Physics of Solar Energy

APPH 4130, Fall 2018

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Outline

It is now a common sense that solar energy will become the main source of energy solely based on economics. The price of solar cells is already so low that it is the least expensive source of electricity in most part of the world. Owing to large-scale mass production, the manufacturing cost of solar cells is reducing constantly. Solar thermal application is undergoing a significant transition, and will be in even more widespread use. Because solar radiation is intermittent, to make solar energy the main source, energy storage is a major issue.

The course covers the physics of solar energy as the scientific background of its exploration in a logical and unified way, focused on issues with practical significance, including detailed descriptions of many actual devices. It is organized in 24 75-minute lectures. It requires two exams and a term paper. The content is divided into 13 chapters. The number following the chapter title indicates the number of lectures for that chapter.

Prerequisite: general physics (PHYS C1401x, C1402y, C1403x, C1601x, and C1602y), freshman mathematics including ordinary differential equations and complex numbers (MATH V1201 and V1202, E1210x or y). Familiarity in thermodynamics, electromagnetism, quantum mechanics, solid-state physics and electronic device physics is preferred.

Textbook

Physics of Solar Energy, C. Julian Chen, John Wiley and Sons, 2011. ISBN 978-0-470-64780-6, call number TJ811.C54 2011. A reserved copy is available in the Science-Engineering Library. With a CU UNI, you may download an EBook of Physics of Solar Energy from either Wiley-Blackwell Online Books or EBook Central Academic Complete.

List of Chapters

Chapter 1: Introduction (3)

Basic scientific facts of solar energy. Pollution and environmental consequences of burning fossil fuels. Hubbert limit. Comparison of various renewable energy resources. History of solar energy utilization. Brief descriptions of various approaches of utilizing solar energy.

Chapter 2: Nature of Solar radiation (3)

Light as electromagnetic wave. Applications of Maxwell's equations to solar energy problems: optics of transparent thin films and metals. Black-body radiation. Photoelectric effect and the concept of photons. Einstein's derivation of the black-body radiation formula.

Chapter 3: Origin of Solar Energy (1)

Basic parameters of the Sun. The Kelvin-Helmholtz time scale. Energy source of the Sun. Internal structure of the Sun.

Chapter 4: Tracking sunlight (3)

A spherical trigonometry primer. Rotation of the Earth: latitude and longitude. Treatment in solar time. Treatment in standard time. Direct sunlight at any surface and any place on the Earth.

Chapter 5: Interaction of sunlight with Earth (2)

Interaction of radiation with matter. Interaction of sunlight with atmosphere: The AM1.5 solar spectral irradiance. Storage of solar energy in the ground: the shallow geothermal energy.

Chapter 6: Thermodynamics of solar energy (2)

Definitions. The first law of thermodynamics. The second law of thermodynamics. Thermodynamic functions. The ideal gas. Ground-source heat pump and air conditioning.

Chapter 7: Quantum transitions (1)

Basics of quantum mechanics. Many-electron systems. Semiconductors. The Golden Rule. Interactions of matters with photons.

Chapter 8: pn-Junction (1)

p-type and n-type semiconductors. Formation of a pn-junction. Analysis of pn-junctions. The Shockley equation.

Chapter 9: Semiconductor solar cells (3)

Basic concepts. The Shockley-Queisser limit. Other efficiency-limiting factors. Anti-reflection coatings. Crystalline silicon solar cells. Thin-film solar cells. Tandem solar cells.

Chapter 10: Solar Photochemistry (1)

Physics of photosynthesis. Artificial photosynthesis. Dye-sensitized solar cells. Organic solar cells.

Chapter 11: Solar Thermal Energy (2)

History of solar thermal energy applications. Selective absorption coatings. Solar thermal energy collectors. Concentration solar power. Solar thermal applications.

Chapter 12: Energy storage (1)

Thermal energy storage. Compressed air energy storage. Flywheels. Rechargeable batteries. Electrical automobiles powered by solar energy. Short-term distributed energy storage.

Chapter 13: Building with Sunshine (1)

Building materials and insulation. Solar architecture: history, status, and outlook. Building integrated photovoltaics.

Schedule of Lectures and Exams

Lecture 1: September 5. Basic scientific facts of solar energy. Pollution and environmental consequences of burning fossil fuels. The Hubbert limit.

Lecture 2: September 10. Comparison of various renewable energy resources. Homework 1.

Lecture 3: September 12. Various approaches of utilizing solar energy. Policy and business aspects of solar energy.

Lecture 4: September 17. Light as electromagnetic wave. Applications of Maxwell’s equations to solar energy problems: optics of thin films and metals. Homework 2.

Lecture 5: September 19. Black-body radiation.

Lecture 6: September 24. Photoelectric effect and the concept of photons. Einstein's derivation of the black-body formula. Homework 3.

Lecture 7: September 26. Origin of Solar Energy.

Lecture 8: October 1. A spherical trigonometry primer. Rotation of the Earth: latitude and longitude. Homework 4.

Lecture 9: October 3. Treatment in solar time. Treatment in standard time.

Lecture 10: October 8. Direct sunlight at any surface and any place on the Earth. Homework 5.

Lecture 11 October 10. Interaction of radiation with matter. Interaction of sunlight with the atmosphere: The AM1.5 solar spectral irradiance.

Lecture 12: October 15. Storage of solar energy in the ground. Homework 6.

October 17: Midterm exam. Topic of term paper finalized

Lecture 13: October 22: A thermodynamics primer.

Lecture 14: October 24. Ground-source heat pump and air conditioning. Homework 7.

Lecture 15: October 29. Quantum transitions.

Lecture 16: October 31. pn-Junction**.** Homework 8.

Lecture 17: November 7**.** Semiconductor solar cells. The Shockley-Queisser limit.

Lecture 18: November 12. Other efficiency-limiting factors. Anti-reflection coatings. Homework 9.

Lecture 19: November 14. Crystalline silicon solar cells. Thin-film solar cells. Tandem solar cells.

Lecture 20: November 19. Solar Photochemistry. Homework 10.

Lecture 21: November 26. Selective absorption coatings. Solar Heat Collectors.

Lecture 22: November 28. Concentration solar thermal systems. Stirling engine. Homework 11.

Lecture 23: December 3. Solar thermal applications. Energy storage**.**

Lecture 24: December 5. Building with Sunshine. Homework 12.

December 10 - 12: Review for final exam. Term paper due.

December 14 - 21: Final exam (exact date will be published by registrar).

Grading policy

The final grade is based on the accumulated points (maximum points 100). There are 12 sets of homework. Each homework set is due a week from the date of issuing. Each homework counts for 3 points, with a total of 36 points. The midterm exam counts for 20 points. The final exam counts for 30 points. Term paper counts for 14 points.

Both midterm exam and final exam are closed book. For both exams, a calculator is required. No computers and smart phones.