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UV Degradation of Polycarbonate

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Physics Senior Project

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Abstract:

The decrease in visible and ultraviolet transmission spectra of polymeric and glass spacecraft materials has been measured to determine the extent of degradation due to high-energy UV radiation similar to the solar spectrum (both above and below the stratosphere, which is where most of the UV radiation is absorbed). This project looked at the effects that the atmosphere has in regards to blocking UV radiation and thus, slowing down the UV degradation process. A polycarbonate sample was exposed to radiation from a focused high intensity deuterium lamp source, which generates radiation in the UVA and UVB spectrum. A particularly severe effect might result from atmospheric oxygen exposed to intense UV radiation, which can produce atomic oxygen. The materials' UV/VIS/NIR transmission spectra (200nm to 1700nm) were examined with a fiber optic spectrometer to determine the effects of being exposed to the radiation and to the pressure of atmospheric gases.

Introduction:

UV radiation has short wavelengths. "The radiation environment in space can be classified into two types; firstly the UV radiation with wavelength between 115 nm and 300 nm and, secondly, the high energy radiation consisting of particles and higher energy photons." [2]. The shorter wave length radiation has more energy than visible light or microwave radiation. From the photoelectric effect, we know that each material has what is called a threshold frequency. Most materials threshold frequency is in the ultraviolet region. If the material is exposed to light that has a higher frequency than its threshold frequency, then the material will eject electrons. If the material is exposed to light with a lower frequency than the threshold frequency for the material, then no electrons will be ejected from the material no matter how intense the light is. This can cause the atoms to turn into ions with enough energy being added to the material (process known as ionization). To determine what affect this energy has on a material, the intensity can be measured

using a spectrometer (HR 4900 Ocean Optics). The spectrometer measures relative intensity as a function of wavelength, which can then be translated into transmission spectra. Light is directed through a fiber optic cable into the spectrometer through a narrow aperture (entrance slit). The slit vignettes the light as it enters the spectrometer. The divergent light is then collimated by using a concave mirror and directed onto a grating. The grating then disperses the spectral components of the light at slightly varying angles, which is then focused by a second concave mirror and imaged onto the detector. The spectrometer measures the intensity in counts which are how many times a photon is detected. Each number in the calculation ($B_{uv}(\lambda), B(\lambda), I_0, I_{60}$) have units of counts. The initial transmission is to show how the material initially reacts to being exposed to UV radiation and the final shows how the material changed from the radiation. The equations to find transmission and change in transmission are:

$$T_i = \frac{I_0 - B(\lambda)}{B_{uv}(\lambda) - B(\lambda)} \quad (1)$$

$$T_f = \frac{I_{60} - B(\lambda)}{B_{uv}(\lambda) - B(\lambda)} \quad (2)$$

$$\Delta T = T_f - T_i \quad (3)$$

where $B(\lambda)$ is the intensity in counts of the background when the over head lights and source are off with no material in between the fiber optics. $B_{uv}(\lambda)$ is the intensity in counts with the over head lights off and the UV source on with no sample between the fiber optic cables. I_0 is when the over head lights were turned off and the source on and the sample placed between the fiber optic cables, and I_{60} is when the source is on with the sample between the fiber optic cables after 60 minutes of radiation from a deuterium lamp source.

Procedures:

To obtain the intensity curve or spectra, the setup, [Fig. 1], was an important aspect. If not done properly, the data will be over saturated and unusable. The fiber optic cables could not be to

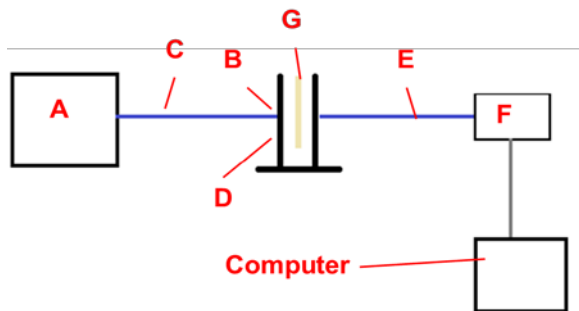


Fig. 1: Schematic of the experiment setup. The Deuterium light source (A) is connected to a fiber optic cable (C) which goes to a lens expander (B) attached to the sample holder (D). The sample (G) goes between the two posts of the sample holder. Another fiber optic cable (E) is attached to the opposite side of the sample holder, which goes to the Spectrometer (F). The spectrometer then hooks up to the computer where the data is imported into the Spectra Suit program.

close together otherwise the data was oversaturated. The posts of the sample holder had to be adjusted so that oversaturation did not occur.

To decrease the amount of saturation, the distance between the fiber optic cables can be increased (move the sample holder posts farther apart). The deuterium source (A) is attached to a fiber optic cable (C) that then goes to a lens expander (B) that screws into the sample holder (D). The HR 4900 Ocean Optics spectrometer (F) was also hooked up to a fiber optic cable and expander (E) that was screwed into the sample holder (D) [Fig.2].

The sample (G) then went midway between the two posts of the sample holder [Fig.1]. Further testing can be done to determine the dependence of the sample having to be placed directly in the center of the posts of the sample holder or if it can be placed anywhere between as long as the fiber optics have good separation. The spectrometer (F) was also hooked up to a computer so that the data could be recorded using the program "Spectra Suit". The spectrometer uses a CCD detector, which has a signal to noise ratio of 300:1. The detector has a range of 200nm to 1100nm and has a sensitivity of 100 photons per count at 800nm. For this deuterium source, the specifications were not found which made it difficult to find how the source varied with wavelength. The characteristics of the source were modeled using the experimental setup (Fig. 2) and having the overhead lights turned off. The

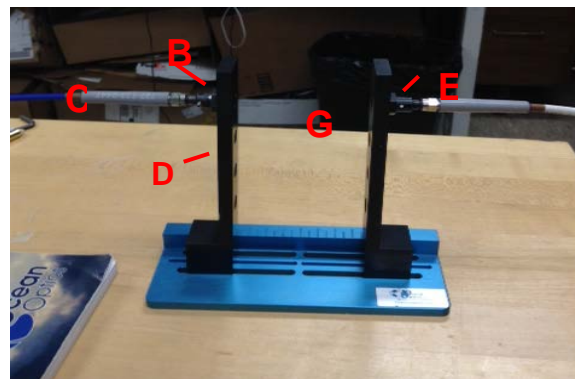


Fig. 2: Experiment setup. Fiber optic cable (C) from deuterium source goes to lens expander (B) which attaches to the sample holder (D). The sample (G) is placed between the two posts of the sample holder. On the opposite side of the sample holder there is another lens expander and fiber optic cable (E).

spectra of the deuterium source can be viewed in [Fig. 3].

Results:

The polycarbonate had some interesting results. First, the intensity was measured at the beginning and at the end of a 60-minute radiation period [Fig. 4]. Using the spectra data the initial and final transmission was calculated using (1) and (2). The Spectra-Suit program gave the data as intensity. [Fig. 4] does seem to have some issues. It is interesting to see that the intensity is lower than zero before radiation. This most likely was caused by the limitations of the spectrometer. [Fig. 4] contains the raw data of the intensity from $t = 0$ min and $t = 60$ min. A possible interpretation of this data is that the material at first did not let the UV radiation through but then over time the material properties changed and allowed the UV radiation to transmit through the polycarbonate sample. It also seems that the polycarbonate sample does not allow for the middle of the UV radiation spectrum to transmit through as well as other wavelengths.

To get a better picture of how the material is changing we took our transmissions that were determined using (1) and (2), and then applied (3). By finding the change in transmission, it can be seen how the properties of the material changed. [Fig.5] shows the percent change in transmission along with the initial and final transmission lines. The percent change in

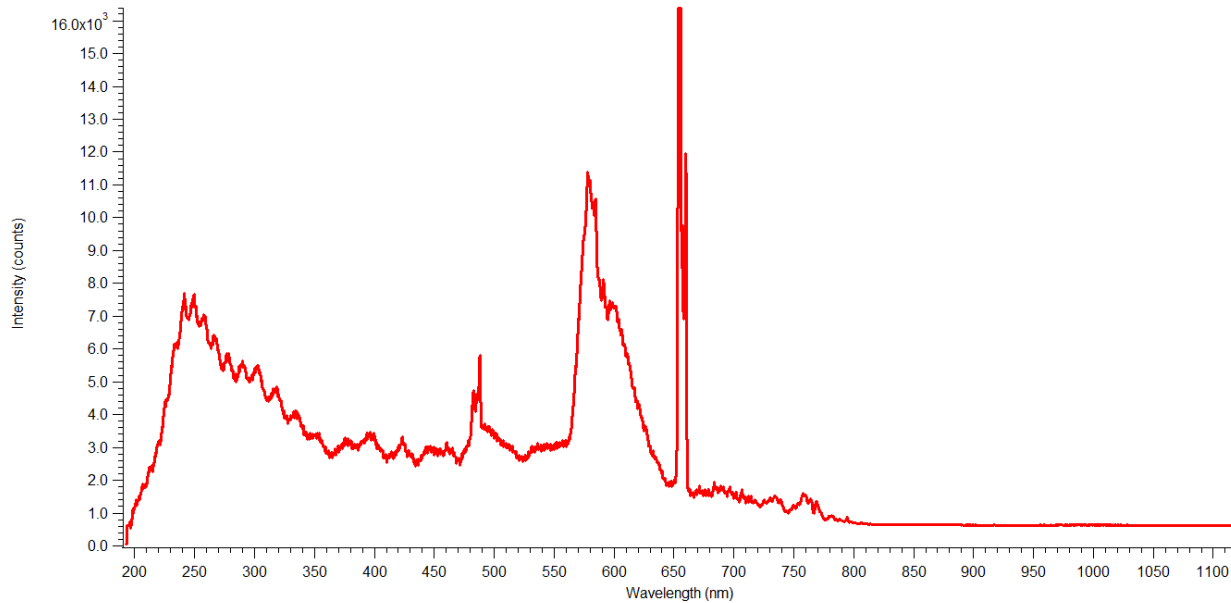


Fig. 3: Spectra for deuterium lamp source over all wavelengths covered by the HR 4900 spectrometer.

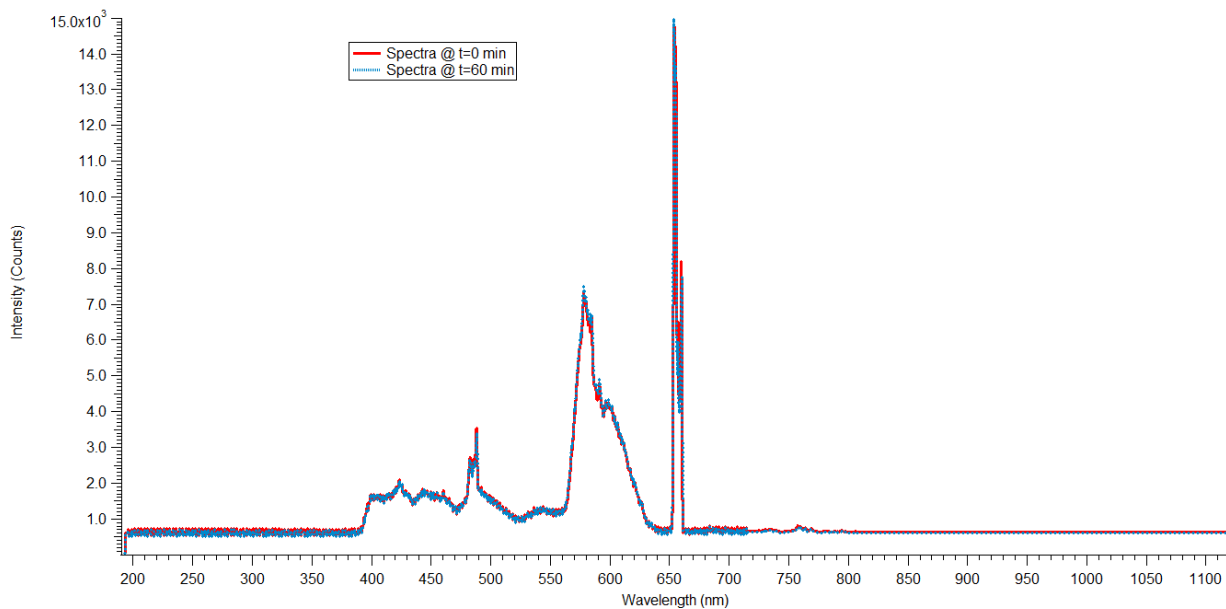


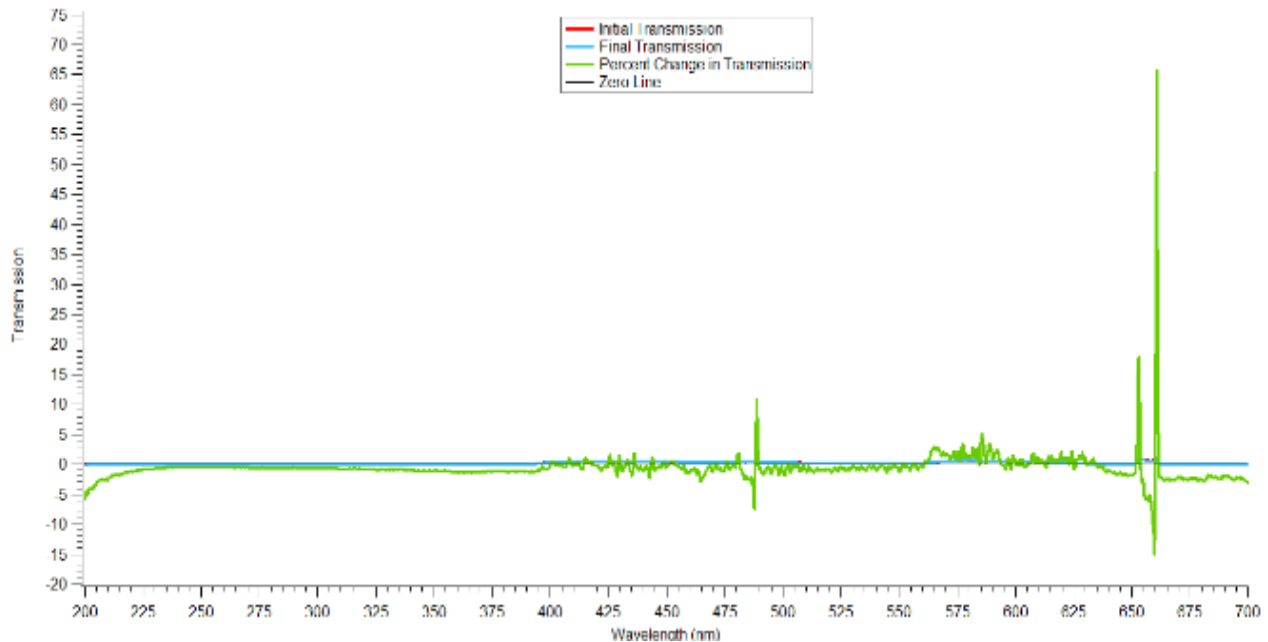
Fig. 4: Spectra for polycarbonate. The red line indicates the spectra at the start of radiation ($t=0$ min), while the blue is the final spectra after 60 minutes of radiation.

transmission is a better comparison tool than just the change in transmission because percentage is more comprehensible and has more meaning than just a number.

To find the percent change in transmission you find the change in transmission and then multiply that by 100 to get a percent.

Discussion and Conclusion:

The data that was produced from this experiment had some parts that did not make any sense. In order to try to find something useful, the 200 nm to 700 nm wavelength was focused on in [Fig. 5]. The change in transmission decreased at 200nm by 5.8 % and 7.5% at 490 nm. When looking at the specifications from Ocean Optics for the deuterium source it was determined that



the source is about 17.29% of the AM0 Solar intensity in the ultraviolet and 2.33% of total Solar intensity (where AM0 represents an air mass filter that represents a space environment where the Sun is perpendicular or straight above, the Earth). When this was equivocated to the exposure time of the Sun necessary to produce this change, it was found that the sample would only be exposed to the Sun at AM0 for about 10 minutes with only ultraviolet radiation and about 84 seconds in total radiation. This is quite significant especially when comparing this exposure time to the lifetime of a satellite.

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