Ultraviolet Radiation

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Abbreviation:

UV: Ultraviolet radiation

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Abstract

UV radiation (100 and 400 nm) can be divided into 3 divisions: UVA, UVB and UVC while UVA has the longest wavelength, lowest energy (3.1-3.9 eV) and UVC has the shortest wavelength, highest energy (4.3-6.5 eV). UV irradiation can transfer its energy to biological molecules such as protein and DNA. The most important class of UV photoproducts formed in native DNA are the 5,6-cyclbutyl dipyrimidines, or pyrimidine dimers. UV is the primary reason for skin cancer. UV dose meter is the best method to determine the dose of UV irradiation.

Introduction

Ultraviolet radiation (UV) comes naturally from the sun. The sun is responsible for the development and continued existence of life on the Earth. Ultraviolet radiation is defined as all radiation between 100 and 400 nm [1]. UV is only a small portion of the radiation we receive from the sun, but has a large impact on biological activity. UV is divided into at least three different categories based on wavelength: UVA wavelengths (320-400 nm) are only slightly affected by ozone levels. Most UVA radiation is able to reach the earth's surface and can contribute to tanning, skin aging, eye damage, and immune suppression; UVB wavelengths (280-320 nm) are strongly affected by ozone levels. Decreases in stratospheric ozone mean that more UVB radiation can reach the earth's surface, causing sunburns, snow blindness, immune suppression, and a variety of skin problems including skin cancer and premature aging; UVC wavelengths (100-280 nm) are very strong affected by ozone levels, so that the levels of UVC radiation reaching the earth's surface are relatively small [2]. The subdivisions are arbitrary and differ somewhat depending on the discipline involved. The division between UVB and UVC is chosen as 280 nm (or 290 nm) since ultraviolet radiation (UVR) at shorter wavelengths is unlikely to be present in terrestrial sunlight, except at high altitude [3]. The choice of 320 nm as the division between UVB and UVA is perhaps more arbitrary. Although radiation at wavelengths shorter than 320 nm is more photobiologically active than longer wavelength UVR, research showed that a subdivision at 330-340 nm may be more appropriate [4].

General Characteristics

Light is a form of the energy we call electromagnetic radiation. Other forms are called radio and TV waves, microwaves, infrared (IR), ultraviolet (UV), x-rays, and gamma rays. Physicists think of all of these as examples of the same phenomenon with different energies. In some ways these forms of energy act like waves, so they are traditionally described in terms of their wavelengths. In other ways they act like particles and then it is more useful to describe them in terms of their photon energies. Electromagnetic radiations transfer their energy in units of photons: $E=h\nu$, that is the energy of a photon (E) is directly proportional to its frequency of vibations per second (ν), with h being Planck's constat (6.62×10^{-34} J·s). Table 1 shows the energy spectra of different electromagnetic radiations.

Table 1. Energy spectra of electromagnetic radiations.

Name	Energy Range(eV)	Wavelength Range (nm)
Infrared	**less than 1.6**	**greater than 760**
Visible Light	**1.6 - 3.1**	**760 - 400**
Red	1.6-2.0	760-610
Orange	2.0-2.1	610-590
Yellow	2.1-2.3	590-540
Green	2.3-2.6	540-480
Blue	2.6-2.8	480-450
Violet	2.8-3.1	450-400
Ultraviolet	**greater than 3.1**	**less than 400**
UV-A	3.1-3.9	400-320
UV-B	3.9-4.3	320-290
UV-C	4.3-6.5	290-180

(*Adapted from the National Science Education Standards (NRC)).

As we can see from Table 1, for expressing the energy of a single UV photon, the erg and the Joule (J) are rather large units. We use the electronvolt (eV), defined as the energy gained by an electron in passing through a potential difference of 1 volt, which equals 1.6×10^{-12} erg or 1.6×10^{-19} J. Radiation of the ultraviolet and the adjacent visible spectral range is summarily called nonionizing radiation, as opposed to ionizing radiation [1]. The main reason for this distinction is their interaction with matter: ionizing radiations, in contrast to nonionizing radiations, are capable of ionizing all kinds of atoms and molecules. Absorption of nonionizing radiations typically leads to electronic excitation of atoms and molecules [1]. An atom or molecule absorbing a UV photon assumes for a period of 10^{-10} to 10^{-8} s an excited state, in which the energy of the electrons is increased by the amount of photon energy [1]. The lifetime of a molecule in its usual excited state (10^{-10} to 10^{-8} s), which is still longer compared with the time required for the energy absorption itself (approximately 10^{-15} s), can be greatly extended if the excited electron is trapped in a triplet excited state [1].

UV absorption by nucleic acids, proteins, and other biologically relevant molecules

The biological effectiveness of UV radiation is primarily due to its absorption by nucleic acids, and to a much lesser extent by proteins and other biologically important molecules. Since nucleic acids from a variety of organisms may show considerable differences in their base compositions, not all absorption spectra of nucleic acids are alike. Figure 1 shows the typical absorption spectra of nucleic acids.

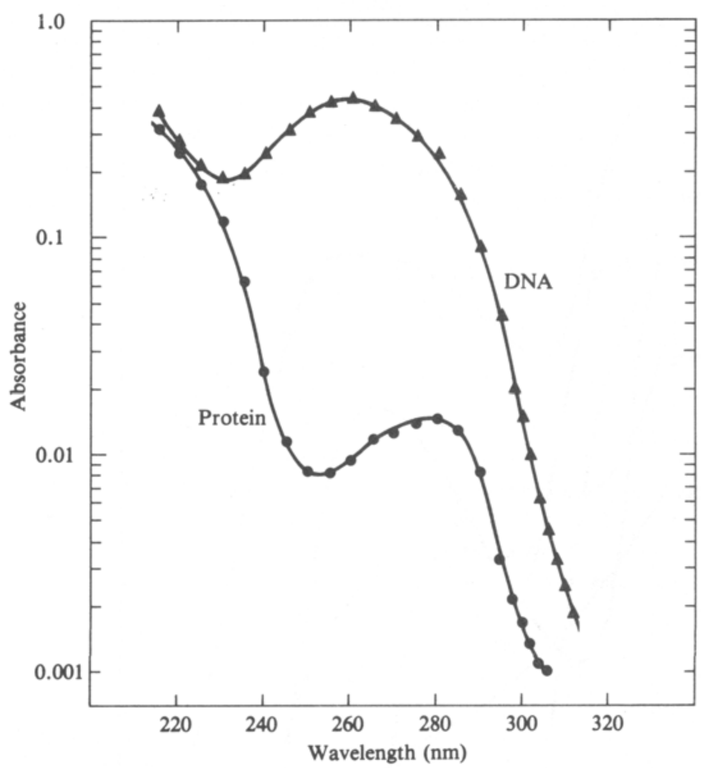

Figure 1. Absorption spectra of DNA and protein in the same concentration solution. (Adapted from [1].)

From figure 1, we can see an absorption maximum in the 260-265 nm region and a rapid decline toward longer wavelengths. And the spectrum has a shallow minimum near 230 nm, before it increases again toward shorter wavelengths. Absorption of most protein in the far-UV region from 240 to 300 nm is much lower than that of nucleic acid solutions of equal concentration (figure 1). The reason is that, in contrast to all the nucleotide residues in DNA, only a few of the amino acid residues of protein absorb measurably in this region [1].

An action spectrum displays the relative efficiencies of incident photons, as a function of their energies (or wavelengths), for producing a given biological effect. Comparison of an action spectrum with absorption spectra of appropriate bio-organic substances might indicate which one of them is primarily responsible for the effect. Figure 2 shows the UV absorption spectra correspond to the UV killing effect.

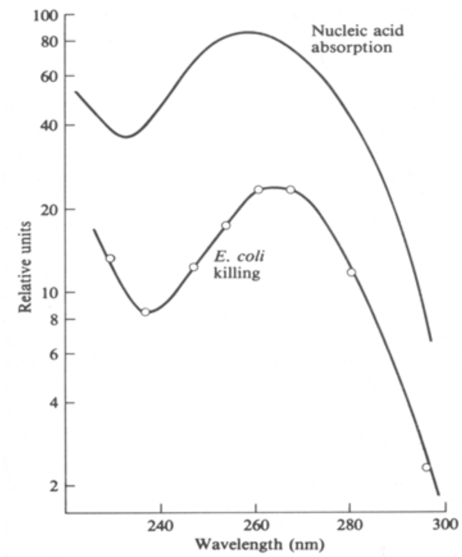

Figure 2. UV absorption spectra correspond to the UV killing effect. (Adapted from [1].)

Long before the function of DNA as the genetic material of organisms was recognized, action spectra indicated that nucleic acids are the predominant UV-absorbing material involved in the inactivation of bacteria and phage [1].

UV photodamage

The most important class of UV photoproducts formed in native DNA are the 5,6-cyclbutyl dipyrimidines, or pyrimidine dimers. They have four isomers (figure 3).

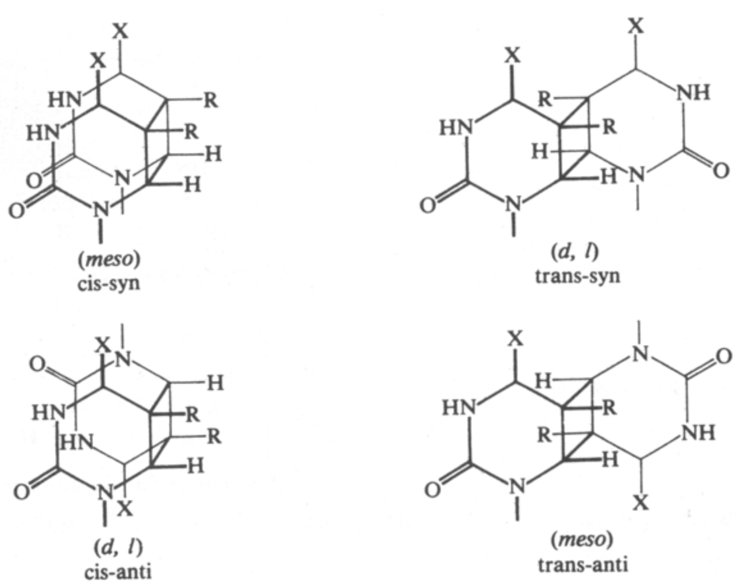

Figure 3. Four isomers of pyrimidine dimers. (Adapted from [5].)

Other photoproducts formed in UV-irradiated cells include pyrimidine adducts, spore photoproduct, pyrimidine hydrates and DNA-protein crosslinks (figure 4).

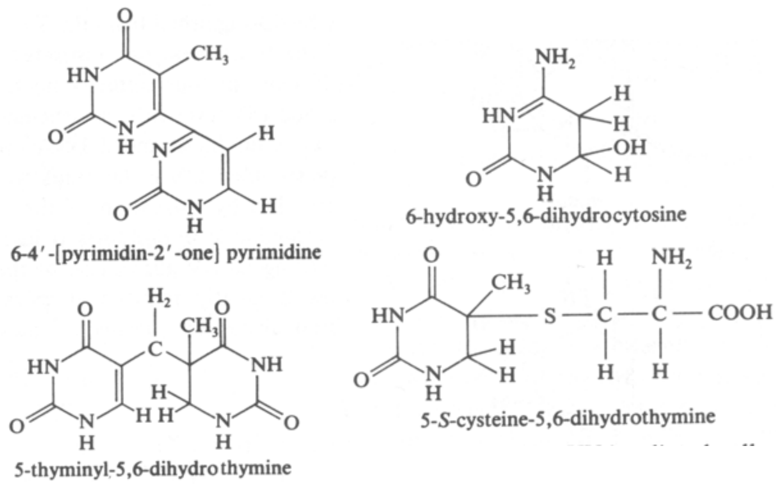

Figure 4. Photoproducts of UV-irradiation. (Adapted from [1].)

Tryptophan and tyrosine are the two amino acids found in most protein that absorb at wavelengths >290 nm and are photoactive [6]. In the presence of oxygen, energy transfer from the excited triplet state of tryptophan to oxygen occurs producing singlet oxygen [6]. Thus, tryptophan in protein acts as an endogenous photosensitizer in the UVB wavelength range by producing $^1O_2$, which reacts with protein, unsaturated lipid, and the base in nucleic acids. The final product of these reactions is N-formylkynurenine, which plays an especially improtant role in photobiological responses [6]. The excited states of N-formylkynurenine react to produce hydroxyl radicals [6]. The triplet state of tryptophan can also transfer an electron to oxygen to form superoxide ($O_2^{\bullet-}$) [6].

$O_2^{\bullet-}$ can be converted to hydroxyl radicals via Fenton reaction:

$Fe(III) + O_2^{\bullet-} \rightarrow Fe(II) + O_2$ $\quad$ $Fe(II) + H_2O_2 \rightarrow HO^{\bullet} + OH^- + Fe(III)$

UV carcinogenesis

UV radiation is the primary cause of skin cancer. People who live in areas with year-round bright sunlight are at higher risk for developing skin cancer [1]. UV can induce pyrimidine dimers in DNA, if one has deficits in the repair system, the possibility of neoplasms is much higher than the normal individual [1]. The mitogen-activated protein kinase (MAPK) signaling cascades are targets for UV and are important in the regulation of the multitude of UV-induced cellular responses [7]. The mechanism of carcinogenesis of caused by disorder of this pathway is still under research.

Radiometry of UV radiation

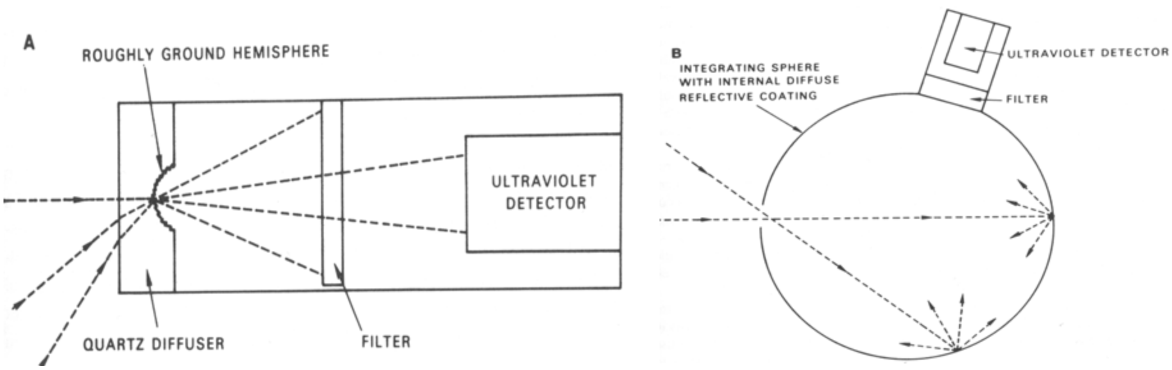

Figure 5. UV radiometer input diagram. (A) with quartz diffuser. (B) with integrating sphere. (Adapted from [7].)

In general, there are five types of detectors suitable for the measurement of UV radiation. These are photomultipliers, solid-state photodiodes, vacuum photodiodes, thermopiles and pyroelectrics [8]. Detectors are placed behind calibrated UV-transmitting filters (in radiometers) or monochromators (in spectroradiometers) to measure UV irradiance in a given spectral region. Figure 5 shows the diagram of the detectors.

Summary

UV is a component of sunlight. It has higher energy than visible light. UV irradiation can cause DNA and protein damage, which in part accounts to oxidative damage. The carcinogenesis of UV may be caused by deficit in pyrimidine dimers repair pathway or UV induced MAPK pathway disorder. The method to detect UV radiation is UV-dose meter specific to certain wavelength.

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