Thermodynamics of radiating systems and the optics of solar cells (001-2-4053)

3 Credits

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Motivation

Solar energy is the ultimate renewable energy source at our disposal. Accordingly, scientists and engineers are looking for better ways of its utilization. This course takes a broader view of this matter by dealing with the limitation that thermodynamics poses on the ability to perform this task. We will begin with Carnot's approach for the ultimate work-production efficiency by heat conduction between a hot and a cold reservoir without reference to the mechanism by which it is performed. In our case, the sun is the hot source, and its energy is conveyed as radiation. We will learn how this fact affects Carnot's general framework and the subsequent reduction in efficiency it causes. Not all solar power production schemes are purely thermodynamic, however. In that regard, the photovoltaic (PV) approach is responsible for most solar energy produced today. PV has additional constraints on top of basic thermodynamics laws and the nature of radiation. As a result, the PV ultimate power production efficiency is reduced even further. (Nonetheless, its simplicity and the fact that it converts radiation directly into electricity make it favorable over another approach.) Accordingly, we will learn the basics of PV efficiency calculation as in the Shockley and Queisser approach (SQ). We will also learn how it relates to classical thermodynamics and the Carnot-based flux balance approaches. Naturally, solar power production is related to optics by the nature of radiation. Over the years, optical approaches for boosting the efficiency of PV cells have emerged. We will describe these approaches' rationale from the SQ perspective and how they were implemented in practical and conceptual solar cells. Finally, if time permits, we will study conceptual schemes, such as negative illumination, thermo-PV (TPV), and thermophotonics (XPV).

Schedule

Week	Subject	Details
1-2	Introduction to thermodynamics	Energy, free-energy, entropy, heat, temperature, flux balance, and Carnot’s efficiency
3-4	Black-body radiation	The black-body apparatus, Plank’s distribution, the energy, and entropy it stores, their conversion to fluxes, and Kirchhoff’s radiation law
5-6	Thermodynamics of solar power production	Landsberg and related approaches for incorporating the nature of radiation into Carnot’s framework
7-8	Introduction to the photovoltaic effect	Conduction and valance energy bands, their thermal occupation by electron and holes, the relation to Planks

		statistics, fermi and quasi-fermi levels, free-energy and chemical potential, the generalized Plank law (Bose-Einstein statistics).
9-10	The PV efficiency: Shockley and Queisser approach	The detailed balance law, short-circuit current and open-circuit potential, the circuit model of a solar cell, bandgap dependent efficiency, inclusion of realistic material properties, and multi-junction cells.
11-12	Thermodynamics view about the detailed-balance law	Estimating the photovoltaic free energy, failure of the flux balance laws and possible solution to this problem
13	Optical considerations in the detailed-balance law	Light-trapping, photon-recycling, solar concentration, and angular and spectral restrictions to the cell's emission
-	Advanced topics	Thermo-photovoltaics, reverse illumination, and thermophotonics

Prerequisites

Physics and mathematical level of a physics or engineering post-graduate.

Grading

Final exam

Bibliography

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