LAB 1-2

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Swayam Mehta, Leif Dixon, Emmanuel Mvutu,
Leslie Deras, Ryan Guthrey

Group 7

Objective:

The objective of this lab is to explore various aspects of solar energy by employing the Stefan-Boltzmann Law, solar spectral data, and semiconductor bandgap properties. The aim is to calculate the solar energy density at different locations in the solar system, and to assess the solar irradiance and photon flux relevant for silicon-based solar cells on Earth. The lab also aims to calculate the maximum possible output current density from a silicon solar cell.

Materials/Equipment Needed:

- Excel

Question 1:Use Stefan – Boltzmann Law to calculate the energy density on the surface of the sun at T = 5780K. Based on that result, calculate the solar illumination energy density at the earth's orbital position (outside the atmosphere, ie, AM0). The Radius of the Sun = 6.96 × 108 m and the Distance to Earth = 1.5 × 1011 m. Assume the solar radiation is spatially uniform

Given: $T = 5780K$

Radius of sun = $6.96 \times 10^8 m$
Distance of Earth = $1.5 \times 10^{11} m$
Steffon Boltzman constant = 5.67×10^{-8} $Wm^2 K^{-4}$

Solution:

Energy Density = Stefon Boltman constant * Temperature (K)

$$U = \sigma \cdot T^4$$

$$U = (5.67 \times 10^{-8} \, Wm^{-2} K^{-4}) * (5780K)^4$$

$$U = (5.67 \times 10^{-8}) * (1.127 \times 10^{16})$$

$$U \approx 64 \times 10^7 \, W/m^2$$

Energy density at the Surface of the Sun is approx. $64 \cdot 10^7 W/m^2$

Energy at Earth (Amo)

$$Amo = \frac{\text{Energy density at Sun's Surface} * (\text{Radius of Sun})^2}{(\text{Distence to Earth})^2}$$

$$Amo = \frac{(64 \cdot 10^7 \, W/m^2) * (6.96 \times 10^8 m)^2}{(1.5 \times 10^{11} m)^2} \approx 1.36 \times 10^3 \, W/m^2$$

Solar illumation energy density at Earth's orbital position is approx. $1.36 \times 10^3 W/m^2$

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Question 2:Use solar spectra data (ASTMG173.xls, Global tilt spectrum) from https://www.nrel.gov/grid/solar-resource/spectra-am1.5.html (Links to an external site.) to calculate the solar irradiance (energy density W/m2) on the surface of the earth (AM1.5).

Solar irradiance (w*m^-2*nm^-1) is calculated by using the global spectrum and wavelength provided in the AM1.5 datasheet. Using the formula for power density, each power density for each wavelength can be found. Then the total power density is found by adding up the individual power density of each wavelength. Using excel, a person can calculate the running column of power density wavelength to quickly find the total of all charges. After doing this it was found that the total equated to $1.00x10^3$ (W/m^2).

Power Density = Global Tilt / Δ wavelength
∑ (each power density) = Total power density
Total Power Density: 1.00×10^3 (W/m^2)

E4 fx =C4*(A5-A4)

	A	B	C	D	E	F
1			SOLAR IRRADIANCE			
2	ASTM G173-03 Reference Spectra Derived from SMARTS v. 2.9.2					
3	Wvlgth nm	Etr W*m-2*nm-1	Global tilt W*m-2*nm-1	Direct+circumsolar W*m-2*nm-1	2.37E-23 × ity(W/m2)	
4	280	8.20E-02	4.73E-23	2.54E-26	=C4*(A5-A4)	
5	280.5	9.90E-02	1.23E-21	1.09E-24	6.15E-22	
6	281	1.50E-01	5.69E-21	6.13E-24	2.84E-21	

Question 3:Use solar spectra data (ASTMG173.xls, Global tilt spectrum) from https://www.nrel.gov/grid/solar-resource/spectra-am1.5.html (Links to an external site.) to calculate the available photon flux (photons/s.m2) from the sun that can be absorbed by Si (bandgap = 1.11 eV).

Photon Flux is the amount of photons per second per unit area that can be absorbed by Silicon(Si). The value is important because it estimates the number of generated electrons and the produced current of the solar cell. Photon flux can be calculated by the following equation:

Φ = Power Density / qE(Ev)
q = Electron charge (1.6*10^-19)
Ev = Electron volts

Since power density (W/m^2) and the bandgap of 1.11 are given

Photon Flux Φ = Power Density / (q * 1.11)

Using the formula, the total photon flux was calculated to **6.90e+02** without the bandgap and **5.67E-01** with the bandgap

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H6 fx =G6/C6

	B	C	D	E	F	G	H	I	J	K	L
2								1.11	q(C)	1.60E-19	1.35E+03
3				PHOTON FLUX							
4		ASTM G173-03 Reference Spectra Derived from SMARTS v. 2.9.2									
5	Wvlgth nm	electron energy E	Etr W*m-2*nm-1	Global tilt W*m-2*nm-1	Direct+circumsolar W*m-2*nm-1	Power Density(W/m2)	= Energy Flux / E	Electrons/s*m2			
6	280	4.428571429	8.20E-02	4.73E-23	2.54E-26	2.37E-23	=G6/C6	1.80E-03		hc = plankts constant	1240
7	280.5	4.420677362	9.90E-02	1.23E-21	1.09E-24	6.15E-22	1.39E-22	8.70E-04			
8	281	4.412811388	1.50E-01	5.69E-21	6.13E-24	2.84E-21	6.45E-22	4.03E-03			
9	281.5	4.404973357	2.12E-01	1.57E-19	2.75E-22	7.83E-20	1.78E-20	1.11E-01		Sum of Photon Flux (photons/s.m^2)	
10	282	4.397163121	2.67E-01	1.19E-18	2.83E-21	5.97E-19	1.36E-19	8.49E-01		6.90E+02	
11	282.5	4.389380531	3.03E-01	4.54E-18	1.33E-20	2.27E-18	5.18E-19	3.23E+00			
12	283	4.381625442	3.25E-01	1.85E-17	6.76E-20	9.23E-18	2.11E-18	1.32E+01			
13	283.5	4.373897707	3.23E-01	3.54E-17	1.46E-19	1.77E-17	4.04E-18	2.53E+01		Sum of Photon Flux with badgap (photons/s.m^2)	
14	284	4.366197183	2.99E-01	7.27E-16	4.98E-18	3.63E-16	8.32E-17	5.20E+02		4.01E+02	
15	284.5	4.358523726	2.50E-01	2.49E-15	2.16E-17	1.24E-15	2.85E-16	1.78E+03			
16	285	4.350877193	1.76E-01	8.01E-15	9.00E-17	4.01E-15	9.21E-16	5.76E+03			
17	285.5	4.343257443	1.55E-01	4.26E-14	6.44E-16	2.13E-14	4.91E-15	3.07E+04			
18	286	4.335664336	2.42E-01	1.37E-13	2.35E-15	6.84E-14	1.58E-14	9.86E+04			
19	286.5	4.328097731	3.33E-01	8.38E-13	1.85E-14	4.19E-13	9.68E-14	6.05E+05			
20	287	4.320557491	3.62E-01	2.74E-12	7.25E-14	1.37E-12	3.17E-13	1.98E+06			
21	287.5	4.313043478	3.39E-01	1.09E-11	3.66E-13	5.45E-12	1.26E-12	7.90E+06			
22	288	4.305555556	3.11E-01	6.23E-11	2.81E-12	3.12E-11	7.24E-12	4.52E+07			
23	288.5	4.298093588	3.25E-01	1.72E-10	9.07E-12	8.58E-11	2.00E-11	1.25E+08			
24	289	4.290657439	3.92E-01	5.63E-10	3.50E-11	2.81E-10	6.56E-11	4.10E+08			
25	289.5	4.283246978	4.79E-01	2.07E-09	1.54E-10	1.04E-09	2.42E-10	1.51E+09			
26	290	4.275862069	5.63E-01	6.02E-09	5.15E-10	3.01E-09	7.04E-10	4.40E+09			
27	290.5	4.268502582	6.06E-01	1.38E-08	1.33E-09	6.89E-09	1.61E-09	1.01E+10			
28	291	4.261168385	6.18E-01	3.51E-08	3.90E-09	1.75E-08	4.11E-09	2.57E+10			
29	291.5	4.253859348	5.98E-01	1.09E-07	1.44E-08	5.46E-08	1.28E-08	8.02E+10			

Question2 Question3

Question 4:If all the absorbed photons are converted to electron-hole pairs (EHPs) by Si solar cell, what is the maximum possible output current density Jsc (in mA/cm2)

Output current density is the maximum current delivered by a solar cell. This shows that more current generated by a dollar cell, leads to more power sent to the solar panel. The maximum output current density can be found by using the formula .

$$J_{max} = \Phi \times q$$

Φ = Total Photon Flux

q = Electron Charge

J max = 4.01 * 10^17 photons/s.m^2 * (1.6*10^-19)

= 6.416 *10^-2 A/m^2

Maximum current Jsc = Jmax /10

Jsc = 6.46*10^1 mA/cm^2

Conclusion:

This lab provided valuable insights into solar energy characteristics, both at the Sun and on Earth. Using the Stefan-Boltzmann Law, we estimated solar energy density at Earth's orbit, which serves as a baseline for available solar power. Further calculations with the ASTMG173.xls dataset revealed the solar irradiance and photon flux on Earth, specifically tailored for silicon-based solar cells with a 1.11 eV bandgap. The findings are crucial for understanding the efficiency and limitations of solar energy harvesting technologies.