Highlight

Armin Feldhoff*

Entropy Counts

Keywords: entropy, electric charge, thermal energy, electric energy

DOI 10.1515/ehs-2015-0007

By treating temperature and entropy as primitive quantities like electric potential or electrochemical potential and electric charge, a direct entropic approach to the description of thermoelectric devices (i.e., coolers and generators) has been made by Fuchs (2014). The article presents a simple and straightforward way to the understanding of thermoelectric processes, which are relevant to the operation of thermoelectric generators (i.e., thermally driven electric charge pumps) and thermoelectric coolers (i.e., electrically driven entropy pumps). The role of energy is easily understood. Basically, energy enters a thermoelectric generator with entropy (at high temperature) and leaves it with entropy (at low temperature) and electric charge (at high electric potential or electrochemical potential).

This narrative understanding of the thermoelectric generator is read from a steady-state process diagram, which also considers the production and storage of entropy in the thermoelectric generator, and allows for quantifying the performance directly in terms of first-law or second-law efficiency. It is demonstrated that the second-law efficiency of the device depends only on three parameters, which are the external load, the internal resistance and a figure of merit of the thermoelectric material. The figure of merit is dimensionless and depends only on three parameters, which are the internal resistance, the entropy conductance and the Seebeck coefficient. Temperature does not appear explicitly in the figure of merit but its temperature dependence is implicitly given by those of the three parameters. Note that similar formulation has been given by Feldhoff (2015).

***Corresponding author: Armin Feldhoff,** Institute of Physical Chemistry and Electrochemistry, Leibniz Universität Hannover, Hannover, Germany, E-mail: armin.feldhoff@pci.uni-hannover.de

The meaning of the Seebeck coefficient as *entropy per charge* is obtained by applying the *concept of combined potentials of a substance* that is electrically charged and charged with entropy. The *concept of combined potentials* is well known to the chemist in case of the electrochemical potential, but has been extended by Fuchs (2014) to the *thermo-electro-chemical* potential. It lets us realize that the transports of substance, electric charge and entropy are coupled. When the substance (e.g., electrons) flows, so do the associated amounts of electric charge and entropy. Substance flowing at a certain chemical potential, electric charge flowing at a certain electric potential and entropy flowing at a certain temperature carry related amounts of energy, respectively, which can be addressed as appropriate energy forms (i.e., chemical energy, electric energy, thermal energy). Thermal energy is often called “heat.” The approach by Fuchs (2014), however, interprets temperature as the thermal potential and entropy as the fundamental quantity that is transported in thermal processes. It is then that *the dynamics of heat* can be understood as the *dynamics of entropy*, which of course is accompanied by a specific amount of thermal energy, as has been outlined in the famous textbook by Fuchs (2010).

Based upon energy considerations, Fuchs (2014) gives rather simple “one-line proof” for the equality of the Seebeck coefficient and the Peltier coefficient of a thermoelectric material. The direct entropic approach does not need the cryptic arguments of microscopic reversibility for the equality of Onsagers reciprocity relation, which is needed in the approach of the so-called *thermodynamics of irreversible processes* (TIPs) by de Groot (1951). Note, recently Feldhoff (2015) has shown that the transport equations derived by Fuchs (2014) correspond to what is obtained by TIP theory. Instead, Fuchs (2014) gives a simple and intuitively interpretable description of thermoelectric devices by realizing that thermoelectric phenomena occurs from the coupling of transport of electric charge and entropy. Both entropy and electric charge do flow and are stored. In addition, entropy is produced.

The intention of the article by Fuchs (2014) is to present a simple entry point to the field of thermoelectricity. It is apparent that anybody, including researchers as well as the non-expert, will benefit from this vivid approach. It is particularly of value for the practitioner who is interested in using and optimizing thermoelectric generators. The article by Fuchs (2014) constitutes nothing less than the state-of-the-art reference paper for understanding thermoelectricity.

Finally, it is worth noting that the approach by Fuchs (2014) can easily be extended to phenomena in mechanics, electricity, chemistry and heat if the relevant extensive quantities (momentum, charge, amount of substance and entropy) and their respective potentials (velocity, electric and chemical potentials and temperature) are used consequently from the very beginning of consideration. Doing so, the approach becomes highly relevant for any kind of energy harvester as the role of energy and efficiency are directly addressed. The latter is closely related to the role of entropy, which appears as basic quantity. Energy dissipation can then easily be understood as the amount of energy which leaves the harvester together with the produced entropy.

References

1. de Groot, S. 1951. *Thermodynamics of Irreversible Processes*, 1st ed. Amsterdam: North-Holland Publishing Company.
2. Feldhoff, A. 2015. “Thermoelectric Material Tensor Derived from the Onsager–De Groot–Callen Model.” *Energy Harvesting and Systems* 2:5–13.
3. Fuchs, H. 2010. *The Dynamics of Heat – A Unified Approach to Thermodynamics and Heat Transfer*, 2nd ed. (Graduate Texts in Physics). New York: Springer.
4. Fuchs, H. 2014. “A Direct Entropic Approach to Uniform and Spatially Continuous Dynamical Models of Thermoelectric Devices.” *Energy Harvesting and Systems* 1:253–65.