A study on the transmittivity of Tyvek

Alvaro Chavarria, Physics Department, Duke University

June 20, 2005

Abstract

In this experiment the transmittivity of Tyvek (Dupont, 1073B) was studied. Results were obtained for the transmittivity of a single layer of Tyvek under both dry and wet conditions. The transmission of light through multiple layers of Tyvek was also studied.
It was concluded that there is some variation in the transmittivity of dry Tyvek, even in different regions of the same sheet, and the values lie around **4%-6%** (with a mean value of $4.9 \pm 0.9\%$) of incident light being transmitted.
The same samples of Tyvek were tested under wet conditions by soaking them in both pure water and tap water. For both there was a decrease in the transmittivity of ≈0.2%-0.3%.
Multiple layers of dry Tyvek further reduce the % of light transmitted to $2.3 \pm 0.1\%$ for two layers and $1.10 \pm 0.03\%$ for three layers.

1 Introduction

The purpose of this experiment was to measure the transmittivity of the Tyvek (Dupont, 1073B) that is used in the outer detector of Super-K in Kamioka, Japan. Experiments were done to measure the transmittivity of a single layer of Tyvek under different conditions (wet and dry) and of several layers of Tyvek.

2 Method

A photo multiplier tube (PMT) module (Hamamatsu, HC124-02) was used to make the measurements for the transmittivity of Tyvek . It was concluded earlier (see **Appendix A**) that the light intensity incident on the PMT anode was proportional to the output current of the apparatus in the brightness range at which the light source was operated during the experiment. This way, measuring the output current of the PMT with and without Tyvek between itself and the light source is sufficient to determine the transmittivity of the material. In this case, the light source that was used was a standard green light emitting diode (LED).

A simple circuit was built to control the LED. It consisted of a power supply (variable voltage), a 6.1 kΩ resistor, an ammeter and the LED in series.
It was important to make sure that the experiment was done in the darkest possible conditions, i.e. reduce the dark noise as much as possible. To do this, the experiment was set up inside a cardboard box that was sealed with duct tape. Figure 1 shows the PMT inside the cardboard box.

Figure 1: PMT and cardboard box.

To even further reduce the dark noise, the cardboard box itself was placed inside a plastic box that was painted black in the inside. The black box had a lid that was set into place while the experiment was under way. Figure 2 is a picture of the sealed black box.

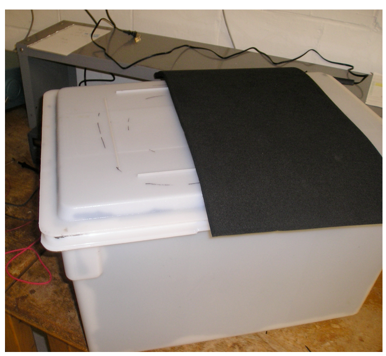

Figure 2: Black box.

A small cardboard case was made and placed on top of the LED. This case had a hole and the Tyvek was slid into position to cover it. Measurements were done with and without the Tyvek in place. The LED and its case were placed opposite to the PMT and their relative positions were kept constant.

The following pictures show the case with a piece of Tyvek in place (Figure 3) and the positions of the LED and PMT inside the cardboard box (Figure 4).

Figure 3: Piece of Tyvek in place.

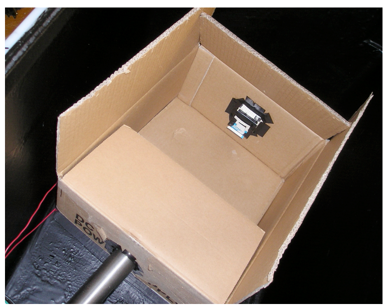

Figure 4: Cardboard box with PMT and LED.

Seven different pieces of Tyvek (labeled from **a** to **g**) were used in the experiment. They were all cut from random locations of the same sheet of Tyvek and there was some variation in their sizes (all were a few centimeters wide and long). The general process for making the readings was the following. For each run the output current of the PMT without any Tyvek was measured. Then, a reading was taken for each Tyvek piece (**a** through **g**) in place. The process was repeated at least three times (each corresponding to a different run).

In the experiments where wet Tyvek was used, the same pieces that were used for the dry Tyvek measurements were placed in water and left for a few days. Then, when the reading was going to be done the piece was taken out of the water, the measurement was taken and then the piece was put back into the water.

For the measurements of light transmitted through multiple layers of Tyvek two or three of the pieces that were tested individually were placed one on top of the other and then slid into position making sure that all layers were covering

the hole.
It was made sure that the Tyvek pieces were laying flat against the case and the hole was completely covered and the LED current (which should me proportional to its brightness) was kept constant.

3 Results and Analysis

For all of the experiments the LED current was kept at 2.0 ± 0.05 mA and the dark noise was < 0.05 mA.

3.1 Under dry and wet conditions

The first table shows the results for dry Tyvek. There are two "No Tyvek" readings because the pieces **f** and **g** were tested later on and independently, therefore for **f** and **g** the transmittivity should be calculated using the inferior value for "No Tyvek".

Dry Tyvek					
	PMT output current / mA $\pm$ 0.05mA				
	Run 1	Run 2	Run 3	Run 4	Run 5
No Tyvek	54.6	54.1	54.0	54.0	53.9
a	2.0	2.5	2.4	2.3	1.9
b	2.6	2.4	2.4	2.6	2.5
c	3.0	3.1	3.0	2.9	3.0
d	2.1	1.9	2.0	2.0	2.0
e	3.1	3.1	3.1	3.0	3.0
No Tyvek	55.5	57.5	57.5	57.1	56.6
f	2.8	3.0	2.9	2.9	2.9
g	3.2	3.2	3.2	3.1	3.1

The results for wet Tyvek follow. In both cases the pieces were left in the water for two days. The measurements for pure water were done first.

Wet Tyvek (pure water)			
	PMT output current / mA $\pm$ 0.05mA		
	Run 1	Run 2	Run 3
No Tyvek	57.8	58.0	57.3
a	2.3	2.3	2.0
b	2.6	2.5	2.5
c	3.0	2.9	2.7
d	2.0	1.9	1.9
e	3.3	3.1	3.2
f	3.3	3.3	2.8
g	3.1	3.0	2.9

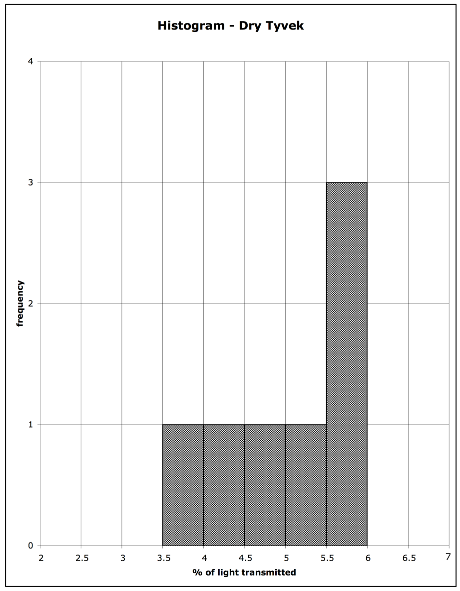

Figure 5: Histogram showing the distribution in transmittivity of different pieces of Tyvek under dry conditions.

Wet Tyvek (tap water)				
	PMT output current / mA $\pm$ 0.05mA			
	Run 1	Run 2	Run 3	Run 4
No Tyvek	54.0	55.9	55.5	55.2
a	1.8	1.8	2.0	2.1
b	2.4	2.4	2.5	2.4
c	2.5	3.0	2.9	2.6
d	1.8	1.9	1.9	1.9
e	3.1	3.1	3.0	3.0
f	2.5	2.7	2.7	3.3
g	2.9	2.8	2.8	2.9

For each measurement the % of light transmitted was calculated in the following way

$$T = \frac{i}{i_o} \times 100 \tag{1}$$

where T is the % of light transmitted, i is the PMT output current with the Tyvek piece in place and i_o is the PMT output current without any Tyvek.

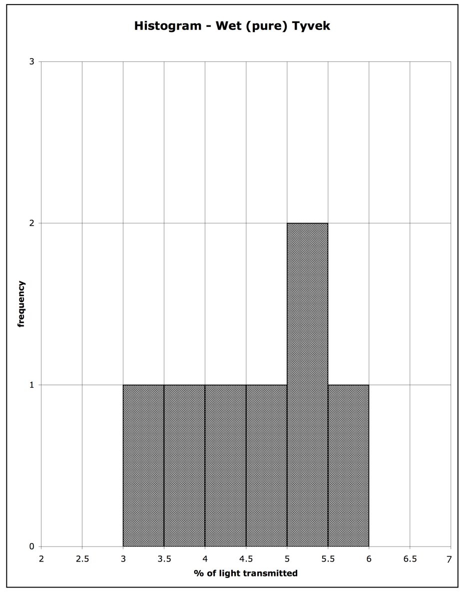

Figure 6: Histogram showing the distribution in transmittivity of different pieces of Tyvek under wet (pure water) conditions.

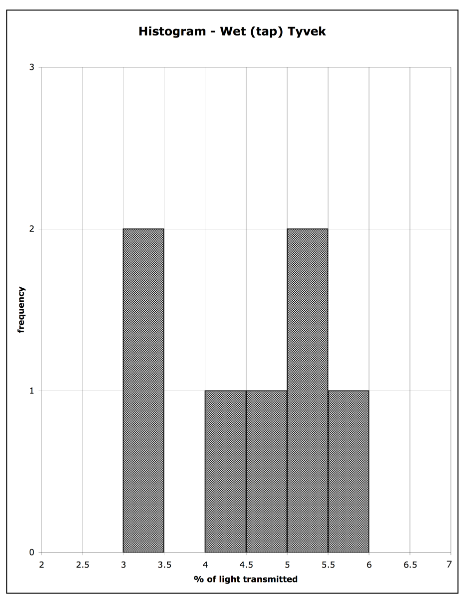

Figure 7: Histogram showing the distribution in transmittivity of different pieces of Tyvek under wet (tap water) conditions.

These percentages (T) were calculated for each run for a particular piece (**a** through **f**) and an average was obtained. The assigned uncertainty is the standard error of the mean over the runs. This was done for dry, wet (pure water) and wet (tap water). The results are presented below.

	% of light transmitted				
	Dry	Wet (pure water)	Wet (tap water)	Δpure	Δtap
a	4.1 ± 0.2	3.8 ± 0.2	3.5 ± 0.2	0.3 ± 0.4	0.6 ± 0.4
b	4.6 ± 0.1	4.4 ± 0.1	4.4 ± 0.1	0.2 ± 0.2	0.2 ± 0.2
c	5.5 ± 0.1	5.0 ± 0.2	5.0 ± 0.2	0.5 ± 0.3	0.5 ± 0.3
d	3.7 ± 0.1	3.4 ± 0.1	3.40 ± 0.03	0.3 ± 0.2	0.3 ± 0.1
e	5.65 ± 0.04	5.5 ± 0.1	5.5 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
f	5.10 ± 0.03	5.4 ± 0.3	5.1 ± 0.4	-0.3 ± 0.3	0.0 ± 0.4
g	5.6 ± 0.1	5.2 ± 0.1	5.2 ± 0.1	0.4 ± 0.2	0.4 ± 0.2

The last two columns in the table show the decrease in transmittivity between dry Tyvek and both wet (pure water) and wet (tap water) respectively. As it can be seen from the previous table there is some variation between different Tyvek pieces which is not accounted by the assigned error (see graph in next section). Yet, it can be said that the transmittivity of dry Tyvek lies in the 4%-6% range with a mean of $4.9 \pm 0.9\%$.

Dupont gives 92% for the opacity of Tyvek. The opacity is defined as the percentage of light that is reflected back by the Tyvek. If it is considered that for light incident on a piece of Tyvek

$$I = R + T + A \tag{2}$$

where I is the incident light, R the reflected light, T the transmitted light and A the absorbed light.

Then, if we take R and T as percentages of the incident light, it must hold that $R+T < 100$. The value of R is given by Dupont and T has just been calculated. Thus, by checking that $92 + 4.9 < 100$ is true, it can be seen that the result obtained for the transmittivity of Tyvek is consistent with Dupont's value.

The results for the % of light transmitted of wet Tyvek (both pure and tap water) were lower for all but one piece (Δpure for **f**). This suggests that there is a slight decrease in the transmittivity of Tyvek when it gets wet. This decrease is only a few tenths of a percent and is not the same for every piece of Tyvek. Yet, a decrease of 0.2%-0.3% lies within the uncertainty of all Δs but one (the same one that actually showed an increase in Tyvek transmittivity (Δpure for **f**)). So, it can be said that the decrease in the transmittivity of Tyvek as it gets wet is $\approx$ 0.2%-0.3%.

It is very hard to tell if there is any difference in the transmittivity of Tyvek between the two types of wet Tyvek (pure and tap water). For every single piece (**a** through **f**) there is a range at which Δpure and Δtap overlap, so it might very well be that they are the same, although it is hard to tell due to the size of the uncertainty. It can then be said that the difference in transmittivity between wet (pure water) and wet (tap water) Tyvek is very small or nonexistent.

3.2 Multiple layers of Tyvek

In this experiment the transmittivity of multiple layers of Tyvek was investigated. The following tables present the raw data. For example, "**d** & **b**" means that, for this particular set up, Tyvek piece **d** was placed on top of piece **b**. Similarly with the three layer trials, "**f** & **g** & **d**" means that pieces **f**, **g** and **d** were placed on top of each other in that order. The arrangement of the multiple layers of Tyvek was random.

Two layers			
	PMT output current / mA $\pm$ 0.05mA		
	Run 1	Run 2	Run 3
No Tyvek	56.5	57.6	56.9
d & b	0.9	0.9	0.9
c & e	1.5	1.5	1.5
f & g	1.5	1.3	1.5
f & c	1.6	1.6	1.2
e & b	1.3	1.2	1.3

Three layers			
	PMT output current / mA $\pm$ 0.05mA		
	Run 1	Run 2	Run 3
No Tyvek	56.1	57.1	57.1
f & g & d	0.6	0.6	0.6
c & e & b	0.7	0.8	0.8
a & c & d	0.5	0.5	0.5

Using the same computation as before the % of light transmitted (T) was calculated for every trial. The uncertainty assigned is also the standard error from the mean. The next table presents these results.

	% of light transmitted
d & b	1.58 ± 0.01
c & e	2.63 ± 0.02
f & g	2.5 ± 0.2
f & c	2.6 ± 0.3
e & b	2.2 ± 0.1
f & g & d	1.06 ± 0.01
c & e & b	1.3 ± 0.1
a & c & d	0.88 ± 0.01

The data above plus the results obtained for a single piece of dry Tyvek (**a** throught **f**) (from the "Dry Tyvek" column in the results of the previous subsection) are plotted in Figure 8. Note from the plot that there is some variation in the values for both two and three layers. This is expected as the pieces that were used have different transmittivities themselves.
The mean values for the transmittivity of two and three layers of Tyvek were calculated to be $2.3 \pm 0.1\%$ and $1.10 \pm 0.03\%$ respectively. From these values and the graph (Figure 8) it can be seen that as the number of Tyvek layers increases the % of light transmitted decreases.
It was attempted to fit an exponential decay function to the experimental values. The simplest expression that seemed to properly fit the data was

$$i = 10.3 \times \exp\left(-\frac{n}{1.34}\right) \tag{3}$$

where i is the % of light transmitted and n is the number of layers of Tyvek. From the previous equation it can be seen that, when $n = 0$, $i = 10.3\%$. This means that about $100 - 10.3 = 89.7\%$ of the incident light is reflected right at the surface. This is consistent with Dupont's value for the opacity (92%) as $89.7\% < 92\%$ (the % of light reflected at the surface is smaller than the total % of reflected light).

4 Conclusion

In this experiment the transmittivity of Tyvek (Dupont, 1073B) was studied. It was found that its value lies around 4%-6% and for all samples the mean value was $4.9 \pm 0.9\%$. There was some variation from sample to sample. Under wet conditions (both pure water and tap water) the transmittivity dropped $\approx$0.2%-0.3% (for practical purposes these numbers are negligible). Multiple layers of Tyvek further decrease the transmittivity to $2.3 \pm 0.1\%$ (for two layers) and $1.10 \pm 0.03\%$ (for three layers).
Although the values were mostly consistent (except for sample **f**) they could have been much better. Both Δpure and Δtap had rather large uncertainties which made it impossible to tell if there was actually any variation from one wet condition to the other. Also, it is also possible that the variation of the transmittivity of dry Tyvek is much greater than what was suggested by this experiment.
In order to improve this it would be a good idea to use many more samples of Tyvek (from various regions of different Tyvek sheets). If, for example, one hundred samples were used, then a clearer picture of the distribution of transmittivity values within this type of Tyvek could be obtained. Also, it would be good to do many more trials for each piece of Tyvek. This way, the results could be more consistent and the standard error from the mean might decrease. After doing this, maybe some difference between Δpure and Δtap could be observed.

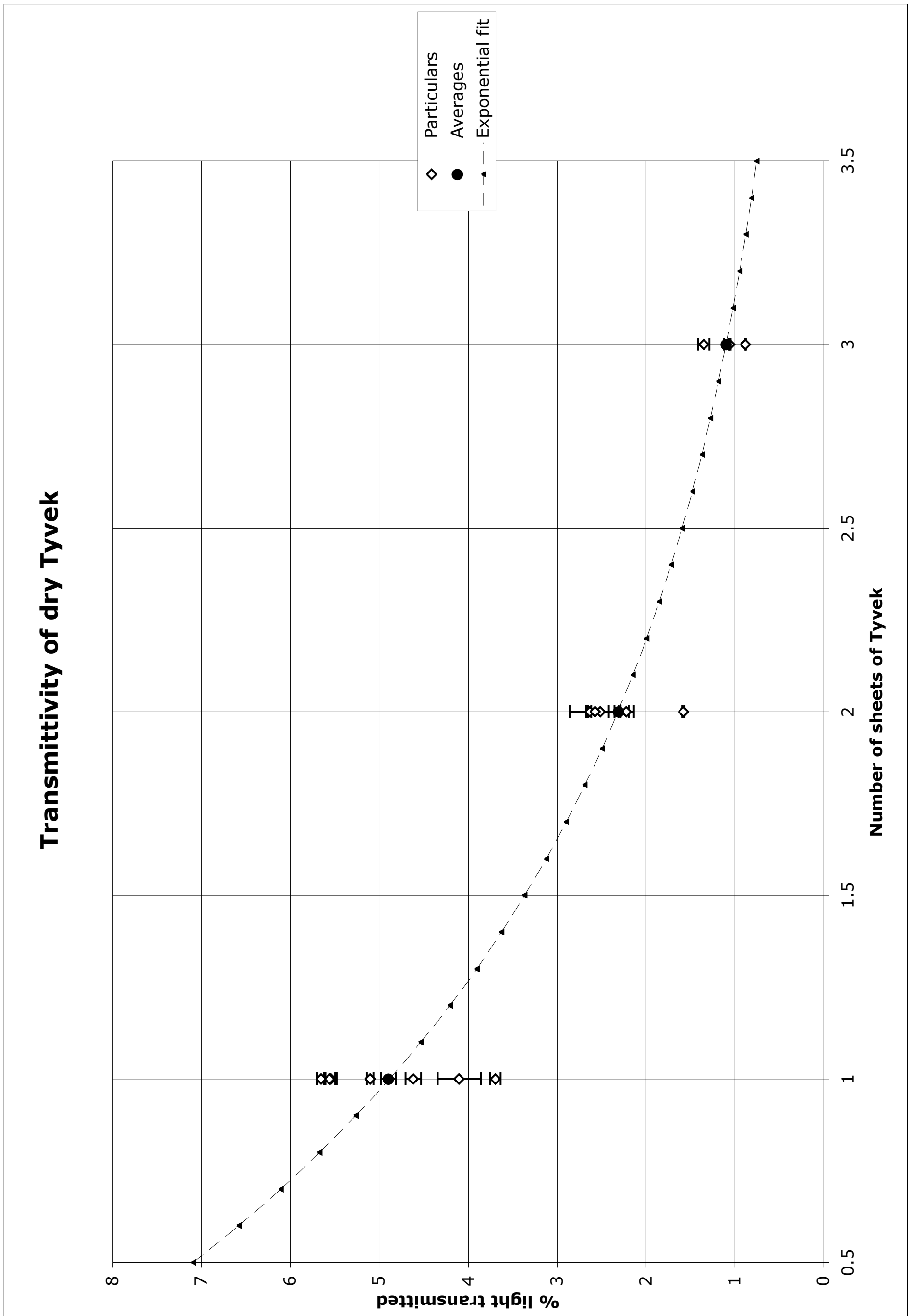

Figure 8: Graph showing how the transmittivity of dry Tyvek varies as the number of layers increases.

Appendix A - Some properties of the Hamamatsu HC124-02

The Hamamatsu HC124-02 Photo Multiplier Tube (PMT) Module was tested to see if its output was proportional to the intensity of the input light. The plot below shows the PMT output voltage (which should be proportional to the PMT output current) versus the light source (LED) current (which should be proportional to its brightness). This was done for three different LED colors to see if the wavelength of the incident light had any effect on the PMT output.

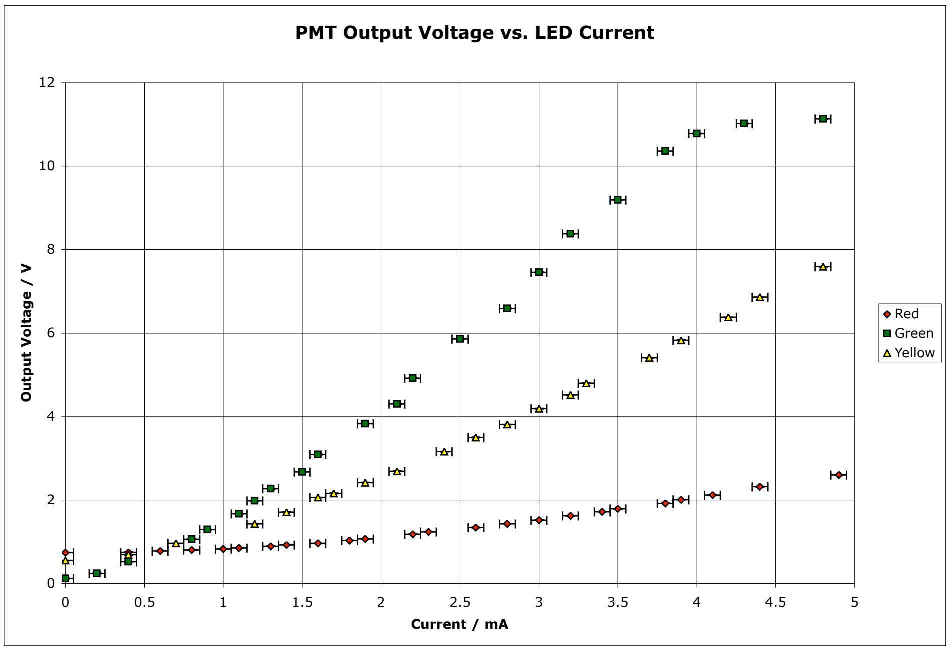

Figure 9: Plot showing the relationship between the LED current and the PMT output.

As it can be seen, there is a wide range for which the plot looks linear. It is not linear at low LED currents but this is probably due to the LED current-light intensity relationship not being proportional at those values. Once the LED current is greater than $\approx$ 1mA the relationship between the LED current and the PMT output is linear until the PMT reaches its saturation range ($\approx$ 11V).
So, as long as the PMT is operated in conditions below its saturation range, its output should be proportional to the intensity of the light incident on it.
It was observed that the PMT was most sensitive to the light with the shortest wavelength (green) and as the wavelength increased the PMT output decreased. According to Hamamatsu, the HC124-02 sensitivity should peak at $\approx$ 400nm, which is a shorter wavelength than green light, and therefore the results are

consistent with Hamamatsu.

In later testing it was noticed that the HC124-02 output was not very stable. The output value will decrease for a while and it will take a long time for it to settle. It was not known if this decrease was caused by the PMT itself or the green LED that was being used as a light source. Two sets of measurements were taken. For both trials the PMT was left on for a few hours before the experiment. In one of the trials the LED was turned on and measurements were taken immediately. For the second trial both the LED and the PMT were left on for about two hours with the light from the LED to the PMT being blocked. Then, the LED was uncovered letting light reach the PMT and measurements were taken. For both trials the LED current was kept constant (4.0 mA). These results are shown in Figure 10.

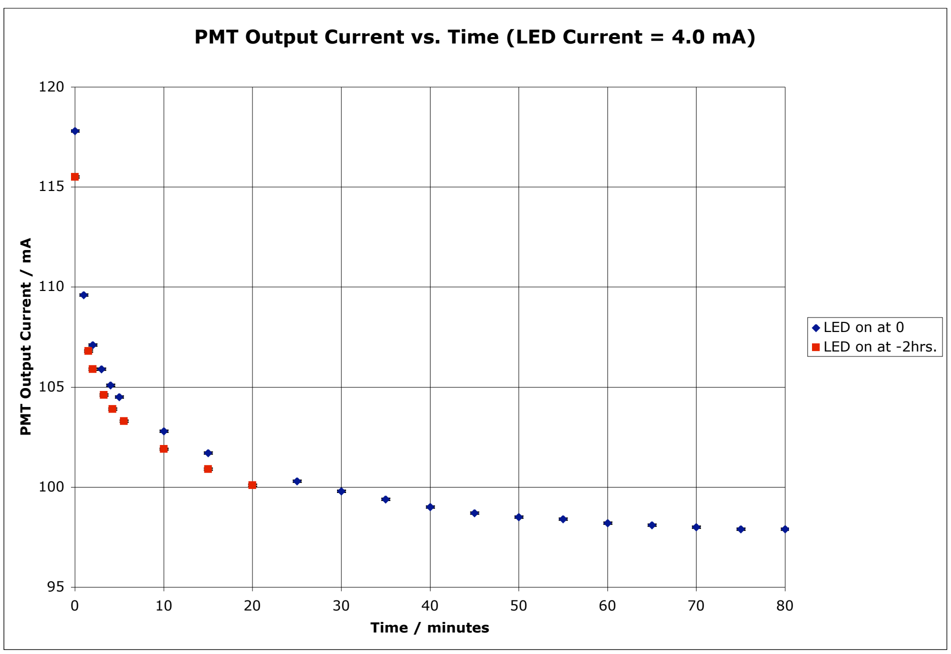

Figure 10: Plot showing the decrease in PMT output over time with the LED under two different conditions.

It can be concluded from the results that, because there is no significant difference between the trials, it was the PMT and not the LED what was responsible for the decrease in the output current. It took some time ($\approx$ 1 hour) for the PMT to give a constant reading.
To know if this was the case for all light intensities, measurements were done

for different LED currents. Again, the PMT was left on for a few hours and once the LED was turned on measurements were taken for as long as the PMT output was not constant. The results are shown in Figure 11.

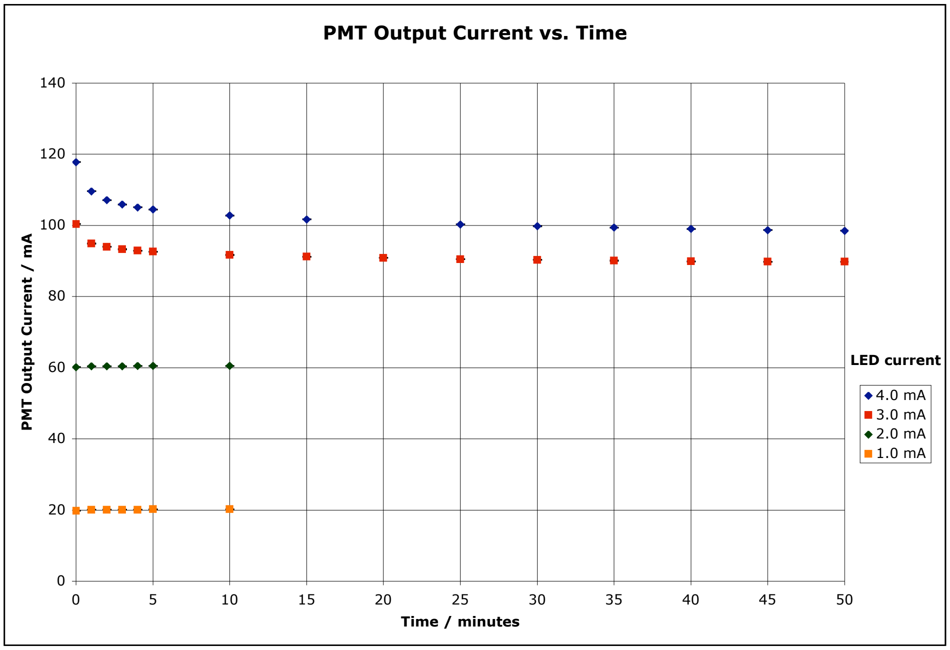

Figure 11: Plot showing the decrease in PMT output over time for different LED currents.

As it can be seen, the decrease in PMT output is only noticeable for LED currents greater than 2.0 mA, which correspond to a PMT output current greater than ≈ 60 mA. For the trials where the LED current was 2.0mA and 1.0mA the PMT output was constant. From this it can be concluded that if the HC124-02 is operated in conditions where its output is ≈ 60mA or lower, then the output reading should be constant (given that the PMT has been left on long enough to warm up).