Institute of Physics Publishing European Journal of Physics

Eur. J. Phys. **26** (2005) 313–320 doi:10.1088/0143-0807/26/2/009

# Physics concepts of solar ultraviolet radiation by distance education

**A V Parisi**

Center for Astronomy, Solar Radiation and Climate, Faculty of Sciences, University of Southern Queensland, Toowoomba 4350, Australia

E-mail: parisi@usq.edu.au

Received 21 September 2004, in final form 14 January 2005
Published 24 February 2005
Online at stacks.iop.org/EJP/26/313

**Abstract**

A series of activities that are suitable for distance education students to illustrate physics concepts related to solar radiation are described. The students can undertake the activities at any location without having to attend the home institution. Detectors interfaced to computers that make the data available on Web pages are employed. The data are updated every 5 min and can be considered to be in real time. Employing the framework of solar radiation to teach the physics concepts in these activities means that the students can identify how these concepts apply to every day situations.

(Some figures in this article are in colour only in the electronic version)

## Introduction

Laboratory work for a distance education course in the physical sciences is a challenge. A method that has been extensively used is through the conventional method of the students attending the university for a short period of time to undertake a concentrated session of laboratory work at a residential school. This may require the student to interrupt normal daily life to attend the university and travel a long distance that in today's era of global education may even be overseas. Once at the laboratory classes, the student may suffer from information overload due to the necessity to provide as much information as possible in a short period of time. Additionally, there may be local students who are unable to attend scheduled classes or a residential school due either to clashes with scheduled classes or work commitments. These constraints have provided the motivation to develop activities that illustrate the required physics concepts and may be undertaken without the necessity for the student to attend a residential school.

One approach to overcoming this difficulty has been previously reported where the students are mailed a kit of physics apparatus that they then employ to undertake a series of exercises at home for a first year conceptual physics course [1]. This apparatus is inexpensive

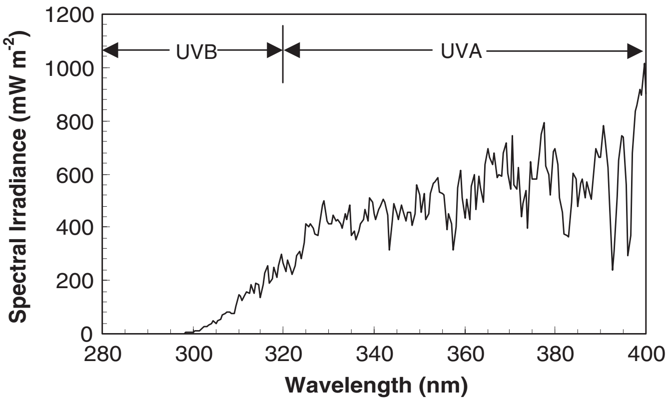


**Figure 1.** Typical solar UV spectrum showing the wavebands.

and readily available, and reinforces the concept that physics is not necessarily only a laboratory activity but forms the basis of an extensive range of everyday applications. Another exercise that has been reported for distance education is to use a Web browser to control and take readings from a computer-controlled instrument at the home institution [2].

This paper reports on a series of activities that form a different approach to eliminating the necessity for the student to attend a residential school. For these activities, the data are collected from detectors at the home institution by automatic data loggers and made available online for the students to access. The activities designed for this and described in this paper reinforce the physics concepts of solar UV radiation. The measurement of ultraviolet radiation will be used in the instruction of distance education students in the physics concepts associated with measurement, the electromagnetic radiation spectrum, the energy of electromagnetic radiation, data analysis, molecular absorption and scattering. The experiments show the relevance and application of physics principles within the framework of an everyday application and a topical society issue.

## Background

### *UV radiation*

The solar electromagnetic radiation is distributed over a wide range of wavelengths. Wavelengths shorter than 400 nm are known as the UV waveband and wavelengths longer than 700 nm are known as infrared radiation. The wavelengths of 400–700 nm are the visible waveband. In this visible waveband, the shorter wavelength corresponds to violet and the longer wavelength corresponds to red. The UV waveband is further sub-divided into the three wavebands, UVA (320–400 nm), UVB (280–320 nm) and UVC (100–280 nm). A typical solar UV spectrum showing the UVA and UVB wavebands is in figure 1. There is no solar UVC on the surface of the Earth due to the absorption of the solar radiation by the atmosphere. The dips in the spectrum are due to the Fraunhofer absorption lines due to absorption by elements in the Sun's atmosphere.

The effectiveness of the UV wavelengths for producing a particular biologically damaging process is wavelength dependent. The biological process considered in this paper is erythema or skin reddening which is wavelength dependent with the shorter wavelengths having a higher effectiveness. This is defined by a weighting function called the erythemal action spectrum [3].

The effectiveness of this action spectrum is about 1000 times higher in the UVB waveband compared to the UVA. The erythemal irradiance, $UV_{ery}$ can be determined by measuring the solar UV spectrum, $S(\lambda)$, weighting each wavelength with the effectiveness of the erythemal action spectrum, $A(\lambda)$, at that wavelength and then summing over the UV wavelengths of interest, namely

$$UV_{ery} = \sum_{UV} S(\lambda)A(\lambda)\Delta\lambda$$

where $\Delta\lambda$ is the wavelength increment of the recorded solar spectrum. Alternatively, the erythemal UV can be measured with a detector that possesses a response that approximates the erythemal action spectrum.

### *Units*

For both the unweighted broadband irradiance and the irradiance that has been weighted with an action spectrum, the irradiance is the incident power divided by the surface area of the receiving object. Consequently, the SI units are Watts per square metre (W $m^{-2}$). When the irradiance is incident on an object over a period, the radiant exposure is the incident energy divided by the surface area of the receptor and the units are Joules per square metre (J $m^{-2}$).

For the UV exposure that is weighted with the erythemal action spectrum, there are also two other units that are widely used. The erythemal exposure can be reported in units of minimal erythemal dose (MED) which is the amount of UV exposure that will produce barely perceptible erythema 8–24 h after exposure. The amount of exposure to produce just perceptible reddening of unacclimatized white skin 8–24 h after exposure is one MED [4]. The value of 200 J $m^{-2}$ has been employed for one MED [4]. Another unit that has been defined for erythemal exposure is the standard erythema dose (SED) which equals 100 J $m^{-2}$ of erythemal UV exposure [5].

The UV index has been developed as a standard, agreed to by the World Health Organization (WHO), World Meteorological Organization (WMO), United Nations Environment Programme (UNEP) and International Commission on Non-Ionizing Radiation Protection (ICNIRP). The UV index generally acts to increase the public awareness of UV radiation and the necessity of employing UV minimization strategies. The UV index may be employed in the form of a forecast for the next day; however, it may also be a nowcast giving the current value or a past record. A model employing the extraterrestrial solar UV spectrum and the absorption and scattering properties of the atmosphere is used for the calculation of the UV index. As a forecast, it is the maximum predicted for that day. In this current exercise, it is employed as a nowcast as it is recorded after direct measurement by a metre and updated every 5 min on a Web site.

The UV index is obtained from the erythemal UV irradiance by multiplying the erythemal irradiance in units of W $m^{-2}$ by 40 to produce a unitless quantity. This produces a value that is generally less than about 12, but can range as high as 16 at tropical and sub-tropical sites in summer. The categories of moderate, high, very high and extreme are assigned to the UV index ranges of less than 3, 3 to 6, 7 to 9 and greater than 9 respectively [6].

### *Influencing factors*

The influencing factors on the amount of solar UV radiation on the Earth's surface are the absorption and scattering by molecules in the atmosphere, the solar zenith angle, the absorption and scattering due to aerosols, clouds, the solar irradiance at the top of the atmosphere, the

**Figure 2.** The erythemal UV and UVA metres on an unshaded roof.

reflection of the surface and surroundings and the altitude above sea level. The activities described will investigate the first four of these influencing factors.

The molecules and particles in the atmosphere provide a wavelength-dependent scattering of the radiation. A review of the atmospheric scattering processes for solar UV radiation is provided in Parisi *et al* [7]. When the scattering is due to molecules in the atmosphere, the scattering particle is small compared to the wavelength of the radiation and this is called Rayleigh scattering. This type of scattering will occur in the atmosphere even if there are no clouds. This type of scattering is inversely proportional to the fourth power of wavelength. This results in a higher relative amount of scattering for the shorter UVB wavelengths compared to the longer UVA wavelengths and the visible wavelengths.

Aerosols that are small solid or liquid particles suspended in air have a size comparable to the wavelength of the radiation. Mie scattering is due to aerosols and the amount of scattering by aerosols is proportional to the inverse of the wavelength.

As the solar zenith angle increases, the path of the radiation through the atmosphere becomes longer. This results in an increase in the amount of atmospheric scattering and absorption. Additionally, as the solar zenith angle increases, the radiation is incident more obliquely on a surface. This results in the direct radiation from the Sun spreading out over a larger surface area and the direct UV irradiance ($UV_D$) is reduced to

$$UV_D \cos(\theta)$$

where $\theta$ is the solar zenith angle.

Clouds have greatest influence on the solar UV radiation on the surface of the Earth. In addition to at times reducing the solar UV, the diffused or scattered solar UV may be increased by clouds and there may even be certain configurations of cloud that can produce greater than clear sky UV irradiances [7].

## Instrumentation

Two UV metres (Solar Light Co., Philadelphia, PA, USA) are installed on an unshaded roof of a building at the University of Southern Queensland (figure 2). One records the UVA exposure

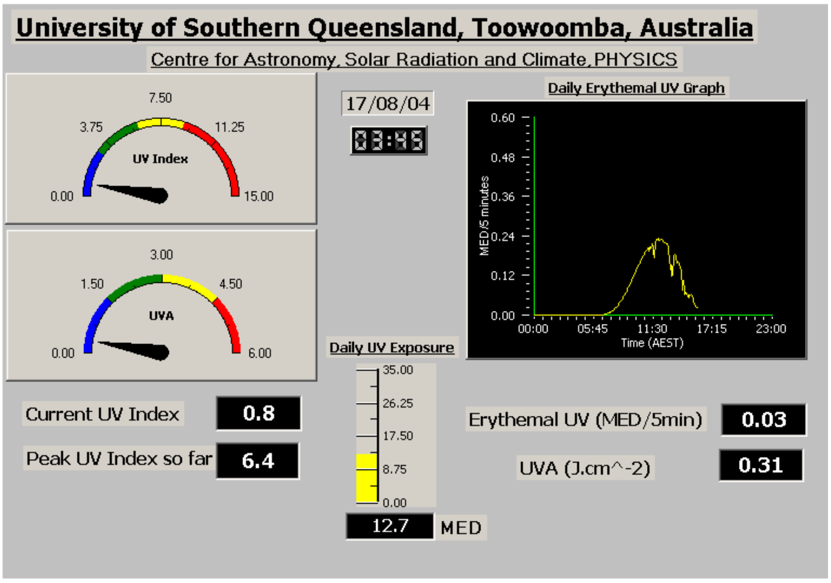


**Figure 3.** An example of the information provided on the Web site. This information is for late in the afternoon of a winter's day.

and the other records the erythemal UV exposure. Both are connected via an 80 m cable to a data logger in the laboratory. This data logger records the UV exposures in both wavebands for each 5 min period of the day. The erythemal UV exposure is recorded in units of MED for the previous 5 min and the UVA exposure is recorded in units of J cm$^{-2}$. At each 5 min interval, the data logger is accessed by the IDL software (Solar Light Co., Philadelphia, PA, USA) in order to download the data to the local computer. The software produces a gif file containing information about the daily data for erythemal UV and the UVA. This information is written to a remote server that makes the information available on the World Wide Web with an update provided every 5 min. An example of the data provided on the Web page is given in figure 3. The Web site for this information is http://www.usq.edu.au/uv.

On this Web page, there is a link to a page that contains a total sky image at the University of Southern Queensland that has been recorded by a total sky imager (TSI) (model TSI-440, Yankee Environmental Systems, MA, USA). This instrument consists of a charged couple device (CCD) camera mounted over a hemispheric mirror that is on a horizontal plane and faces upwards. An example of the unprocessed and processed images is provided in figure 4. The thin line from the bottom to the centre of the image is due to the thin pipe suspending the camera over the mirror. The thick black band in the image is the shadow band that obscures the solar disc from being imaged by the camera. This is taped to the hemispheric mirror and the mirror rotates during the day to track the Sun. The clouds are represented as white in the processed image and the dark areas are the cloud-free parts of the sky. The circular white disc on the black band in the processed image is the position of the Sun. Image processing software provides the percentage cloud cover on each image. In this particular example, the fractional cloud cover has been calculated as 46%. The instrument records an image at each 5 min point and software uploads it onto the Web site between 8 am and 4 pm.

This instrumentation allows the provision of real-time data for analysis to students who are studying by distance education. These data are a result of direct measurement and, as

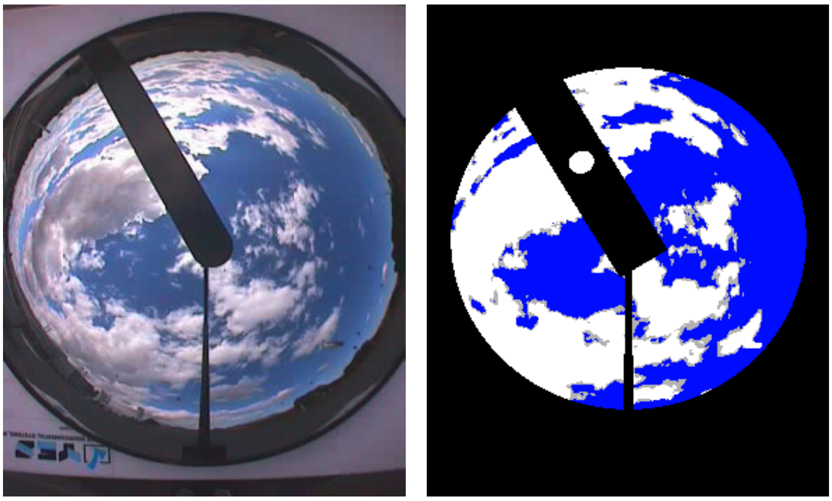

**Figure 4.** An example of the unprocessed (left) and processed (right) total sky images with 46% cloud cover.

a result, the technique takes into account variations throughout the day that are due to the influencing factors of time of day and year, clouds, ozone and aerosols.

## Analysis

The data collection component of the activities involves students accessing, at regular intervals, the Web site to collect the data displayed there from the sensors. At an hourly interval, the students obtain the information on the erythemal UV, the UVA and the current UV index for a cloud free day between 7 am and noon in summer and in winter. This is repeated for a cloudy day in each season. The clear sky cases can be determined as the times when the irradiances fall on a bell-shaped curve. This is the case for the first half of the day in the graph in figure 3. In the second half of the day, there are cases when there was cloud. Another means of determining the amount of cloud cover is to access the information from the total sky image that provides the percentage of cloud cover. This is available from the link on the UV page.

For the analysis, the solar zenith angle (SZA) is required. The SZA is the angle between the zenith and the position of the Sun. The SZA value can be obtained by accessing the UV Naval Observatory site http://aa.usno.navy.mil/data/docs/AltAz.html.

On this page it is possible to input the day, latitude and longitude of your location and the number of hours that your location is east or west of Greenwich to obtain a table of the altitude of the Sun at a user-specified interval throughout the day.

The students are requested to plot

- erythemal UV as a function of SZA for the cloud-free day;
- erythemal UV as a function of SZA for the cloudy day;
- UVA as a function of SZA for the cloud-free day;
- UVA as a function of SZA for the cloudy day;
- ratio of UVA to erythemal UV as a function of SZA for the cloud-free day;
- ratio of UVA to erythemal UV as a function of SZA for the cloudy day.

The students are asked to calculate the

- ratio of the erythemal UV for the cloudy day at a given SZA to the erythemal UV for the clear day at the same SZA;
- ratio of the UVA for the cloudy day at a given SZA to the UVA for the clear day at the same SZA;
- average of the respective two ratios above;
- conversion of the erythemal exposure in a 5 min period in units of MED to J $m^{-2}$;
- average irradiance in W $m^{-2}$ over the 5 min period, assuming that the irradiance is constant over that period;
- conversion of the previous exposure in MED to the UV index;
- time required for an exposure of one MED on a clear day in summer and winter at noon. Repeat this for 9 am, 10 am, 2 pm and 3 pm for summer and winter.

Sample calculations are provided in the appendix.

## Summary

This paper provides activities for distance education students to illustrate a number of physics concepts related to solar radiation. The experimental data are provided by instruments interfaced to computers that make the information available on a Web site. The data are updated every 5 min and can be considered to be in real time. Employing the framework of solar radiation to teach the physics concepts in these activities means that the students can identify how these concepts apply to every day situations. The activities are open ended in that they are no longer restricted to a strict timetable of when they are to be performed and the amount of time to devote to them.

## Appendix. Sample calculations

- Conversion of erythemal exposure in MED to J $m^{-2}$

$$0.2 \text{ MED} = 0.2 \text{ MED} \times 200 \text{ J m}^{-2}/\text{MED} = 40 \text{ J m}^{-2}.$$

- Average irradiance in W $m^{-2}$ over the 5 min period, assuming that the irradiance is constant over that period

$$40 \text{ J m}^{-2} = \frac{40 \text{ J m}^{-2}}{5 \text{ min} \times 60 \text{ s min}^{-1}} = 0.13 \text{ W m}^{-2}.$$

- Conversion of exposure in MED to the UV index

$$0.2 \text{ MED} = \frac{0.2 \text{ MED} \times 200 \text{ J m}^{-2}/\text{MED}}{5 \text{ min} \times 60 \text{ s min}^{-1}} \times \frac{40}{\text{W m}^{-2}} = 5.$$

- Time required for an exposure of one MED on a clear day in summer and winter at noon

$$\text{Summer exposure of } 0.48 \text{ MED/5 min}: \frac{1 \text{ MED}}{0.48 \text{ MED/5 min}} = \frac{5 \text{ min}}{0.48} = 10.4 \text{ min}$$

$$\text{Winter exposure of } 0.15 \text{ MED/5 min}: \frac{1 \text{ MED}}{0.15 \text{ MED/5 min}} = \frac{5 \text{ min}}{0.15} = 33.3 \text{ min}.$$

## References

[1] McAlexander A 2003 Physics to go *Phys. Teach.* **41** 214–8
[2] Lindgren B 2001 Measurement techniques on distance using a Web browser *CAL-laborate* Oct 2001 21–3
[3] CIE (International Commission on Illumination) 1987 A reference action spectrum for ultraviolet induced erythema in human skin *CIE J.* **6** 17–22
[4] Diffey B L 1992 Stratospheric ozone depletion and the risk of non-melanoma skin cancer in a British population *Phys. Med. Biol.* **37** 2267–79
[5] CIE (International Commission on Illumination) Standard 1998 Erythema reference action spectrum and standard erythema dose *CIE S 007/E-1998* Vienna
[6] Lemus-Deschamps L, Rikus L and Gies P 1999 The operational Australian ultraviolet index forecast 1997 *Meteorol. Appl.* **6** 241–51
[7] Parisi A V, Sabburg J and Kimlin M G 2004 *Scattered and Filtered Solar UV Measurements* (Dordrecht: Kluwer)