The principle of detailed balance, opto-electronic reciprocity, and the thermodynamics of light trapping in solar cells

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The principle of detailed balance connects any physical action with its inverse process in any physical system close to equilibrium. For the case of solar cells the maximum thermodynamically possible efficiency, the Shockley-Queisser (SQ) limit,[1] is derived from the principle of detailed balance. However, a solar cell exposed to sunlight and working in its maximum power point is a system far from thermal equilibrium. This contradiction is not that much relevant for the idealized limiting case, but matters much when investigating real world solar cells. The opto-electronic reciprocity theorem,[2] like the SQ-limit, is derived from the principle of detailed balance, but in contrast to the latter can be tested experimentally by analyzing four independent predictions.[3] The presentation will discuss methods how these predictions can be tested and give a sketch of a theory that covers deviations from the predictions of reciprocity. Finally, the question will be adressed, how the optical properties of the solar cells can be involved in the theory.

1 Shockley, W.; Queisser, H. J., *J Appl Phys* **1961,** *32* (3), 510-519.
2 Rau, U., *Phys Rev B* **2007,** *76* (8), 085303.
3 Rau, U., *IEEE J. Photov.* **2012,** *2* (2), 169-172.