Beijing 100193, People's Republic of China
[4] Instituto de Ciencia de Materiales de Madrid, CSIC, 28049 Madrid, Spain

Topology meets thermodynamics

We bring together topology and thermodynamics by investigating quantum transport and thermoelectrical properties of a finite-size Su-Schrieffer-Heeger (SSH) model[1]. The SSH model is a paradigmatic model for a one-dimensional topological insulator, which displays topologically protected edge states. By coupling the model to two fermionic reservoirs at its ends, we can explore the non-equilibrium dynamics of the system. We demonstrate that the edge states can be exploited to design a refrigerator driven by chemical work or a heat engine driven by a thermal gradient, respectively.

SSH chain as open system

Our system is described by a **tight-binding Hamiltonian** $H = \sum_{\alpha=\mathrm{R,L}} H_\alpha + H_{\mathrm{SSH}} + H_{\mathrm{c}}$ that consists of left and right semi-infinite leads $H_{\mathrm{L,R}}$ with nearest-neighbor hopping τ_0, the SSH chain H_{SSH} with $\tau_0 \pm \delta\tau$, and system-reservoir coupling H_{C} with $\tau_{\mathrm{L,R}}$:



- We calculate the **non-equilibrium Green's function** (GF) of this system.
- Knowledge of the GF leads to physical quantities like **transmission** T.
- T gives us **particle and energy current** (I_{M} and I_{E}) in a Landauer representation ($f_{\mathrm{L,R}}(E)$ labels the Fermi functions of the leads)

$$I_{\mathrm{M}} = \int \frac{dE}{2\pi} T(E)\,[f_{\mathrm{L}} - f_{\mathrm{R}}]$$
$$I_{\mathrm{E}} = \int \frac{dE}{2\pi} T(E) \cdot E\,[f_{\mathrm{L}} - f_{\mathrm{R}}]$$

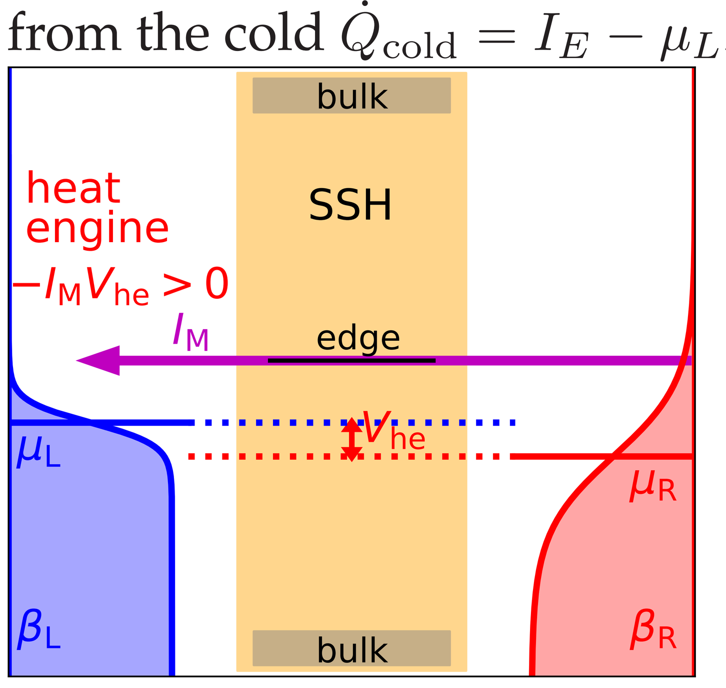
- Moreover, we can calculate **Fano factor** $F = S/|I|$ and **noise** S

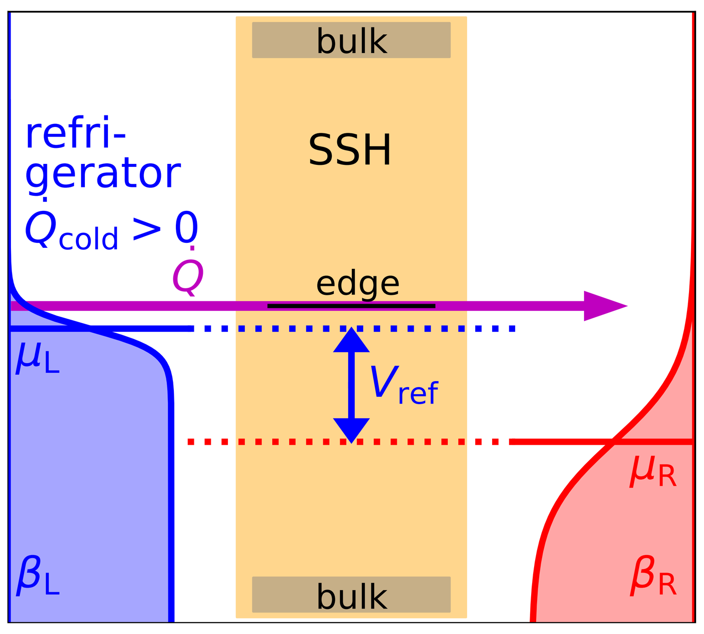
$$S = \int \frac{dE}{2\pi} \left\{ T(E) \left[\sum_\alpha f_\alpha (1 - f_\alpha) \right] + T(E)\,[1 - T(E)]\,[f_{\mathrm{L}} - f_{\mathrm{R}}]^2 \right\}$$

This method[2,3] is exact and not restricted to weak reservoir coupling.

Thermoelectric devices

We introduce a temperature and a chemical gradient ($\beta_L > \beta_R$, and $\mu_L = V/2 = -\mu_R$) and calculate the generated **power** $P = -I_M \cdot V$, **heat current** from the hot reservoir into the system $\dot{Q}_{\mathrm{hot}} = -(I_{\mathrm{E}} - \mu_R I_{\mathrm{M}})$, and the one from the cold $\dot{Q}_{\mathrm{cold}} = I_E - \mu_L I_M$.

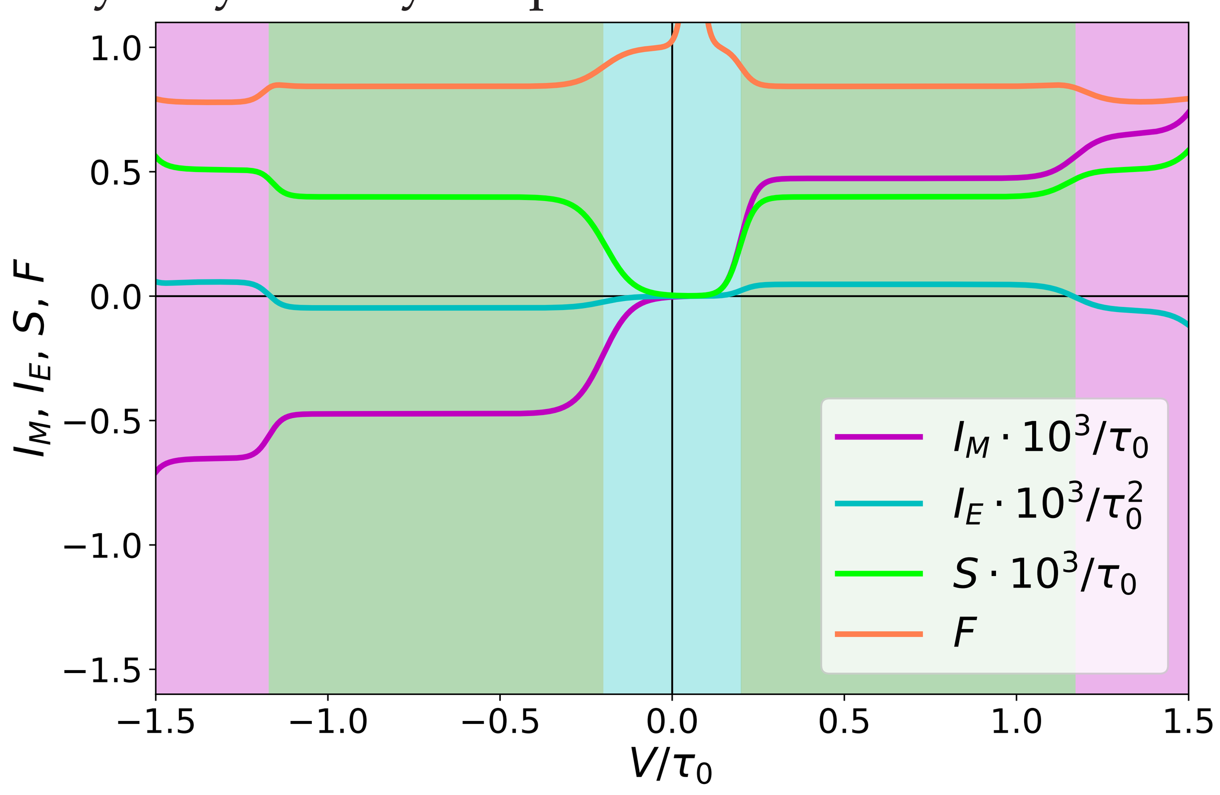


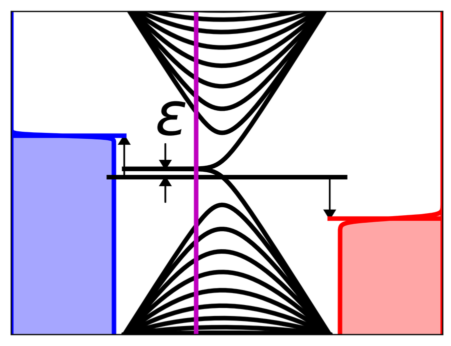


- **Heat engine:** Heat enters from the hot reservoir and generates power with an efficiency η bounded by its Carnot value η_{C}.
- **Refrigerator:** Heat leaves the cool reservoir and effectively cools it. The efficiency of this process is measured by the **coefficient of performance** (COP), also bounded by its Carnot value COP_{C}.

Implementation and results

Following **results** are obtained for small V in the topological phase ($\delta\tau = -0.3\tau_0$). Here, transport is dominated by topologically protected edge states which are confined to one end of the SSH chain and therefore effectively very weakly coupled to the reservoir at the other end.

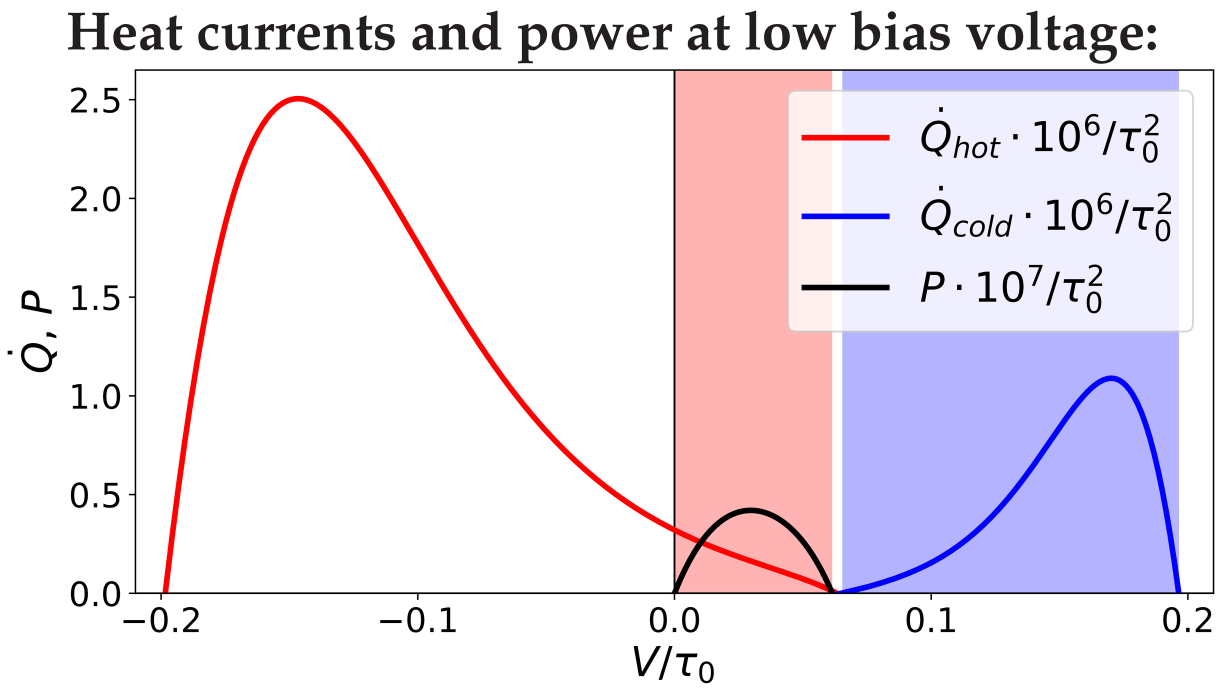




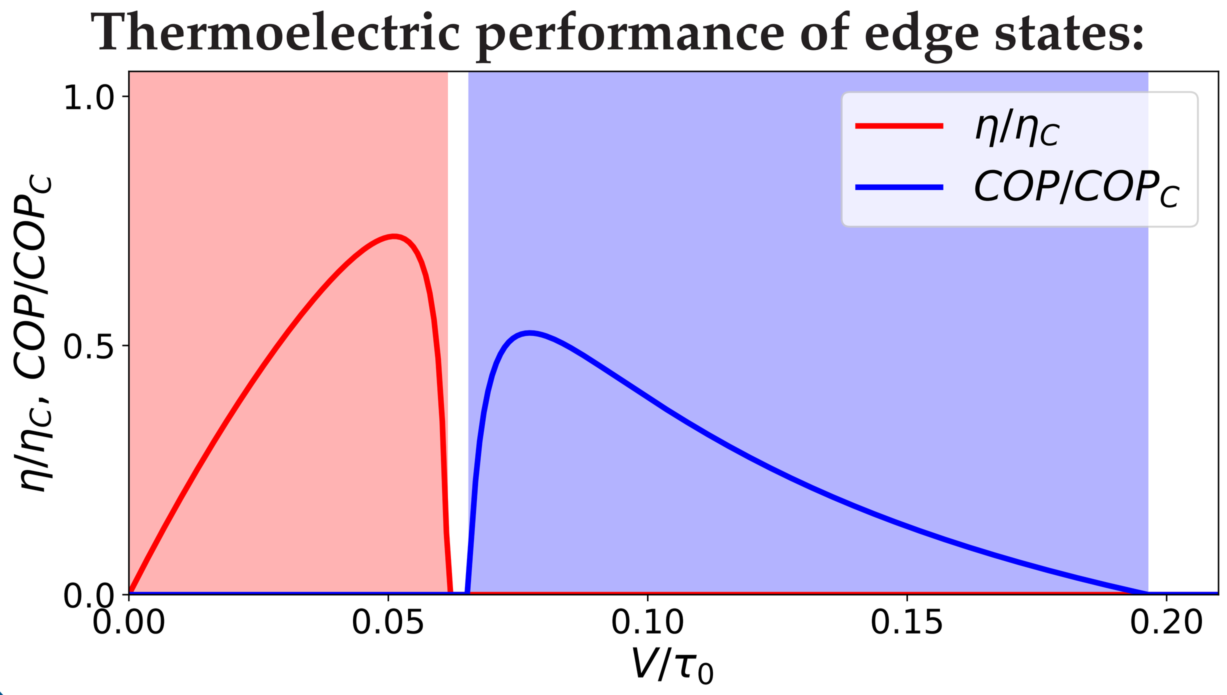
Transport properties: Apply onsite potential ε on all sites of the SSH chain to obtain finite I_{E}.

Choice of $\delta\tau$ should not take us too far into the topological phase to obtain a higher T (otherwise, edge state transport has to vanish).

Heat currents and power at low bias voltage:



Thermoelectric performance of edge states:



Thermoelectric devices can be implemented by choosing the right bias voltage: *Red regime:* **Heat engine.** *Blue regime:* **Refrigerator.** The gap between these regimes decreases with reservoir coupling. Single electron transistors in this parameter regime perform much worse as they do not achieve tight coupling.

Conclusions

- Non-equilibrium Green's function method for analytic treatment.
- Highly efficient, topologically protected heat engine and refrigerator.
- Edge state confinement to one end of the chain leads to tight coupling.
- Dissipative preparation of edge states and transport in presence of disorder are investigated in [4].

[1] W. P. Su et al., *Phys. Rev. Lett.* **42**, 1698 (1979).
[2] E. N. Economou, *Greens functions in quantum physics*, (Springer, 2006).
[3] H. Haug and A.-P. Jauho, *Quantum kinetics in transport and optics of semiconductors*, (Springer, 2008).
[4] S. Böhling et al., *Phys. Rev. B*, **98**, 035132 (2018).

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