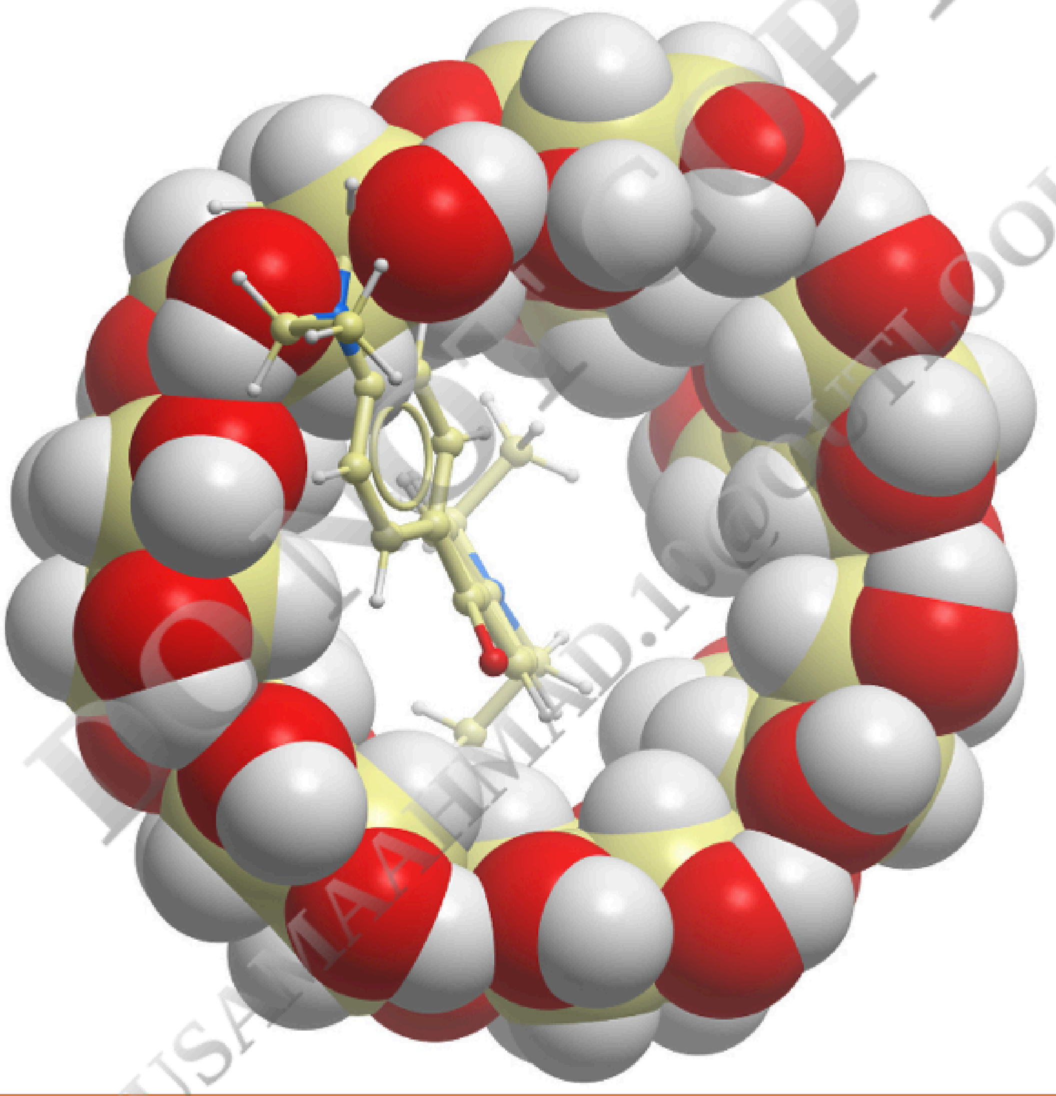
Cyclodextrins for UV Rays Filtration



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Designed cover image: Self-created by the editor, Sivakumar Krishnamoorthy

First edition published 2026
by CRC Press
2385 NW Executive Center Drive, Suite 320, Boca Raton FL 33431

and by CRC Press
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

ISBN: 9781032795669 (hbk)
ISBN: 9781032795683 (pbk)
ISBN: 9781003492757 (ebk)

DOI: 10.1201/9781003492757

Typeset in Times
by Newgen Publishing UK

11 Cyclodextrins

Revolutionizing Sunscreen Performance and Protection

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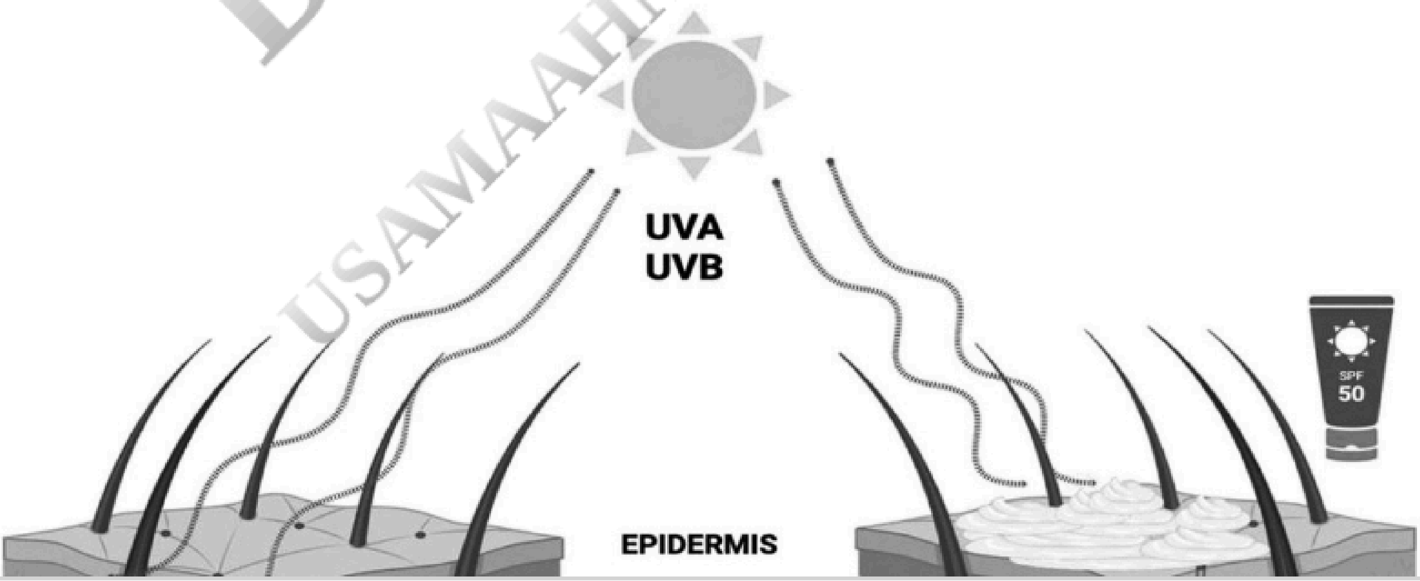
DOI: 10.1201/9781003492757-11

11.1 INTRODUCTION

The sun emits UVR, with UV-A (315–400 nm) reaching the Earth's surface the most, while the ozone layer partially absorbs UV-B (280–315 nm), and UVC (100–280 nm) is completely absorbed. UVR has biological impacts like vitamin D synthesis in humans, but overexposure can lead to harmful effects like skin damage, DNA mutations, and increased cancer risk [1]. Sunscreens are essential in mitigating these effects by blocking or absorbing harmful UVR. These are divided into organic sunscreens that absorb UV light and inorganic that deflect or disperse it. Sunscreen efficacy is measured by SPF, primarily reflecting UVB protection, with higher SPF values indicating better protection [2].

UVR absorbers are essential in sun protection, preventing harm from prolonged UV exposure. In sunscreens, they reflect, absorb, or disperse UV rays, minimizing skin radiation. Chemical filters like oxybenzone, ensulizole, and avobenzone block UVA and UVB rays. However, concerns exist about their potential systemic absorption and negative consequences. To address these issues, CDs are used as carriers for UVR absorbers, increasing their concentration and stability in the skin's top layers while reducing direct skin contact. This encapsulation technique preserves sun protection effectiveness and enhances UVR absorbers' photostability without endangering skin health. Combining CDs with UVR absorbers advances sun protection technology [3]. UVR absorbers enclosed in CDs have improved photostability, ensuring effective long-term UV protection. CD complexes with UVR absorbers provide a more consistent protective factor at the skin's surface and lower the risk of adverse side effects by preventing deeper skin penetration. Dispersed in natural waters, UVR absorbers must be environmentally friendly and meet regulatory standards for safety and efficacy to prevent harm to wildlife and the environment [4]. Figure 11.1 shows UV penetration without protection on the left and sunscreen blocking UV rays on the right.



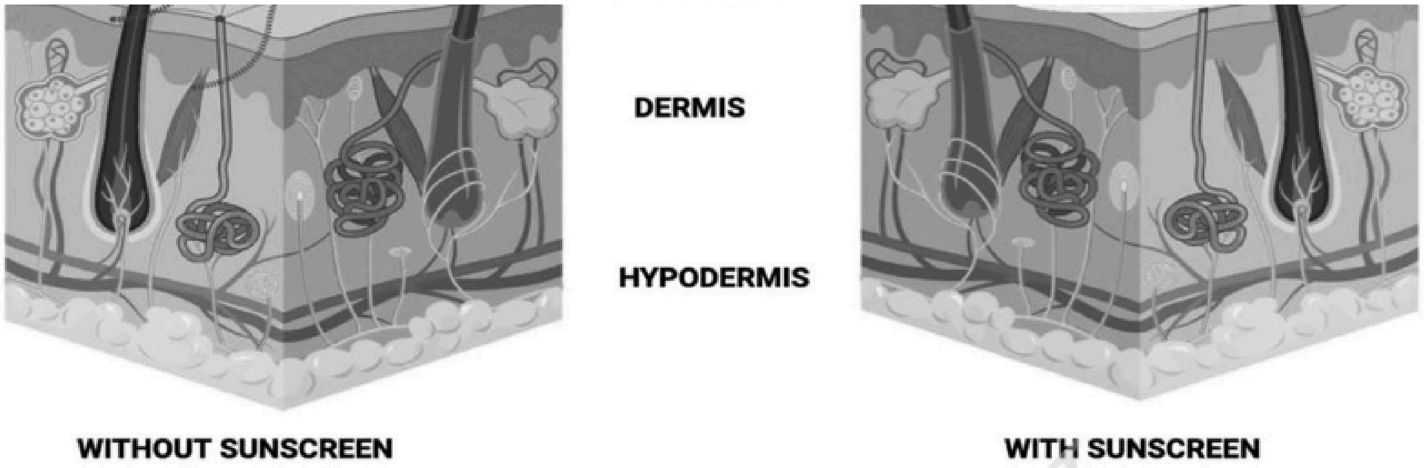


FIGURE 11.1 Impact of CD-based sunscreen on UVR penetration through skin layers.⏎

11.2 UVR ABSORBERS: MECHANISM OF ACTION

Mechanism of action of various commonly used UVR absorbers is described in Table 11.1.

TABLE 11.1
Mechanism of Action of Various Commonly Used UVR Absorbers⏎

UVFilter	Mechanism of Action	Remarks
Avobenzone	Converts absorbed UVA energy into harmless heat. Neutralizes ROS.	84.6–95.5% of the absorbed UV filter was found in the stratum corneum, with only a small percentage reaching the epidermis [5]. Its antioxidant properties neutralize ROS, reducing their harmful effects on skin cells and DNA.
Ensulizole	Absorbs UVB and UVA rays. Reduces ROS.	Its absorption spectrum shows strong absorption at around 303 nm, blocking considerable harmful UVB radiation [6]. The PL spectrum shows a pronounced blue shift in polar solvents, moving from 445 nm in non-polar solvents to 412 nm in polar solvents like water and ethanol.
Padimate O	Absorbs UVB rays. Neutralizes ROS.	Upon exposure to UVB radiation, Padimate O absorbs the energy and undergoes a photochemical reaction, preventing UVR from penetrating the skin [7]. By reducing ROS levels, Padimate O helps prevent chain reactions leading to further cellular damage and inflammation.
Homosalate	Absorbs UVB and UVA rays. Converts UV energy into heat. Reduces ROS	HMS undergoes ultrafast excited state intramolecular proton transfer. This minimizes the formation of harmful photoproducts from UV exposure [8]. HMS has low dermal permeability and does not cause endocrine disruption, which are significant concerns for many existing UV filters.
Meradimate	Absorbs UVA rays. Reduces ROS.	Meradimate absorbs UVR, converting it into less harmful energy. The ultrafast dynamics of meradimate reveal complex energy behaviors influencing its protective capabilities [9].
	Absorbs UVB rays. Minimizes	Cinoxate effectively absorbs UVB radiation, reducing the risk of sunburn and skin damage [10]. Like nitroxides, cinoxate scavenges ROS generated by UV

Cinoxate	Absorbs UVB rays. Minimizes ROS formation.	Like nitroxides, cinoxate scavenges ROS generated by UV exposure, protecting skin cells from oxidative damage [11].
Aminobenzoic acid	Absorbs UVB rays. Reduces ROS	PABA effectively absorbs UVR, reducing its skin penetration. It can also photosensitize singlet oxygen formation, a reactive species implicated in oxidative stress and skin ageing [7].
Dioxybenzone	Absorbs UVB and UVA rays. Reduces ROS.	Dioxybenzone acid absorbs UVR, preventing DNA damage like thymine dimer formation, linked to skin cancer. Its antioxidant properties reduce oxidative stress, inhibiting apoptosis and matrix metalloproteinase expression associated with skin ageing [12].
Octocrylene	Absorbs UVB and UVA rays. Neutralizes free radicals.	Octocrylene's structure includes a chromophore that absorbs UVR, providing broad-spectrum protection. It undergoes ultrafast non-radiative relaxation after UV-B excitation, quickly returning to its ground state, enhancing its protective capabilities [13].
Oxybenzone	Absorbs UVB and UVA rays. Minimal antioxidant effect. Neutralizes some free radicals	Oxybenzone absorbs UVR across a broad spectrum, particularly in UVA and UVB ranges, crucial for its protective function [14]. The molecule undergoes ESIPT, facilitating energy dissipation through pathways, including internal conversion to its ground state [15].
Octinoxate	Absorbs UVB and UVA rays. Minimal antioxidant effect. Neutralizes some free radicals.	Octinoxate absorbs UVB radiation, converting harmful UV energy into less harmful heat [16]. It modulates AhR signalling, inhibiting CYP1A1 and CYP1B1, potentially affecting skin health and metabolism [17].
Sulisobenzone	Absorbs UVB and UVA rays. Minimal antioxidant effect. Neutralizes some free radicals.	Sulisobenzone effectively absorbs UVB and UVA radiation, preventing skin damage by converting harmful UV energy into heat [18].
Titanium dioxide	Reflects, scatters, and absorbs UVB and UVA rays. Stays on the skin surface.	TiO_2 is widely used in sunscreens as it absorbs and scatters UV radiation, preventing skin penetration. The absorption of UV radiation by TiO_2 excites electrons from the valence band to the conduction band, creating electron-hole pairs [19].
Zinc Oxide	Reflects and scatters UVA and UVB rays, providing broad-spectrum protection. Remains on the skin surface, minimizing absorption and irritation.	ZnO absorbs UVR and converts it into less harmful infrared radiation, dissipating away from the skin [20]. ZnO nanoparticles enhance the antioxidant defense system by increasing antioxidant enzyme activity such as superoxide dismutase and catalase [21].

11.3 INTERACTION OF CDS AND UVR ABSORBERS