TESTING THE SOLAR ULTRAVIOLET TRANSMISSION OF CLOTHING AND SHADE MATERIALS

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ABSTRACT

An experiment is described to expose students in a ‘hands-on’ manner to the physics of instrumentation, measurement, electromagnetic radiation and in particular UV radiation. The students will have no difficulty in setting up the apparatus themselves and they will obtain reliable results within a normal school practical period. Additionally, the students will undertake a scientific experiment relevant to everyday life.

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SOLAR RADIATION

The sun is the most common form of ultraviolet (UV) radiation to which humans are exposed. The surface temperature of the sun is approximately 5700 ^{o}C and at this temperature the peak intensity in the emitted electromagnetic radiation is in the visible waveband along with emission in the infrared and UV wavebands (Parisi and Kimlin, 1997a). A schematic of the wavebands in Figure 1 shows that with decreasing wavelength there is increasing energy per photon of electromagnetic radiation. The UV waveband is subdivided into:

UVC – 200 to 280 nm

UVB – 280 to 320 nm

UVA – 320 to 400 nm

This radiation undergoes scattering and absorption by molecules and aerosols in the earth's atmosphere to form the terrestrial solar UV. The terrestrial UV is comprised of a direct and diffuse component (Parisi and Kimlin, 1998) with no UVC and only part of the UVB present at the Earth's surface.

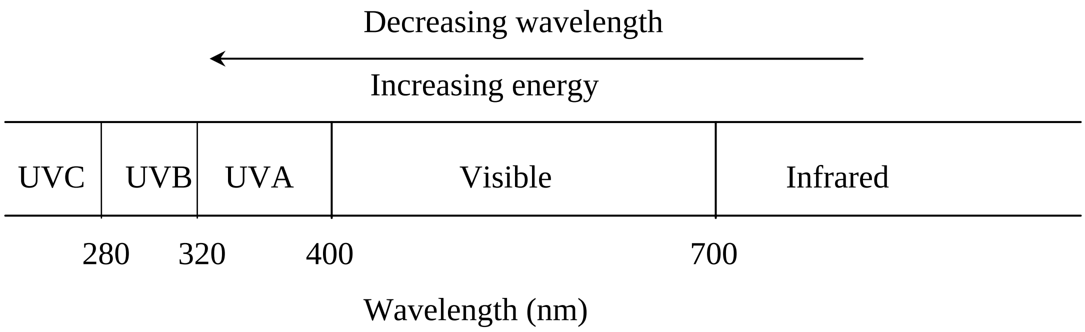

Figure 1 - Schematic of some of the wavebands in the electromagnetic spectrum.

Ultraviolet radiation exposure has a causative role in human skin cancer, eye disorders and premature wrinkling and aging of the skin (Longstreth et al., 1995). The effectiveness of UV radiation to produce reddening of human skin or erythema is highly dependent upon the radiation wavelength with some wavelengths more effective than others. The erythemal response of human skin is given by the erythemal action spectrum developed by the CIE (International Commission on Illumination) (1987) (Figure 2). The y axis is the effectiveness of the wavelengths for producing erythema, normalized to unity for wavelengths of 298 nm and shorter. The most effective UV wavelengths are the UVB and UVC wavelengths. Fortunately no UVC reaches the surface of the Earth. The sensitivity of the erythemal response decreases by a factor of approximately 1000 for the UVA wavelengths. However, there is a higher UVA than UVB irradiance present at the Earth's surface.

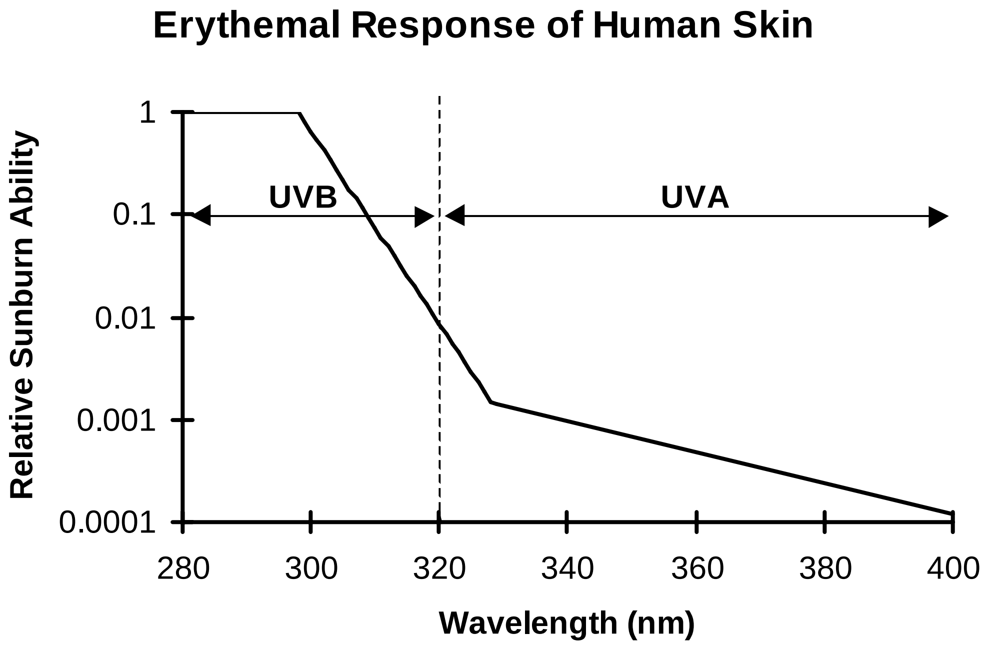

Figure 2 – The human erythemal action spectrum (CIE, 1987). The y axis is the effectiveness of the wavelengths for producing erythema, normalized to unity for wavelengths of 298 nm and shorter.

The media reporting of the predicted UV levels for the day are provided in terms of the UV-index, which is a measure of the effects on human skin due to solar UV. The index is the daily maximum of the erythemally weighted UV averaged over 30 minutes and multiplied by a constant. Values of less than 3 are moderate, 3 to 6 are high, 6 to 10 are very high and greater than 10 are extreme.

Clothing can be employed as an effective protective strategy against solar UV exposure. The UV protection of fabrics has been measured and quantified by the introduction of the ultraviolet protection factor (UPF) (Gies et al., 1994). This experiment is designed to introduce students to some of the scientific concepts involved.

EXPERIMENTAL

The specific aims of the experiment are:

1. To expose the students to basic physics principles of UV radiation;
2. To measure solar UV radiation and its transmission through various materials.

Apparatus

- A UV meter. A cost effective model is the Bluewave BW10 model available from Diagnostic Instruments Pty Ltd, PO Box 159, Victoria Park, Perth, WA 6100 or Imbros Pty Ltd, PO Box 427, Moonah, TAS 7009 at a cost of $300 to $400. The BW10 meter employs filters to produce a response approximating the human erythemal response.
- Various common materials and fabrics, for example, cotton T-shirt material, synthetic fabric, green and fawn shadecloth and polycarbonate sheeting.

Measurement of ultraviolet protection

The protection provided by clothing has been quantified with the concept of the ultraviolet protection factor (UPF) defined as follows (Gies et al., 1994):

$$UPF = \frac{ERY}{ERY_T} = \frac{\sum_{280}^{400} S(\lambda)A(\lambda)\Delta\lambda}{\sum_{280}^{400} S(\lambda)A(\lambda)T(\lambda)\Delta\lambda} \qquad (1)$$

where ERY is the erythemal UV and ERY_T is the erythemal UV transmitted through the material, S(λ) is the solar UV spectrum measured at wavelength increments of Δλ, A(λ) is the erythemal action spectrum and T(λ) is the spectral transmission of the material. A spectroradiometer system to measure S(λ) and T(λ) with a very narrow bandwidth of the order of 1 nm is employed in the determination of the UPF for clothing materials. Nevertheless, a reasonable evaluation of the UPF can be determined with broad band meters such as the BW10 that possess a response approximating the erythemal action spectrum to measure ERY and ERY_T.

The percentage reduction of erythemal UV is calculated by:

$$R = \frac{ERY - ERY_T}{ERY} x100 \qquad (2)$$

1. A simple system for the UV measurements can be set up in an open outdoor area at least 10 m from any buildings or structures. This eliminates the variable of UV reflections. A cloud free day provides the optimum conditions for the experiment as it eliminates the variable conditions and changing UV environment provided by cloud (Parisi and Kimlin, 1997b). If the weather conditions do not permit a cloud free day for the experiment, then a period with the cloud free of the solar disc should be employed.
2. As this experiment involves some time in the sun exposed to solar radiation, it is necessary to take appropriate UV protective strategies, for example, clothing, hat, sunscreen and sunglasses to reduce the personal UV exposure.
3. Place the BW10 radiometer on a horizontal plane with the white sensor facing up and the user standing on the south side of the instrument in order to reduce any

shading of the sensor. The ERY measured with the BW10 will vary with the angle of the sensor to the sun. Investigate this by recording the ERY on a horizontal plane and then rotate the meter 10^o to the horizontal plane and take another reading. Repeat this for each 10^o increment till the meter is in a vertical plane.

4. Return the meter back to a horizontal plane and measure the ERY and ERY_T with the BW10 meter with the ERY_T obtained by placing a piece of the material over the white sensor of the meter. One of the authors is shown in Figure 3 about to take a reading with the UV meter and a piece of material.
5. Repeat the measurements of ERY and ERY_T for each material and calculate the UPF for each material employing the first part of Equation (1).
6. For each material, employ Equation (2) to calculate the percentage reduction in erythemal UV.
7. Repeat the experiment during another season of the year when the predicted UV index is different.

Figure 3 - One of the authors about to take a reading with the UV meter and a piece of material.

Sample Results

A sample of results is provided in Table 1. The units of ERY and ERY_T are based on the meter readings with the meter providing a number between 0 and 9.9 with 9.9 corresponding to 250 mW m^{-2} of erythemal UV. The variation in the value of ERY is due to cloud. The results obtained by the students may vary from these according to the types of materials employed.

Increasing the UPF above 50 only marginally decreases the percentage reduction in the transmitted erythemal UV. For example, for a UPF of 50, the percentage reduction is 98% compared to a UPF of 100 with a percentage reduction of 99%.

Table 1 – Table of sample results.

Material	ERY	ERY_T	UPF	R (%)
Shadecloth (Green)	3.4	0.2	17	94
Shadecloth (Fawn)	1.8	0.1	18	94
Cotton T-shirt	4.8	0.6	8	88
Wet cotton T-shirt	4.7	0.9	5	81

USEFULNESS OF THE EXPERIMENT

The principle and design of the experiment is not complicated and presents some basic scientific principles. The students are exposed in a ‘hands-on’ manner to the physics of instrumentation, measurement, electromagnetic radiation and in particular UV radiation. The students will have no difficulty in setting up the apparatus themselves and they will obtain reliable results within a normal school practical period. Additionally, the students will undertake a scientific experiment relevant to everyday life. Skin cancer is a serious problem in the community and large benefits are to be gained by reducing personal UV exposure in the community. An understanding of the UV index and UPF as provided by this experiment are important to this.

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