Supradegeneracy, thermophotovoltaics, and the second law of thermodynamics

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Recently, a new thermodynamic phenomenon has been investigated – supradegeneracy [1] – in which the statistical degeneracy of a system increases more rapidly with energy than its Boltzmann exponential decreases such that its higher energy levels can be more populated than its lower ones, thus creating something akin to population inversion – at equilibrium! (Population inversion is typically associated with nonequilibrium systems like lasers.) Although supradegenerate systems do not occur in Nature, they appears possible to create in the laboratory. This presentation reviews recent experimental attempts to generate this phenomenon in the bandgap of silicon. By doping with multiple acceptor impurities having increasing energy with respect to silicon's valence band edge (i.e., B (0.045 eV); Ga (0.072 eV); In (0.16 eV)), but each in exponentially increasing concentrations, we are attempting to create a supradegenerate energy ladder (SDEL) up which electrons can climb into the bandgap, via roughly thermal energy increments, to energies that they would normally would be unable to attain using individual thermal transitions. Such energy ladders could improve the efficiency of thermophotovoltaics. Additionally, SDELs could provide sensitive experimental tests of the second law [2] when incorporated into thermophotovoltaic diodes constructed from narrow-gap semiconductors (e.g., HgCdTe, InSb). In this scenario, electrons would ford the entire band gap of the narrow-gap semiconductor via a 3-4 rung SDEL, transforming thermal energy into dc electric current.

[1] D.P. Sheehan and L.S. Schulman, "'Populaton inversion' at equilibrium" Physica A, in press (2019).

[2] V. Capek and D.P. Sheehan, "Challenges to the second law of thermodynamics: Theory and experiment" Springer (2005).