Sun, Safety, Spectroscopy - The Science of UV Measurement and Assessing Sun Protection

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The long hot days of summer may be waning, but the effects of summer UV exposure, accelerated aging and deadly melanoma, can linger on. Many of us try our best to avoid the worst of this damage by donning sunglasses and slathering on the sunscreen, but just how effective are the products people rely on to protect themselves? Spectroscopy can tell us. The versatility of miniature spectroscopy can be used to characterise the amount of protection common interventions like sunglasses and sunscreen can provide.

With a plethora of these products in the market, at varying price points and protection factors, it's difficult to gauge their effectiveness. But with miniature spectroscopy, the UV transmission properties of sunglass lenses and sunscreen can be quantified and assessed.

Assessing UV Protection of Sunglasses

Sunglasses often are treated as fashion accessories or a means to simply block out irritating light. However, their most important job is to block UV radiation from the sun. Good eye protection prevents cataracts, benign growths on the eye's surface, and photokeratitis -temporary but painful sunburn of the eye's surface.

UV protection can be manufactured into sunglasses lenses, altering the capacity of the lenses to absorb UV radiation. Various additional coatings may be added to reduce glare, remove polarisation, or add colour. However, those coatings do not significantly contribute to blocking UV radiation.

Transmission of UV and Vis-NIR wavelengths in sunglasses is regulated in many countries. With sunglasses, the focus is on the capacity of the lenses to absorb UV radiation, which can harm the eyes. Since most UVC radiation (100-280 nm) is blocked by the Earth's ozone layer, the emphasis is on UVA (315-400 nm) and UVB (280-315 nm) wavelengths. With the range of options and price points available in sunglasses, it's difficult for the consumer to know which will be most effective in the critical UVA-UVB range. A simple setup with a modular spectrometer can measure the transmission characteristics of sunglass lenses.

Characterising UV Transmission of Sunglasses

We used a compact, modular spectrometer to characterise transmission over the UV-Vis-NIR (200-1000 nm) range. A deuterium tungsten halogen light source was paired with a balancing filter to provide illumination over a wide range (~230-2500 nm), simulating exposure to sunlight. An integrating sphere was introduced to measure transmission through the curved, irregular surfaces of the sample sunglass lenses. An integrating sphere ensures repeatability of measurements, even when reflectivity of the sample changes at different viewing angles. Light was delivered via a collimating lens through the sample sunglasses and into the integrating sphere, which was coupled to the spectrometer. Each sample was measured in three different locations and the results were averaged.

To evaluate a range of eyewear options, six samples ranging from discount store sunglasses to luxury brand eyewear were tested:

Table 1. Sample Eyewear

Eyewear Type	Estimated Price in US$
Inexpensive sunglasses with black lenses	$1
Plastic lab safety glasses (standard lab eyewear protection against chemicals or projectiles)	$10
Plastic UV blocking eyewear (designed for use with UV sources)	$30
Progressive lens prescription eyewear with Transitions® coating that darkens with exposure to UV light	$300
Luxury brand polarised sunglasses with blue glass lenses	$350
Luxury brand polarised sunglasses with grey plastic lenses	$125

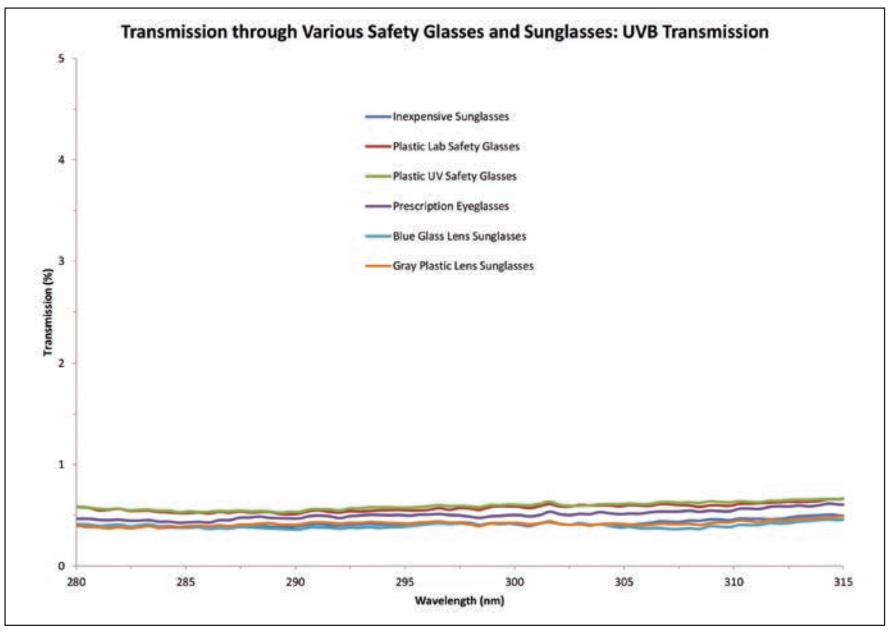

Figure 1. Regardless of lens composition, the glasses tested were effective in blocking UVB radiation (280-315 nm).

The glasses were oriented with the outside of the eyewear lens touching the integrating sphere. Eyewear orientation, proximity to the integrating sphere, and measurement location had little or no observed effect on the consistency of the measurements.

Regardless of the composition of the lenses (glass or plastic, with or without different coatings to provide colour and remove polarisation), the eyewear had similar blocking efficiency of light in the UVB region with very low (~0.5%) transmission across the entire UVB range *(Figure 1)*. This level of blocking extended throughout the UVA region up to ~380 nm, where the lab safety glasses began transmitting light *(Figure 2)*. This was not unexpected as these glasses were not designed to block UV.

All of the sunglasses had increased transmission of light starting at ~400 nm with varying degrees of blocking through the Vis-NIR range *(Figure 3)*. Interestingly, blocking across the Vis-NIR range had a similar profile for all the sunglasses measured with the best blocking (lowest transmission) across the visible range by the more expensive sunglasses. This suggests that the sunglasses share similar coatings or materials to provide better blocking in the visible region.

Based on this experimental setup, the eyewear designed to absorb UVA and UVB radiation did so effectively, regardless of price. However, the more expensive sunglasses were the most effective in filtering visible wavelengths, which might be worthwhile for people who require polarisation (light from the sun is unpolarised) or spend a lot of time in bright sunshine. Those considerations aside, even the inexpensive sunglasses helped protect from damaging UV rays.

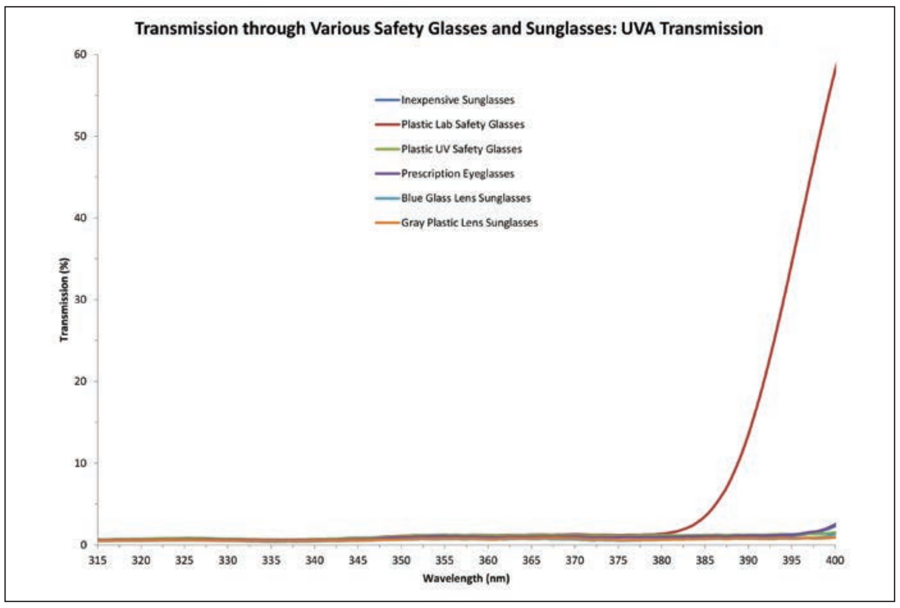

Figure 2. All eyewear samples tested demonstrated effective blocking of UVA wavelengths (315-400 nm) up to 380 nm.

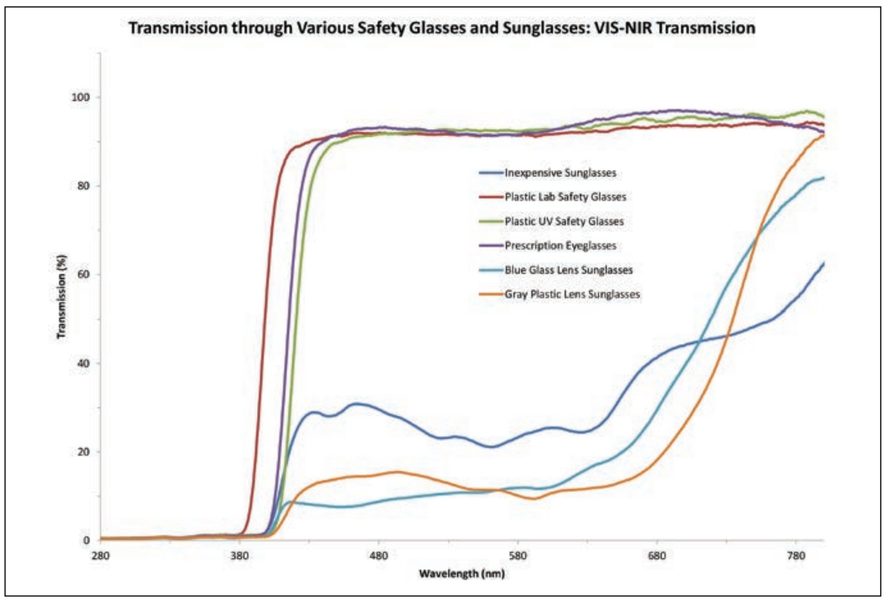

Figure 3. The Vis-NIR blocking efficiency of the more expensive eyewear options was very high, but even the least expensive glasses performed reasonably well.

Verifying the Sun Protection Factor of Sunscreen

A person's tolerance to sun exposure varies significantly, and depends on skin type. Exposure before burning may be as short as just five minutes for a person with fair skin and hair, or far longer for someone with dark skin and hair. Applying sunscreen extends a person's exposure time depending on the sun protection factor (SPF). For example, for someone who burns at 5 minutes of unprotected exposure, an SPF of 20 should increase the person's ability to avoid sunburn by a factor of 20 minutes, giving them 100 minutes of sun protection. (Regardless of skin type and SPF level used, dermatologists recommend reapplying sunscreen every two hours).

In the past, the sun protection factor was measured using human subjects. Small patches of skin on the back of volunteers were exposed to increasing amounts of UV light, some areas protected with the sunscreen under test, some patches left unprotected as a control. The ratio of the exposure times that led to the first sign of reddening with and without sunscreen then gave the sun protection factor for the sunscreen. Not only is this method potentially painful and subject to variability in volunteers' skin, it is also difficult to find volunteers for this type of testing now that the dangers of UV radiation are common knowledge. A spectrometer is a pain-free, accurate and objective way to quantify SPF.

Determining SPF Spectrally

Sunscreen works by absorbing or reflecting UV light before it reaches the skin. White pigments, such as titanium dioxide used in high-SPF sun blockers, work in reflection mode. Most other ingredients, such as benzophenones, absorb a portion of the UV radiation. Of interest for the measurement of the sun protection factor is the percentage of the UV light that is transmitted and still reaches the skin.

To test this, a general purpose UV-Vis spectrometer (200-850 nm) with focusing lens was combined with sample holders and an integrating sphere for the experimental setup. A deuterium light source simulated natural UV light.

The sample holders were prepared with surgical tape (to receive a more even distribution of sunscreen), numbered, and weighed (to later determine the amount of sunscreen applied). The transmission through the blank sample holders was determined using a separate, marked, microscope slide with surgical tape (but no sunscreen) as the reference. As this sample preparation method would scatter the incoming UV light, an integrating sphere was placed after the sample to collect all of the transmitted and scattered light *(Figure 4)*.

A thin layer of sunscreen was applied to the sample holder, scraped to create a thin, even layer, then weighed again and left to dry for 60 minutes. After this drying period, the transmission through the scattering reference slide was set again as the 100% reference to account for any changes in the lamp output over time. Finally, the transmission through the actual samples with applied sunscreen was measured. A total of eight spectra were recorded for each sample and then averaged, to account for any measurement-to-measurement variation.

Each transmission spectrum *(Figure 5)* indicates what percentage of the incoming UV radiation reaches the skin. However, not all UV wavelengths are created equal; some are more dangerous than others, depending on the amount of incoming sunlight and the susceptibility of the skin to sunburn as a function of wavelength. For example, radiation between 300-320 nm is the most dangerous of the rays reaching the Earth's surface, which explains why sunscreens often predominantly absorb UV light in this region.

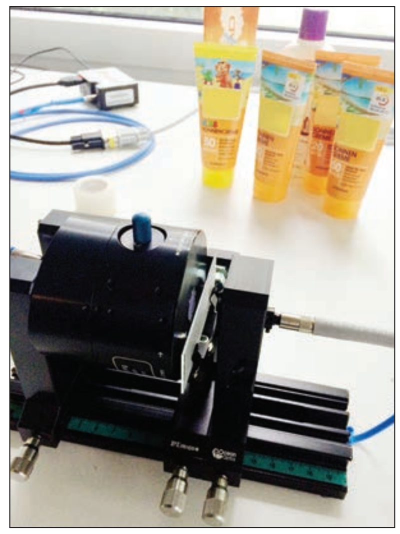

Figure 4. A miniature spectrometer configured for transmission measurements was used to test sunscreen samples applied to surgical tape on microscope slides.

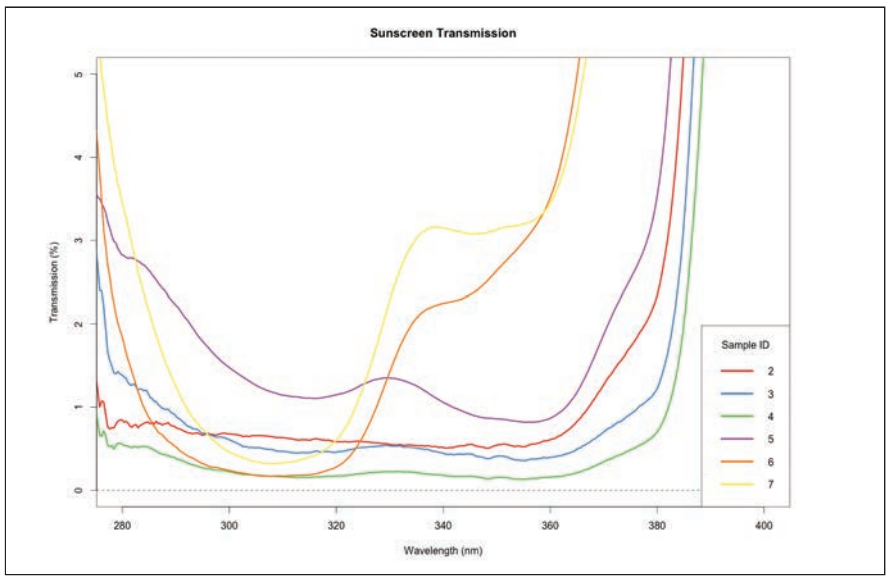

Figure 5. Transmission spectra for the sunscreen samples were averaged over eight measurements to account for variations in the spectrometer, sampling devices and UV source output.

Calculating SPF

In our experiments, SPF is calculated by taking the ratio of the known total sunburn danger without sunscreen compared to the reduced sunburn danger as a function of the sunscreen's transmission blocking efficiency. The results are summarised in *Table 2*.

Table 2. SPF Determination for Six Sunscreen Samples

Sample ID	Brand	Notes	SPF Claimed	SPF Measured
2	A	Regular	20	79
3	A	Regular	30	99
4	A	Regular	50	193
5	A	Baby	50	48
6	B	Hard to spread	45	32
7	C	Store brand	30	35

Overall, most of the sunscreens tested in this experiment offered the claimed sun protection. In fact, the SPF determined for the regular sunscreens of brand A (Samples 2, 3 and 4) exceeded their SPF claims by a factor of 3 to 4. However the 'Baby' sunscreen from the same brand (Sample 5) fell short of its claimed SPF. The other sample that failed to meet the claimed SPF (Sample 6) was noted as difficult to spread evenly, which appears to have negatively affected its protection benefits.

Summary: Stay Safe in the Sun

Just because summer is ending, doesn't mean that the dangers of UV exposure go away. The UV index, the measure of skin-damaging ultraviolet radiation at a particular location and time, can remain high even when it's not particularly sunny or hot. Ground-based reflection from environmental factors like sand or snow can also have a strong effect on UV index. As we head into fall and winter, protect your eyes and skin outdoors, confident in the fact that spectroscopic characterisation of transmission properties can confirm that sun protection claims are reliable.

The modular spectrometers and accessories described here can be applied to similar types of transmission measurements of automobile windows and other products designed, in part, for UV protection. Also, the SPF setup described here could be used to measure SPF factors of fabrics and other materials in a manner that is both robust and reproducible.