2.626 / 2.627: Fundamentals of Photovoltaics
Problem Set #1, Fall 2013
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In this assignment, you will familiarize yourself with the solar resource and its spectral characteristics, as well as the optical losses in a PV device.

Please note: Excel spreadsheets, MATLAB, Mathematica, or plotting programs such as OriginLab (or anything similar) may be used to calculate the answers to many of the problems below, but **any submitted code or spreadsheets will not be reviewed by the grader**. If you require Excel or Matlab, please write-out the formulas or methodology used to calculate your answer in a clear and concise manner. **If methodology is not presented, then answers will receive no credit.** Additionally, clearly circle all final answers.

Question #1
(Integrated Spectral Irradiance):

- Download the AM0 and AM1.5 spectral irradiances from the link http://pveducation.org/pvcdrom/appendices/standard-solar-spectra.
  Note: these spectral irradiances comprise the first three columns (the first column is the photon wavelength; *i.e.* independent variable).

a) Using Excel (if possible), numerically integrate each spectral irradiance and determine the irradiance of each.

   Note: Plotting each spectral irradiance may be a helpful visual aid before integrating.

b) Convert each spectral irradiance to units of kW m^{-2} eV^{-1}. Using unit analysis may help you figure out the conversion factor for this.

   Note: In the Excel file containing the raw AM0 and AM1.5 spectral irradiances, the units are given in kW m^{-2} nm^{-1}.

- Re-plot each spectral irradiance, now over the independent variable "photon energy (eV)".

- Numerically integrate each spectral irradiance again, this time over "photon energy (eV)" and show that the irradiance of each is the same as when integrating over "photon wavelength (nm)" respectively.

c) **GRAD STUDENTS ONLY** (2.626): Fit the function

$$A\frac{\varepsilon^3}{\exp(\beta\varepsilon)-1}$$

to the AM0 spectral irradiance over photon energy. Note: A and β are constant fitting parameters. To get you started, $\beta = (k_B T_S)^{-1}$, with k_B = 8.617 x 10^{-5} eV K^{-1} and T_S = 5800 K.

- What is the numerical value of A in units of W m^{-2} eV^{-4} ?

- Analytically integrate the function above and show that the answer closely matches the numerical integration for AM0 performed earlier in this problem.

  Note: This integral solution may be helpful…

$$\int_a^b \frac{[x+c_1]^n}{exp(x)-1}dx = [-1]\sum_{p=0}^{n}\frac{n!}{[n-p]!}[x+c_1]^{n-p}\left\{\sum_{j=1}^{m}\left[\frac{1}{j^{p+1}}\right]exp(-jx)\right\}\Bigg|_a^b$$

Question #2

(Peak Power vs. Energy): Consider a flat PV panel and a tracking solar concentrator in Phoenix, AZ and in Boston, MA. Please use NREL solar maps, located at www.nrel.gov/gis/solar.html and cite which map was used.

a) Notice the integrated spectral irradiance for AM1.5D (appropriate for solar concentrators) is *lower* than AM1.5G (appropriate for flat panels). Describe under what conditions a tracking solar concentrator device could produce more energy than a flat panel (of identical peak power rating) over the course of a typical day.
b) For a typical September day, provide an estimate for the daily energy output (in units of kWh/day) for a 100 MW_{peak} system in Phoenix, AZ and Boston, MA.
c) Which system (tracking vs. fixed) produces more energy per day in Phoenix? In Boston? What accounts for the difference? Use yearly average data.

Question #3 (Estimating Land Requirements): Obtain estimates for (a) time-averaged and (b) peak power consumption for a typical home.

a) Calculate the space required in Boston, MA to meet the time-averaged power requirements for a home. Assume a 15% efficient photovoltaic system, and that the average home uses around 2kW of electricity on average.
b) How do these values change, if peak demand must be met (i.e., no energy storage device is available)? Often peak energy is estimated as double the average load.

c) Repeat a) and b) for an electric car. To estimate the electricity consumption for a car, assume the fuel efficiency and peak power of a Tesla roadster (vroom!)
d) Given your answers in a), b) and c), where do you think more PV will be deployed in the long run: on cars or on homes?

Question #4 (Reflection and Absorption losses) For many of these problems, you may need to look up the index of refraction or absorption coefficient for silicon and SiN_x (hint: PVCDROM, Appendices). You may assume that the absorption for a thin SiN_x layer is negligible. Please cite all sources.

a) For 550nm light (near the peak of the solar spectrum), what percentage of light is reflected off the front surface of a polished silicon wafer?
b) If SiN_x is used as anti-reflection coating (ARC,) what thickness should be used if we optimize for 550nm light?
c) If we assume only one pass of light through the silicon, estimate the thickness required to absorb 90% of incident, non-reflected photons at 1070nm? How would thickness change if we texture the surface? You may assume the upper theoretical limit for light-trapping.