Measurement of Light Transmission in Radiation Damaged Quartz Bars for Q_{weak}

Katie Kinsley
Advisors: Dave Mack, Julie Roche
Thomas Jefferson National Accelerator Facility
Newport News, VA
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Background Information:

The purpose of this experiment was to determine how much light was absorbed in irradiated Spectrosil 2000 fused silica (henceforth referred to as "quartz") which had been glued with the silicone elastomer SES406. Glued quartz bars will be used in the Q_{weak} experiment at Jefferson Lab (JLab)[1]. The primary objective of Q_{weak} is to compare the scattering probability of polarized electrons spinning in opposite directions. In order to do this, we take a continuous beam of electrons and shoot it at a hydrogen target. The beam of electrons will sometimes come into contact with the electrically charged parts of the hydrogen target, causing the beam to scatter at different angles. By studying the deflected beam of polarized electron, scientists can better understand the scattering probability of electrons with opposite spin. In order to study the impact of the electrically charged hydrogen target, Q_{weak} plans to have Cherenkov detectors that can measure the intensity of the scattered electrons. These detectors use photomultiplier tubes and large pieces of quartz bar that will allow high energy electrons to produce Cherenkov light[2]. It was more economical to buy two long pieces of quartz bar (plus lightguides) and glue them together than to purchase one really long piece of quartz. However, the continuous electron beam emits powerful amounts of radiation, and the transparency of the glue could be compromised due to radiation damage. With 100 kilorads of radiation being the expected dose of radiation, we tested the transmission of the glue and quartz after being exposed to 0 kilorad, +100 kilorads, and +1 Mrad of radiation, for a total of 1.1 MRad. The ability of the glue to withstand high levels of radiation needed to be tested in order to ensure that the Cherenkov light detectors could measure as much light as possible, and that the glue would not absorb more light with increasing radiation damage.

Abstract:

Electron accelerators are used to study particles at a subatomic level. In the Q_{weak} experiment, scientists are attempting to learn more about scattering probability for polarized electrons with opposite spin. Detectors are being used in Q_{weak} to measure Cherenkov light. These detectors are large, and in order to build them quartz bars must be glued together using a UV transparent glue such as SES406. These quartz bars and glue will be exposed to high levels of radiation, and it is essential to be sure that the glue will remain transparent up to 1 MRad. Using a JLab light transmission facility consisting of a monochromator and current-mode PMT under computer control, we took measurements with glued quartz slides as well as non-glued controls which had all been exposed to 1.1 Mrad of radiation. The final result showed that the SES406 absorbed <2% of the light at the shortest wavelengths, independent of irradiation.

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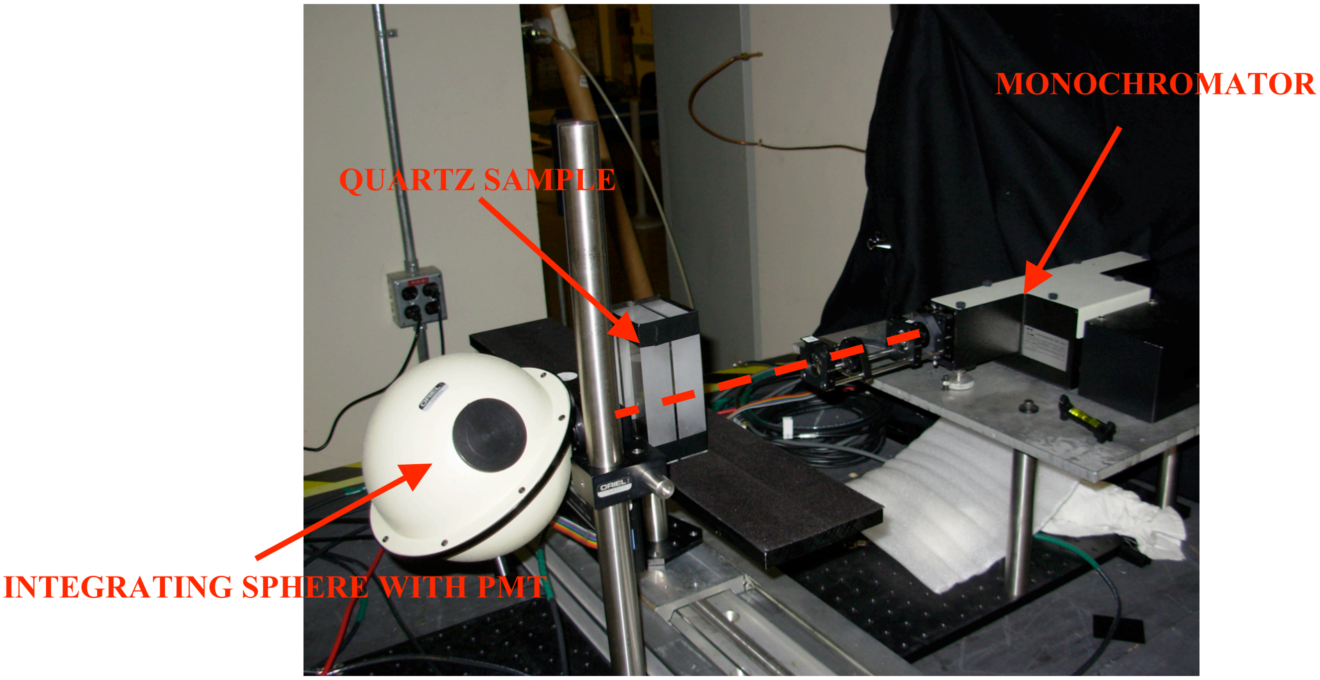
[1] http://www.jlab.org/qweak
[2] For more information on Cherenkov light, go to http://en.wikipedia.org/wiki/Cherenkov_radiation

Experimental Procedure:

The apparatus consisted of a monochromator that shoots a beam of light of a specified wavelength through the sample bars. After the light travels through the quartz, it goes though an open shutter, bounces around the integrating sphere, and is detected in a PMT. The shutter can be opened and closed from outside the dark box to allow measurement of the dark current. All of the equipment is connected to a MS-DOS computer program, which displays the output current for each run after 1 second integration. Our samples were a pair of glued slides and a non-glued control slide. The control slide was a single slide of quartz that had been exposed to 1.1 Mrad of radiation. A pair of slides was glued together with SES406 and also exposed to 1.1 Mrad of radiation.



Startup of the facility was as follows. First, the high pressure Hg lamp was turned on and allowed to stabilize for a few hours. The rest of the apparatus could only be turned on after the lamp because the EMP from the ignition arc would send random pieces of digital equipment into limbo. With the shutter closed, the sample was placed on the translation stage, centered, and the software offset was zeroed so the readback would give an easily interpretable relative position. We then checked that the software value for the wavelength agreed with the hardware encoder on the side of the monochromator. If they disagreed, as sometimes happens if one has to unexpectedly exit the program, the software offset was updated. The dark box was then closed.

The procedure for measuring the transmission of light though the quartz slides at fixed wavelength was the following: We measured the dark current by closing the shutter and blocking all light from the PMT. Usually the dark current measured around -14.500 nA. We then opened the shutter and took measurements of the PMT current with the sample in the beam and sample out of the beam. We would take a total of 10 runs, alternating with the quartz sample in and out of the beam of light, providing 5 runs with the sample in and 5 runs with the sample out. [3] Then we would change the wavelength setting (and sometimes the high voltage to keep the maximum PMT at about 1.6 microA) and repeat the process. Our time-consuming procedure traded off accuracy for wavelength coverage, so only five central wavelengths were covered: 250nm, 275nm, 300nm, 400nm, and 500nm. Shorter wavelengths than 250 nm are absorbed in the Qweak PMT window, and longer wavelengths than 500 nm were expected to show little radiation damage, so wavelengths outside this range were low priority.

Data and Analysis:

When taking data, we recorded the dark current, the current with the sample in, and the current with the sample out. Depending on the wavelength and PMT high voltage, the dark current ranged from 1% to 5% of the signal. Once the dark current was known, the shutter was opened and the sample was inserted and removed 5 times. To determine the transmission for an individual run, we used the equation:

$$Tuncor = \frac{(Iin - Idark)}{(Iout - Idark)}$$

We averaged the 5 runs and used the standard deviation of the transmission as an estimate of the random error. This procedure helps to cancel drifts in lamp intensity. It is also the simplest way of estimating the uncertainty without having to take correlations in lamp intensity into account.

After taking an apparently good quality dataset, we found the unphysical result that the corrected transmission was a few percent greater than 100%. Because our known errors were no larger than 0.2%, the significance was very high. The problem was eventually tracked down to stray light from the high pressure Hg lamp, in combination with the inadvertent use of a narrow-band collimator (250 micron versus 1000 micron) installed by other users of this shared facility. The offset from unmeasured stray light was about as large as the measured dark current! This caused an offset error which was relatively high for measurements near 250 nm where the monochromator light output was weak. With 20/20 hindsight, we should have expected some stray light issues since the lamp is inside the dark box and screened only by some black curtains.

In order to reduce this systematic error, we implemented a collimator that reduced the stray light entering the integrating sphere and PMT by about two orders of magnitude. However, our makeshift collimator sometimes scraped the large beam from the 1000 micron slit, so our final measurements were taken with a 500 micron slit which reduced the beam size by about half. To measure the remaining stray light, we used a piece of black tape to block direct light from the monochromator, and took measurements with the shutter open and closed.

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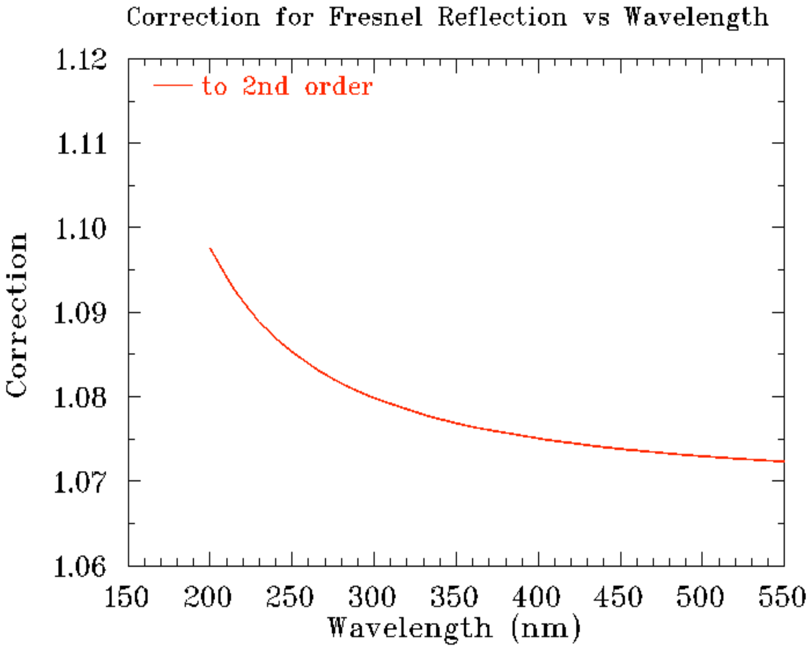
[3] This was tedious because the monochromator control program was not set up to do this, so had to be done by repetitive manual commands. But rapidly inserting and removing the sample was essential for cancelling drifts in the lamp intensity which otherwise would have resulted in random errors on the transmission of 1% rather than the 0.1% achieved here.

This allowed us to separate the dark current from the stray light, and it was determined that only about 0.2 nA of stray light remained. To account for this, our new equation became:

$$Tuncor = \frac{(Iin - (Idark - 0.2))}{(Iout - (Idark - 0.2))}$$

Note that our measurement only gives the transmission without regard to Fresnel reflection from the front and rear surfaces, which is why it is labeled as "uncorrected." With the following graph, we can use these correction factors to determine Tcorrected:



First we tested the control sample at 250nm, 275nm, 300nm, 400nm, and 500nm:

CONTROL QUARTZ

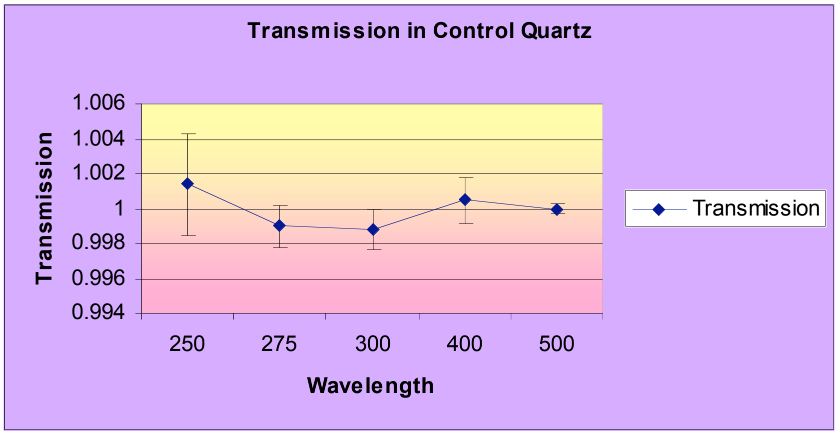
Wavelength (nm)	**Transmission (corrected)**	**Error**
250	1.001377154	0.002904235
275	0.999011988	0.001186208
300	0.998799097	0.001125214
400	1.00047957	0.00129257
500	0.999982549	0.000275202

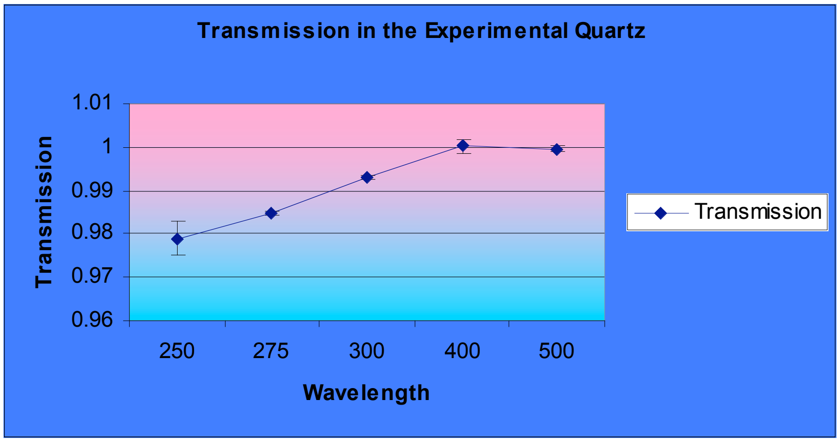
Next we tested the experimental sample at 250nm, 275nm, 300nm, 400nm, and 500nm:

EXPERIMENTAL QUARTZ

Wavelength (nm)	Transmission (corrected)	Error
250	0.979032133	0.003685371
275	0.984740483	0.000589419
300	0.993038851	0.000505773
400	1.000210774	0.001720757
500	0.999671262	0.000548984

The following is a graph of the data recorded for the control and experimental quartz:





Discussion:

The control data are consistent with no absorption in the irradiated quartz to within an uncertainty of +-0.1%. The data for the pair of glued slides indicate a linear decrease in the glue transmission below 400 nm, with about 2% absorption at 250 nm. This level of absorption is consistent with our previous, but less precise, measurements at 0 kRad and 100 kRad.

We note that our previous data for 0 kRad and 100 kRad were taken with the 1000 micron collimator, where the stray light systematic error was at the level of the error bars. The data hinted at a rise in transmission at 250 nm which caused us to wonder if the apparent dip was due to an absorption band around 275 nm. The new measurements in this report control this stray light systematic error, and there is no longer any hint of an absorption band.

Conclusion:

After implementing a collimator to reduce stray light, and then subtracting the remaining small fraction, we determined that the Shin-Etsu Silicone glue SES406 will only absorb <2% of light after exposure to 1.1 MRad. The expected dose of radiation in Q_{weak} is approximately 100 kilorads, so it can be assured that high levels of radiation will not damage the SES406 enough to greatly affect the transmission of light in the Cherenkov light detectors.

Acknowledgements:

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