

ULTRAVIOLET (UV)

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Primary Disciplinary Field(s): Physics, Photobiology, Atmospheric Science

1. Core Definition and Position in the Electromagnetic Spectrum

Ultraviolet (UV) radiation constitutes a segment of the electromagnetic spectrum, defined by wavelengths shorter than that of visible light but longer than X-rays. Conventionally, the UV spectrum is understood to span from approximately 400 nanometers (nm), which marks the boundary with the shortest visible light (violet), down to roughly 10 nm, where the radiation transitions into soft X-rays. This invisible radiation is highly energetic, possessing photons capable of causing chemical reactions and ionization effects that are far more pronounced than those associated with visible light. The designation "ultraviolet" itself derives from the Latin prefix *ultra-*, meaning "beyond," emphasizing its position immediately beyond the violet end of the human visual spectrum.

The energy carried by UV photons is inversely proportional to their wavelength. Consequently, the shorter the wavelength within the UV range (e.g., 10 nm), the greater the energy and the more profound the potential interaction with matter, particularly organic molecules like **Deoxyribonucleic Acid (DNA)**. This energy profile distinguishes UV from the longer-wavelength visible and infrared spectra, where interactions are primarily thermal or related to photoexcitation without significant chemical alteration. Understanding the precise limits and internal divisions of the UV range is critical across various fields, including atmospheric physics, where UV absorption mechanisms dictate stratospheric temperature profiles, and photochemistry, where UV light is harnessed to catalyze or initiate specific reactions.

The source material specifically notes a range from 0.5 nm to 400 nm; while 400 nm remains the standard upper limit, the lower limit often cited for the UV region in physics is closer to 10 nm, with radiation below this point typically referred to as Extreme UV (EUV) or Vacuum UV (VUV), often overlapping with soft X-rays. Regardless of the precise low-end boundary, **UV radiation** is fundamentally a form of non-ionizing radiation until wavelengths drop significantly below 200 nm, yet its high photon energy makes it inherently capable of breaking molecular bonds, a process central to its biological significance.

2. Historical Discovery and Nomenclature

The discovery of ultraviolet radiation followed shortly after the discovery of infrared radiation, providing crucial evidence that the electromagnetic spectrum extended far beyond the visible range known to classical physics. In 1801, German physicist Johann Wilhelm Ritter, experimenting with silver chloride paper--a known light-sensitive compound--noticed that placing the paper just beyond

the violet end of a solar spectrum produced by a prism caused the paper to darken faster than any visible light. Ritter deduced that an invisible form of radiation, which he initially termed "deoxidizing rays" due to their chemical action, must exist. This invisible radiation confirmed the presence of higher-frequency, shorter-wavelength components to sunlight.

Ritter's findings were foundational, establishing that light phenomena were not purely visual but also involved energetic interactions with matter. The term "chemical rays" was used for a time to describe these newly discovered rays, reflecting their immediate observable effect on photographic plates and chemicals. As spectroscopy matured throughout the 19th century, and the relationship between light frequency, wavelength, and energy became formalized, the radiation was eventually termed **ultraviolet**. This nomenclature standardized its placement relative to the visible spectrum and facilitated broader scientific discussion across physics and optics, allowing researchers to categorize and study its unique properties, especially its interaction with various elements and gases.

3. Classification of Ultraviolet Radiation (UVA, UVB, UVC)

For practical and biological purposes, the UV spectrum is typically subdivided into three main bands based on wavelength, corresponding directly to their penetration depth and biological effect: UVA, UVB, and UVC. This classification system is crucial in fields ranging from public health to material science, as the effects of radiation vary dramatically across these bands.

UVA (Long-Wave UV): Spanning approximately 315 nm to 400 nm. UVA is the least energetic of the three types and penetrates the atmosphere and skin most deeply. It is responsible for immediate tanning and is strongly implicated in long-term skin aging and wrinkling, as it affects the dermal layers. Because UVA rays are not significantly filtered by the ozone layer or cloud cover, they account for the vast majority (upwards of 95%) of the UV radiation reaching the Earth's surface.

UVB (Medium-Wave UV): Spanning approximately 280 nm to 315 nm. UVB is more energetic than UVA and is the primary cause of sunburn (erythema). It is vital because it triggers the synthesis of **Vitamin D** in the skin. However, UVB interacts readily with the epidermis, causing direct DNA damage and being the main driver of most forms of skin cancer. The intensity of UVB reaching the ground is highly dependent on latitude, season, time of day, and, crucially, the thickness of the atmospheric ozone layer.

UVC (Short-Wave UV): Spanning approximately 100 nm to 280 nm. UVC is the most energetic and dangerous type of UV radiation. Fortunately, virtually all naturally occurring UVC is absorbed by diatomic oxygen (O₂) and ozone (O₃) in the stratosphere before it reaches the ground. Artificially produced UVC, particularly at 254 nm, is utilized extensively for its potent germicidal properties, capable of destroying microorganisms by disrupting their nucleic acids.

4. Interaction with the Earth's Atmosphere

The interaction between solar **UV radiation** and the Earth's atmosphere is one of the most vital geophysical processes governing life on the planet. The high-energy UVC and much of the UVB radiation are responsible for heating the stratosphere through absorption by atmospheric gases, primarily ozone (O₃). The ozone layer, situated mainly in the stratosphere between 10 km and 50 km altitude, serves as the planet's natural UV shield. This absorption process not only protects terrestrial life but also dictates the thermal structure of the atmosphere, contributing to atmospheric stability.

The mechanism of ozone absorption involves the photolysis of O₃ molecules by UV photons, which breaks the ozone molecule into molecular oxygen (O₂) and an oxygen atom (O). This process, known as the Chapman cycle, is highly effective at filtering out the most damaging, short-wavelength radiation. While UVC is completely blocked, UVB absorption is less complete, allowing a critical amount to penetrate. The thinning of the ozone layer, driven by anthropogenic emissions of chlorofluorocarbons (CFCs), has historically increased the amount of UVB radiation reaching the surface, raising significant environmental and public health concerns regarding increased skin cancer rates and ecosystem disruption, particularly damage to phytoplankton.

5. Biological Effects and Photobiology

UV radiation plays a dual role in biology: it is both essential for certain processes and highly detrimental due to its energetic nature. The most significant beneficial effect in vertebrates, including humans, is the synthesis of **Vitamin D**. Exposure of the skin to UVB triggers the conversion of 7-dehydrocholesterol into previtamin D₃, which is then metabolized into the active form of the vitamin. Vitamin D is crucial for calcium homeostasis, bone health, and immune function. Insufficient UVB exposure, particularly in high-latitude regions or due to excessive avoidance, can lead to widespread deficiency.

Conversely, the high energy of UV photons, especially UVB and UVC, makes them potent mutagens. When UV photons are absorbed by DNA, they can cause molecular changes, most commonly the formation of pyrimidine dimers (e.g., thymine dimers), which link adjacent bases. If these lesions are not efficiently repaired by cellular mechanisms, they disrupt DNA replication and transcription, leading to mutations. In somatic cells, this accumulated DNA damage can initiate carcinogenesis, culminating in various skin cancers, including basal cell carcinoma, squamous cell carcinoma, and the highly aggressive melanoma. Furthermore, chronic exposure to **UVA** contributes significantly to photoaging by generating reactive oxygen species (ROS) in the dermis, damaging collagen and elastin fibers, and compromising the skin's structural integrity.

6. Perception by Non-Human Organisms

Unlike humans, whose visual spectrum typically cuts off around 400 nm (the edge of violet), many non-human species, particularly insects, birds, and fish, possess the necessary photoreceptor pigments to perceive wavelengths within the ultraviolet range. The source content explicitly notes that some fish and insects have photopigments vulnerable to these wavelengths. This **UV vision** grants these organisms a unique perception of their environment, impacting crucial behaviors such as navigation, foraging, and communication.

For example, many flowers exhibit elaborate UV patterns (nectar guides) that are invisible to the human eye but highly visible to pollinating insects like bees. These patterns direct the insect toward pollen and nectar sources, facilitating efficient pollination. In birds, feather coloration that appears uniform to humans often reflects distinct UV markings used in mate selection and territorial displays, enabling complex communication strategies not reliant on human-visible spectrum characteristics. Similarly, various species of fish utilize UV cues for schooling behavior, communication, and differentiating prey against the background of deep water, where short wavelengths penetrate most effectively. The presence of specialized photopigments, often sensitive to wavelengths below 360 nm, illustrates an evolutionary adaptation that leverages the energetic properties of **UV light** for ecological advantage.

7. Technological Applications

Due to its high energy and specific interactions with materials, **ultraviolet radiation** has been harnessed across numerous technological and industrial applications. One of the most critical uses is in germicidal irradiation (GCI), which utilizes UVC lamps (typically 254 nm) for disinfecting air, water, and surfaces in hospitals, laboratories, and municipal water treatment plants. The mechanism relies on the UVC radiation irreversibly damaging the nucleic acids of bacteria, viruses, and spores, rendering them inert.

Other significant applications include industrial curing processes, such as UV curing of inks, resins, and coatings. This method offers rapid drying and hardening, leading to more durable finishes and increased production efficiency compared to traditional heat-curing methods. In forensic science and mineralogy, UV light is used to induce fluorescence in various substances--such as body fluids, trace evidence, or minerals--allowing for enhanced detection and identification. Astronomically, UV observation is crucial for studying extremely hot celestial objects and the interstellar medium, as these environments emit intense short-wavelength radiation that provides insight into stellar evolution and galactic structure, though these observations must be conducted using space-based telescopes since the Earth's atmosphere blocks most astrophysical UV signals.

8. Health Implications and Safety Debates

The debate surrounding the health implications of **UV exposure** centers on balancing the essential need for Vitamin D synthesis against the documented risks of skin damage and cancer. Public health campaigns universally advocate for sun protection, emphasizing the use of broad-spectrum sunscreens that filter both UVA and UVB rays, especially during peak sun hours. However, this advice must be tempered by the understanding that complete sun avoidance can lead to Vitamin D deficiency, prompting ongoing research into optimal exposure strategies.

The source content highlights a specific commercial debate concerning tanning salons, noting claims that "tanning beds... do not contain the same harmful ultraviolet rays that natural sunlight does." Scientific consensus strongly refutes such claims. While modern tanning beds may adjust the ratio of UVA to UVB, they overwhelmingly expose users to high doses of UVA, which penetrates deeply and contributes significantly to photoaging and melanoma risk. Regulatory bodies and health organizations worldwide categorize both natural solar UV radiation and artificial UV from tanning devices as Group 1 carcinogens, underscoring the risks associated with unnecessary, intense exposure. Therefore, the commercial rhetoric often simplifies or minimizes the inherent dangers posed by all high-intensity UV sources.

9. Further Reading

[Ultraviolet - Wikipedia](#)

[Electromagnetic spectrum - Wikipedia](#)

[WHO: Ultraviolet \(UV\) radiation](#)

[Photoreceptor \(Biology\) - Wikipedia](#)