

University of Delaware
Department of Electrical and Computer Engineering
ELEG620: Solar Electric Systems
Homework #1: Solar Radiation (2 units)

Solar Radiation Questions

Do the following questions from the Questions at the end of the Solar Radiation Chapter: #1, #2, #7, #8, #20.

1. A light source consists of monochromatic light with energy of 600 nm with a spectral irradiance of 1×10^{17} photons/cm²/sec. What is the power density of this light source? Is the light source visible to the human eye?

The equation for converting photon flux to power density is photon flux multiplied by the energy

of the photon: $H \left(\frac{W}{m^2} \right) = \Phi \frac{hc}{\lambda}$. In this equation, the units of energy are in Joules. To convert

using the more commonly used unit of energy of electron volts, we use $1 \text{ eV} = q \text{ Joules}$, to get:

$$H \left(\frac{W}{m^2} \right) = \Phi \times \frac{hc}{\lambda} (\text{J}) = q\Phi \frac{1.24}{\lambda(\mu\text{m})}$$

Plugging in the numbers gives 33 mW/m².

Light with a wavelength of 600 nm is viewed as orange-yellow.

2. The following questions involve calculations using the standard AM1.5 solar spectrum, available as an Appendix in the PVCDDROM.

- a. For the AM1.5 solar spectrum, calculate the maximum current if every photon is absorbed and collected.

This problem involves the calculation of the photon flux from the spectral intensity. The power density (needed for part (c)) is calculated by multiplying the spectral intensity by the wavelength interval. From the power density, the photon flux is found by:

$$H \left(\frac{W}{m^2} \right) = \Phi \times \frac{hc}{\lambda} (\text{J}) = q\Phi \frac{1.24}{\lambda(\mu\text{m})}$$

More compactly, the relationship between spectral irradiance and photon flux is:

$$F \left(\frac{W}{m^2 \mu\text{m}} \right) = q\Phi E \frac{1.24}{\lambda^2(\mu\text{m})} = q\Phi \frac{1.24}{\lambda^2(\mu\text{m})} = q\Phi \frac{E^2(\text{eV})}{1.24}$$

The maximum current occurs when every photon gives rise to one electrons, so the photon flux times q gives the maximum current. Adding the current contribution from each wavelength in a spread sheet gives:
69 mA/cm².

- b. A silicon solar cell has a band gap of 1.12 eV. What is the maximum current if every photon above the band gap gets absorbed and converted to current?

For this part of the problem, the calculations are as above except that the current is summed for wavelengths shorter than the band gap, or $\lambda = 1107 \text{ nm}$, rather than over the entire spectrum. The answer is 43.8 mA/cm².

- c. What fraction of the total power in the AM1.5 spectrum is above the band gap of the silicon solar cell? What fraction is lost?
 The power density (the spectral irradiance multiplied by the wavelength interval) is summed for wavelengths shorter than $\lambda = E_g/1.24 = 1107 \text{ nm}$. The answers are 81% and 19%.

7. Calculate the elevation and azimuth angle at solar noon for on Jan 1, March 21st and August 1st for your hometown. You may use as a default Belle Fourche, SD (the approximate geographic center of the US, with latitude of $44^\circ 58' \text{ N}$, $103^\circ 46' \text{ W}$).

This problem shows the simple calculations at solar noon.

Azimuth angle at solar noon is always 180° (in Northern Hemisphere)

Longitude: not needed since calculations are at solar noon.

HRA is always 0 at solar noon. So only need to calculate declination angle, and use simple hemisphere dependent calculations for elevation angle.

$$\delta = \sin^{-1} \left\{ \sin(23.45^\circ) \sin \left[\frac{360}{365} (d - 81) \right] \right\}$$

$$\alpha = 90^\circ - \phi + \delta$$

$$\text{Jan 1: } \delta = -22.9^\circ, \alpha = 22^\circ$$

$$\text{March 21}^{\text{st}}: \delta = 0^\circ, \alpha = 45^\circ$$

$$\text{Aug 1: } \delta = 16^\circ, \alpha = 61^\circ$$

8. On April 14th, in Newark DE, what time of day will the clocks say when it is solar noon? Calculate an estimate for the solar radiation intensity at solar noon. Use $39^\circ 30' \text{ N}$ and $75^\circ 30' \text{ W}$ for the latitude and longitude of Newark.

Time zone difference for Newark is: -5

$$LSTM = 15^\circ \times \Delta T_{GMT} = 75^\circ$$

$$EoT = 9.87 \sin(2B) - 7.53 \cos(B) - 1.5 \sin(B) \quad \text{where } B = \frac{360}{365} (d - 81)$$

EoT = -0.5 minutes

$$T_{\text{ime Correction}} = 4(LSTM - \text{Longitude}) + EoT = -2.5 \text{ minutes}$$

So time on clocks is 12:03 pm

$$I_D = 1.353 \times 0.7^{(AM^{0.678})} \delta = \sin^{-1} \left\{ \sin(23.45^\circ) \sin \left[\frac{360}{365} (d - 81) \right] \right\} = 8.8^\circ$$

$$\alpha = 90^\circ - \phi + \delta = 59^\circ$$

$$AM = 1.16$$

$$I = 911 \text{ W/m}^2$$

20. Diffuse radiation has a higher fraction of high energy radiation than direct radiation. Explain why this is so.

A dominant atmospheric scattering process is Rayleigh scattering, which depends on λ^{-4} . This means that shorter wavelength (higher energy) light is more effectively scattering than longer wavelengths light. Since diffuse light is composed of scattered light, it has a higher component of high energy (blue) light. This is also why the sky appears blue.