Syllabus updated February 13, 2015

PHYS 4400: Principles and Varieties of Solar Energy (3.0 Credit Hours), Spring 2015

Course Catalog Description: Types and extent of solar energy used in human society including photosynthesis, photovoltaic, solar thermal, and concentrating solar electric; scope of the necessary energy storage and long distance electricity transmission.

Class times: Tuesday & Thursday 12:30 – 1:45 pm; **Location**: R1, Room 2360

Instructor: Prof. Randy Ellingson, Office: R1 Room 2100G, x3874, randy.ellingson@utoledo.edu

Office Hours: in lieu of office hours, availability by email, phone, or in person.

Course Overview: This course addresses the physics and technology of solar energy, providing the foundation and context to enable students to understand the rapidly evolving developments in harnessing sunlight for practical purposes. The course covers Earth's solar radiant energy resource, methods of conversion to thermal and electric energy, and the role played by these energy sources in society.

Course Website: http://astro1.panet.utoledo.edu/~relling2/teach/4400.2015/spring2015_phys4400.html

Learning Goals for this course:

1. The basis of our solar resource (fundamentals of energy and the Sun):
    a. Energy and power: distinguish and convert between different forms of energy; the value of each form of energy, energy sources, and determining average power and peak power in various scenarios.
    b. Light and photons: energy of a photon, power within a light source, generation and conversion of light, interactions between light and matter.
    c. The Sun: physics of the Sun, the photosphere, the solar spectrum, and the physics of blackbody radiation (sources of radiant energy).
    d. Sunlight and Earth's atmosphere: standard solar spectra, units of insolation, extraterrestrial vs. terrestrial spectra, air mass, atmospheric effects, direct vs. circumsolar insolation.
2. Conversion of solar energy:
    a. The greenhouse effect: atmospheric CO_2 concentration, greenhouse gases, fossil energy, effect on Earth's climate, weather vs. climate.
    b. Photosynthesis: scientific principles, quantified solar energy conversion, contribution to food supply, production of biofuels.
    c. Solar thermal energy: physics of conversion of light to heat, uses of solar thermal (building-integrated for water and air heating, solar thermal power plants).
    d. Wind energy: connection to the Sun, history, physics and technology, implementation, and industry trends.
    e. Photovoltaics (PV): purpose of PV devices, principles of the photovoltaic effect, architecture of a solar cell; working with the solar spectrum, one electron per photon, integrating the solar spectrum; device characterization (optical absorption and reflection, current vs. voltage, power conversion efficiency, quantum efficiency); types of PV cells; concentrating PV. Semiconductor physics for understanding PV devices.
3. Energy markets, policies, and the environment:

a. Calculating the Levelized Cost of Energy
b. Energy consumption: major fuels, Carbon impact, trends, role of energy efficiency.
c. Renewable energy policies: US, Ohio, and global.
d. Carbon management: cap and trade, carbon tax, case studies.

Guest Lectures (tentative):

- photosynthesis
- PV Project Development
- Perspectives on the PV industry: CdTe solar cells
- Design, installation, and operation of a residential PV system
- Tour of PV module assembly plant (tentative)

Required Textbook: "*Photovoltaics: Fundamentals, Technology, and Practice*", by Konrad Mertens (Wiley, ISBN 978-1-118-63416-5), 2014.

Additional reading will be assigned based on web and other resources, and some lectures will draw from:

- "The Physics of Solar Cells", by Jenny Nelson;
- Wikipedia (an excellent starting point, for rigorous academic investigation and discussion), and Georgia State Univ.s HyperPhysics (http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html);
- PV Education: http://www.pveducation.org/pvcdrom

Final Exam: Tuesday, May 5, 12:30 – 2:30 pm, normal classroom.

Information and instructional methods.

1. Keep current with the coursework and complete assigned reading prior to lecture. As part of the class time, students will present solutions and information on relevant problems in order to initiate and facilitate discussion of important, fundamental, and/or interesting topics. Participation in class through questions and discussion is essential for the most effective learning.

2. Complete the assigned homework on time; the instructor reserves the right to deduct points for late homework: 10% if one day late, then 10% additional for each day late.

3. Follow the University's Missed Class/Excused absence policy; here's one link:

http://www.utoledo.edu/facsenate/missed_class_policy.html

4. Know the University's class withdrawal rules:

http://www.utoledo.edu/offices/registrar/registration_dates_spring.html

GRADING and EXAMS

Only material covered in class or in homework will be used for exams. There will be 2 types of exam:

1. Quiz

The quizzes will be 20-25 minutes and may include short answer and/or multiple choice questions (MCQ). Quizzes are intended to make sure you have understood the basic concepts taught up to that point in the course, and the quizzes are closed-book, closed-notes.

2. Final exam

The Final exam will be a combination of MCQ and short problems. The Final exam will be open-book, open-notes (written or typed class notes only, no PowerPoint slides). Necessary physical constants and equations will be provided.

Grading

Grades will be determined according to: In-class participation: 10%. Homework: 35%. Three in-class quizzes: 30%. Final exam: 25%.

Class dates: Jan. 13, 15, 20, 22, 27, 29, Feb. 3, 5, 10, 12, 17, 19, 24, 26, Mar. 3, 5, 17, 19, 24, 26, 31, Apr. 2, 7, 9, 14, 16, 21, 23, 28, 30. Finals week: May 4 – 7, 2015: **Final Exam → Tues., May 5, 12:30 – 2:30 pm.**

Date	**Topic(s)**
Jan. 13, 15	Introduction; energy vs. power; overview of Earth's energy: forms of energy, sources and use, stored energy, average and peak power.
	Reading: Textbook Sections 1.1 through 1.4. www.pveducation.org Section 1. http://en.wikipedia.org/wiki/Energy (Parts 1-5); http://en.wikipedia.org/wiki/Power_(physics) (Parts 1, 2, 4, and 5). http://en.wikipedia.org/wiki/Light (All parts 1-5); for Units and Measures, familiarize yourself with, and be prepared to explain, Radiant Energy, Radiant Flux, Irradiance, Spectral Irradiance).
Jan. 20,22	Light and photons: generation and destruction of light, interactions between light and matter, photon flux. Blackbody radiation. Insolation, solar spectra, extraterrestrial and terrestrial spectra, air mass, atmospheric effects, direct vs. indirect insolation, integrating the solar spectrum.
	http://en.wikipedia.org/wiki/Electromagnetic_radiation (Introduction, Parts 1.1.1, 1.2, 1.3, 1.7, 3, 4, 5 (incl. 5.8). http://en.wikipedia.org/wiki/Photon (Parts 1, 2 (not 2.1), 13, and 14). http://en.wikipedia.org/wiki/Sun (Parts 1, 2, and 6). http://en.wikipedia.org/wiki/Black-body_radiation (Parts 1-4). Textbook Chapter 2. The solar constant: http://en.wikipedia.org/wiki/Solar_constant http://en.wikipedia.org/wiki/Sunlight (Parts 1- 4, 7, 8); www.pveducation.org Section 2.
Jan. 27, 29	Editing Wikipedia articles (improving Wien's Displacement Law). Introduction to energy conversion. Value of and need for energy conversion and energy efficiency; environmental impacts, and challenges. Fossil energy, the greenhouse effect, global climate change, weather vs. climate.
	http://en.wikipedia.org/wiki/Energy_conversion

Feb. 3, 5	February 3: Quiz #1. Photosynthesis. Scientific principles, quantified solar energy conversion, contribution to food supply. Feb. 12 – Physics and Astronomy Colloquium, 4 pm, on Photosynthesis.
	http://en.wikipedia.org/wiki/Greenhouse_effect http://en.wikipedia.org/wiki/Photosynthesis
Feb. 10, 12	Biomass: conversion to thermal energy, liquid biofuels for transportation.
	http://en.wikipedia.org/wiki/Biomass ; http://en.wikipedia.org/wiki/Biofuels http://en.wikipedia.org/wiki/Climate_change; http://www.camelclimatechange.org/articles/view/151215/ Feb. 12 – Physics and Astronomy Colloquium, 4 pm, on Photosynthesis.
Feb. 17, 19	Solar thermal energy. Generating heat from light; passive solar for space and water heating; solar thermal power plants (generating electricity from solar heat); thermoelectric conversion. Wind energy. Feb. 19, Guest Lecture on *Design, installation, and operation of a residential PV system*, by Brooks Martner, retired NOAA atmospheric scientist.
	http://en.wikipedia.org/wiki/Solar_thermal_energy; Handout chapter on Solar Thermal Energy; http://en.wikipedia.org/wiki/Wind_power; Handout chapter on Wind Energy.
Feb. 24, 26	Photovoltaic effect and fundamental solar cell properties. Diode equation, dark current, light current. Efficiency, J_{SC}, V_{OC}, internal and external QE, maximum power point. Calculation of photocurrent density from quantum efficiency.
	Handout chapter on PV. http://en.wikipedia.org/wiki/Photovoltaic_effect http://en.wikipedia.org/wiki/Photoelectric_effect http://en.wikipedia.org/wiki/Edmond_Becquerel http://en.wikipedia.org/wiki/Diode (Parts Introduction, 1, 4.4, and 4.5). Textbook section 4.1.
Mar. 3, 5	March 3: Quiz #2. Construction of a PV cell: components including substrate or superstrate, transparent conducting layer, light-absorbing layer, charge-separation interface, back electrical contact. Introduction to semiconductor physics concepts: semiconductors; band structure; valence and conduction bands (HOMO-LUMO levels); bandgap energy; direct vs. indirect gap; electrons and holes (“charge carriers”); light absorption; n-type and p-type doping; the p-n junction. Charge carrier transport: drift and diffusion; charge carrier processes: carrier cooling, charge separation, recombination mechanisms (radiative and non-radiative).

	Textbook chapter 3. www.pveducation.org Section 3 and 4. www.pveducation.org Sections 5 and 7.
Mar. 17, 19, 25	Types of solar cells: Crystalline and polycrystalline silicon PV, thin-film PV, organic and nanostructured PV. CdTe solar cells; a-Si solar cells. Nanomaterials: advantages and disadvantages in PV.
	Textbook chapter 4.
Mar. 27, 31, April 2	Solar cell technologies; thin film solar cells.
	Textbook chapter 5.
April 7, 9	April 7: Quiz #3. Design and characterization of PV modules and systems. Characterization and metrology of PV modules and systems
	Textbook chapters 6 and 8. www.pveducation.org Section 7.
Apr. 14, 16	PV system economics: energy and money; energy payback time; calculating the Levelized Cost of Electricity (LCOE), (also known as the Levelized Energy Cost); cost components. Renewable energy policies (US, Ohio, and global). Introduction to energy market economics, policies, and the environment: major fuels, carbon impact, trends, the role of energy efficiency.
	Textbook chapter 10. http://en.wikipedia.org/wiki/LCOE
Apr. 21, 23	Presentations on PV LCOE.
Apr. 28, 30	Review.
May 5	Final Exam: **12:30 – 2:30 pm.**